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GHGs emission scenarios and mitigation opportunities in Energy, Transport and Industrial Sector in Greece till 2030

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TABLE OF CONTENTS

SECTION 1

The dimensions of the problem

1. Basics of Climate Change Economics

1.1 The problem of climate change and its dimensions

Greenhouse gases (hereafter GHGs) include emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O) and a number of high global warming potential (GWP)[1] gases like hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) known as F-gases trapping heat near the surface of the earth and leading to global warming.[2] Due to these various GHGs global warming is considered as one of the most serious environmental problems caused by human activities.

The effects of climate change are serious and several. Coastal flooding from the rise in the sea level, intensive storms and floods and extreme weather conditions, reduced productivity of natural resources like scarce water reservoirs, lower and poorer agricultural production are some of them. Climate change is associated not only to the problem imposed to the environment but also to various physical, social and economic consequences like productivity reductions, population migration and changed climate conditions.

The socio-economic effects of global warming depend on changes in sea level, precipitation, ocean currents, spread of diseases and various other elements difficult to count and predict. As location of sources of GHG emissions is unrelated to the location of the environmental effects in terms of damages and degradation, they are considered as uniformly mixing pollutants[3] with their concentration levels to be invariant from place to place. At the

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[1] The importance of GWP is explained analytically in Section 3.

[2] All these GHGs are regulated by the Kyoto Protocol. Although the effect of water vapor is also significant it is not listed among the GHGs.

same time all emitter countries are influenced by the emissions of the others implying a reciprocal spillover problem from a global public “bad” (Perman et al., 2003). Climate change may be considered as an open access resource problem depending more on the world economy compared to economic activities in individual countries. This implies that actions to cope with the problem demand global cooperation (Stern et al., 2013; Arrow, 2007).[4]

In these lines, climate change is a global externality leading to market failure as the sources of pollution do not bear the full cost of their actions and the resulting external (social) costs imposed to others are not in the majority of the cases taken into consideration. With no policy interventions, polluters have no (or little) motivation to take into consideration the social costs imposed to others in their decision-making. At the same time, economists calculate that doubling of CO_2 concentrations may result to damages equal to around 1%-2% of total output (Wayne, 2008). These are accompanied by the associated GHG emissions’ irreversibility, their very long residence time in the atmosphere and the inability of individual countries to internalize the negative external costs (Arrow, 2007) as well as the existence of various synergistic effects.

The main attention of scientific research has been concentrated on CO_2 emissions with a number of studies using a single pollutant case (Hourcade and Shukla, 2001; Morita *et al.*, 2001). Recently, Granados et al. (2012) examined the short-run determinants of atmospheric CO_2, while Wang et al. (2013) examined the carbon emissions trends in terms of optimal balanced economic growth in the case of China and USA, discussing a number of abatement options for China. Similarly, Du et al. (2012) examined the relationship of CO_2 emissions and economic development in China, and Ibrahim and Law (2014) examined the relationship between social capital and CO_2 emissions. Many researchers have tested the validity of the

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[3] Uniformly mixing pollutants occur when physical processes operate in such a way as to disperse them to the point in which their spatial distribution is uniform (Perman et al. 2003, p. 178).

[4] Arrow (2007) refers to the USA’s contribution (almost 25%) to world CO_2 emissions emphasizing that its own policy to cope with the problem may be influential making a significant difference.

Environmental Kuznets Curve (EKC) hypothesis which corresponds to an inverted U-shaped relationship between environmental damage or pollutants emissions (in our case CO_2) and economic growth (GDP per capita).[5]

The lack of extensive cross-sectional data has led to few studies examining non-CO_2 gases (Chesnaye *et al.*, 2001). At the same time, a limitation of earlier studies may be pointed out on the use of exogenous control cost functions instead of considering non-CO_2 gases in analytic models (Hyman *et al.*, 2002). The consideration of both CO_2 and non-CO_2 control options may have important benefits on the so-called multi-pollutant abatement strategies. Some of these benefits are the higher elasticity in mitigation options (Lucas *et al.*, 2005; Manne and Richels, 2001; van Vuuren *et al.*, 2003; Hyman *et al.*, 2002) and the substantial cost reductions compared to strategies coping only with CO_2 due to possible existence of cheaper control options for some non-CO_2 GHGs (Harmelink *et al.*, 2005; Blok *et al.*, 2001). Van Vuuren *et al.* (2006) and Weyant and de la Chesnaye (2006) cite that across models and on average, a multi-pollutant strategy may achieve a costs reduction of 30-60% in comparison to only CO_2 emissions abatement.

1.2 Evolution of various meetings in terms of global climate policy

The mitigation of harmful emissions is the aim of worldwide legislative frameworks like the European Union, the UK Climate Change Act and the Kyoto Protocol with the aim of reducing GHGs emissions by 5% below 1990 levels during the first commitment time period of 2008-2012. The established in 1988 Inter-governmental Panel on Climate Change by the World Meteorological Organization (WMO) considered technical and socioeconomic research in the climate change area. International efforts to cope with climate change started by the “Earth Summit” in 1992 at Rio de Janeiro leading to the United Nations Framework Convention on Climate Change (hereafter UNFCCC) that was established in 1994 for the

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[5] Halkos (2012) provides a review of a number of studies exploring this issue.

stabilization of greenhouse gas concentrations in the atmosphere and the cooperation in tackling climate change by limiting average global temperature.

Table 1.1 presents the evolution and the results of the various meetings from 1979 to 2015 in terms of global climate policy. A number of states commitments have taken place for additional protection in the 19 *Conferences Of the Parties* so far (**COPs**) in one of which (COP3) in 1997 the Kyoto Conference took place with the states to agree for the reduction of the six GHGs (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) and leading to the Kyoto Protocol. This Protocol committed industrial states to reduce total GHG emissions in the first commitment period (2008 to 2012) by at least 5% lower levels of their 1990 levels.

The COP serves as the Meeting of the Parties to the Kyoto Protocol (**CMP**) where all the Kyoto Protocol Parties States are represented in the CMP, while no Parties States may just participate as observers.[6] The CMP reviews the running of the Kyoto Protocol and decides on the way to implement it effectively. It meets annually during the same period as the COPs. The first CMP took place in Montreal (Canada) in December 2005 together with COP-11.

COP 19 took place in Warsaw and announced the dates and locations of COP 20/CPM 10 taking place within 1-12 December 2014 in Peru (Lima) and COP 21/CPM 11 within 30 November–11 December 2015 in France (Paris). It ended up with a number of decisions apart from advancing the Durban Platform, the Green Climate Fund and Long-Term Finance, the Warsaw Framework for REDD+, the Warsaw International Mechanism for Loss and Damage, REDD+ finance, institutional arrangements and other methodological issues.[7]

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[6] For more information on the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol see http://unfccc.int/bodies/body/6397.php

[7] For more information see http://unfccc.int/

Table 1.1: Summary of climate policy actions

1979	1st World Climate Conference (WCC) in Geneva.
1988	The setup of the Intergovernmental Panel on Climate Change (IPCC)
1990	1st IPCC's assessment report (significant uncertainty for the first evidence that human activities might be affecting climate). 2nd WCC in Geneva (agreement for the negotiation of a global framework treaty).
1991	1st Intergovernmental Negotiating Committee (INC) meeting.
1992	The United Nations Framework Convention on Climate Change (UNFCCC) is established as an international treaty at the Earth Summit in Rio de Janeiro; "Annex I" developed countries undertake to have their emission levels in 2000 as these of 1990; UNFCCC opens for signature together with UNCBD and UNCCD Rio's Conventions.
1994	UNFCCC comes into force.
1995	2nd IPCC's assessment report (with more confidence that human activities may be negatively affecting climate). 1st Conference of the Parties (COP-1) in Berlin (negotiation of the legally binding targets and timetables for reduction of Annex I countries' emissions).
1996	COP-2 in Geneva rejected the proposal of the imposition of uniform policies allowing Annex I countries to develop their own policies.
1997	Kyoto Protocol is officially adopted in December at COP-3 (Kyoto, Japan); Annex I/Annex B countries agree to limit emission reduction to around 5% below 1990 levels by the first commitment period 2008-2012, with various flexibility mechanisms available for compliance; no commitments for emission reductions by developing countries.
1998	COP-4 in Buenos Aires (Argentina) calls attention to make operational the Kyoto Protocol's flexibility mechanisms. 3rd IPCC's assessment report.
1999	COP-5 in Bonn (Germany) monitored the progress on the work program proposed in COP-4 and continued the call for attention to make the flexibility mechanisms of the Kyoto Protocol operational.
2000	COP-6 in Hague and deadlock on the implementation of key conditions of Kyoto Protocol.
2001	COP-6 Bis in Bonn (Germany) in July continued COP-6. George Bush (U.S.A. President) stated in March opposition to Kyoto Protocol. IPCC's 3rd Assessment Report is published. COP-7 in Marrakesh (October) adopted the majority of the recommendations of COP-6 and finalized in details the rules for implementing Kyoto Protocol's flexibility mechanisms (mainly the Clean Development Mechanism) and it set-up new funding mechanisms for adaption and technology transfer.
2005	Kyoto Protocol comes into force. In Montreal we have the 1st meeting of the parties to Kyoto Protocol (MOP1); discussions on next stage of KP under the Ad-Hoc Working Group on additional commitments for Annex I parties (AWG-KP).
2007	4th IPCC's assessment report. On the Bali (Indonesia) Road Map Parties at COP-13 (in December) agreed on a post-2012 outcome in two work streams: AWG-KP and Ad-Hoc outcome in two work issues: the AWG-KP and the Ad-Hoc Working Group on Long Term Cooperative Action Under the Convention.
2008	COP-14 in Poznan (Poland) in December advanced the Bali Action Plan and discussed the development and transfer of technologies and reviewed financial mechanisms of the Convention.
2009	Copenhagen Accord was discussed at COP-15 with countries submitting later their emission control or mitigation plans.
2010	Cancun Agreements discussed and mainly accepted by COP-16.
2011	Durban Platform for Enhanced Action was discussed and accepted by COP-17.
2012	Doha Qatar (Qatar, Amendment to Kyoto Protocol adopted by COP-18 (CMP8).
2013	COP-19 (CMP9) in Warsaw concluded with a set of decisions advancing more among others the Durban Platform, the Green Climate Fund and Long-Term Finance, the Warsaw Framework for REDD+, the Warsaw International Mechanism for Loss and Damage.
2014	COP-20/CPM 10 will take place in December 2014 at Lima (Peru)
2015	COP 21/CPM 11 will take place at the end of 2015 at Paris (France).

Sources: Kolstad and Toman (2005); McKibbun and Wilcoxen (2005); United Nations Framework Convention on Climate Change Secretariat (https://unfccc.int/essential_background/items/6031.php)

1.2.1 The Kyoto Protocol and its mechanisms

As mentioned already, in 1997 the Kyoto Protocol came in action stating that "Annex B" (industrialized "Annex I" in the convention) countries should reduce GHGs with the first period of commitment within 2008-2012 and the second period within 2013-2020. Industrial nations agreed to limit emissions of GHGs to 5.2% below 1990 levels. This would be 30% below the levels projected for 2010. The Kyoto Treaty officially took effect when Russia ratified it in November 2004. No requirements imposed on newly industrialized countries (e.g. China). In USA the Bush administration and many in Congress were opposed to the treaty. The USA would have been required to cut emissions to 7% below 1990 levels by the years 2008 through 2012. Now we have 195 participating countries in the Convention and 192 in the Kyoto Protocol[8].

Countries listed in Annex I of the treaty are industrialized countries. Non-Annex I countries are developing countries. Countries listed in Annex B are a subset of industrial

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[8] **List of Annex I Parties to the Convention**
(Source: http://unfccc.int/parties_and_observers/parties/ annex_i/items/2774.php)
[With ** parties for which there is a specific COP and/or CMP decision].
Austria, Belarus**, Belgium, Bulgaria, Canada, Croatia**, Cyprus, Czech Republic**, Denmark, Estonia, European Union, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy**, Japan, Latvia, Liechtenstein**, Lithuania, Luxembourg, Malta, Monaco**, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation**, Slovakia**, Slovenia**, Spain, Sweden, Switzerland, Turkey, Ukraine**, United Kingdom of Great Britain and Northern Ireland, United States of America.

List of Non-Annex I (Source: http://unfccc.int/parties_and_observers/parties/non_annex_i/items/ 283 3.php)
[With * observer states; with ** parties for which there is a specific COP and/or CMP decision]
Afghanistan, Albania**, Algeria, Andorra, Angola, Antigua and Barbuda, Argentina, Armenia**, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belize, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Burkina Faso, Burundi, Cambodia, Cabo Verde, Cameroon, Central African Republic, Chad, Chile, China, Colombia, Comoros, Congo, Cook Islands, Costa Rica, Cuba, Côte d'Ivoire, Democratic People's Republic of Korea, Democratic Republic of the Congo, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Ethiopia, Fiji, Gabon, Gambia, Georgia, Ghana, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, India, Indonesia, Iran (Islamic Republic of), Iraq, Israel, Jamaica, Jordan, Kazakhstan**, Kenya, Kiribati, Kuwait, Kyrgyzstan, Lao People's Democratic Republic, Lebanon, Lesotho, Liberia, Libya, Madagascar, Malawi, Malaysia, Maldives, Mali, Marshall Islands, Mauritania, Mauritius, Mexico, Micronesia (Federated States of), Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Nauru, Nepal, Nicaragua, Niger, Nigeria, Niue, Oman, Pakistan, Palau, Palestine*, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Qatar, Republic of Korea, Republic of Moldova**, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, San Marino, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia, Seychelles, Sierra Leone, Singapore, Solomon Islands, Somalia, South Africa, South Sudan*, Sri Lanka, Sudan, Suriname, Swaziland, Syrian Arab Republic, Tajikistan, Thailand, The former Yugoslav Republic of Macedonia, Timor-Leste, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkmenistan**, Tuvalu, Uganda, United Arab Emirates, United Republic of Tanzania, Uruguay, Uzbekistan**, Vanuatu, Venezuela (Bolivarian Republic of), Viet Nam, Yemen, Zambia, Zimbabwe.

countries of Annex I in the original UNFCCC. Belarus had not ratified the UNFCCC till COP3 and is excluded from Annex B, as well as Turkey. Kyoto Protocol limits emissions of Annex I of UNFCCC to the levels provided in the Annex B of the Protocol.

The Kyoto Protocol defines three “flexibility mechanisms" to be used by Annex I Parties to achieve emission targets at the lowest costs: the Clean Development Mechanism (CDM); the Joint Implementation (JI); and the International Emissions Trading (IET).

The **Clean Development Mechanism (CDM)** helps countries included in Annex I to achieve compliance with their GHG emission caps by permitting Annex I countries to satisfy part of their emission control targets under the Kyoto Protocol by acquiring Certified Emission Reduction units from CDM emission reduction actions in developing countries to be traded in emission trading schemes. It also assists members not included in Annex I to achieve sustainability and to contribute to their target of UNFCCC.

Certified Emission Reductions (CERs) are a kind of carbon credits or emissions units issued by CDM Executive Board for emissions control achieved and verified by a designated operational entity under the Kyoto Protocol rules. These CERs may be used by Annex I countries to meet their emission targets or by unit operators under the European Union Emissions Trading Scheme to meet the terms of their obligations to give up EU allowances and certified emission reductions for carbon dioxide emissions of their units.

Joint implementation (JI) allows Annex I countries to satisfy part of their targeted emissions by investing in efforts resulting to emissions control credits in other Annex I countries. The traded units are the emission reduction units. In this way, countries with binding GHG emissions targets (Annex I countries) are helped to meet their requirements. Any Annex I country is able to invest in a *joint implementation effort* in any other Annex I country as an alternative emission control plan to reduce emissions at home. Thus countries may reduce the costs of meeting their Kyoto targets by investing in efforts that lower GHG emissions in an Annex I country where abating emissions may be cheaper, and in this way to use the resulting emission reduction units for the achievement of their committed target.

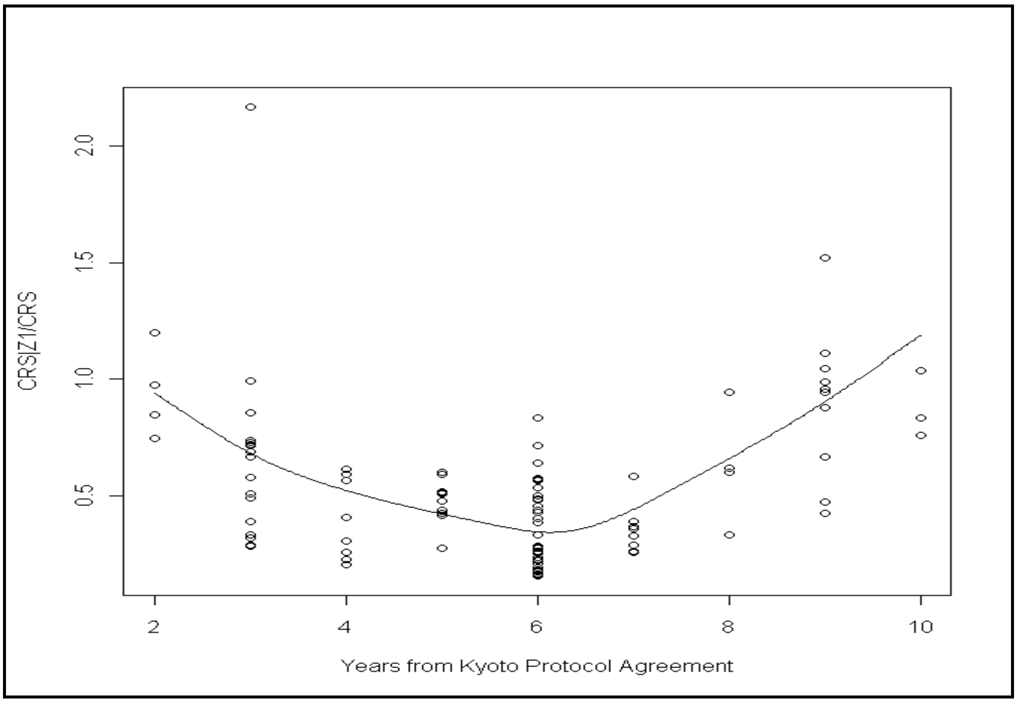
The Kyoto Protocol includes "assigned annual amounts" which may be acquired or transferred. Commitment of the Kyoto Protocol is that every country has to limit GHG emissions to some percentage of 1990 emissions on an average annual basis over a five-year. As mentioned the first commitment period was within 2008-2012. Two or more Annex I countries are allowed to form a "bubble" offering them the opportunity to reallocate permits among themselves. Additionally, the Protocol promotes the joint implementation between countries where a country or a company of a country finances emissions control efforts in another country. The Protocol allows for Clean Development Mechanisms (CDM) by which emission trading can be conducted with non-Annex I countries.

International Emissions Trading (IET) allows Annex I countries to meet part of their targeted emissions by using emissions trading. The total cap of emissions for Annex I countries is determined by the counties with each one agreeing to an individual target. Assigned Amount Units are the traded units each one equal to one ton of CO_2e.

An issue with the Kyoto Protocol agreement is to make developing countries tackle the problem under the constraint of lower income levels and maybe their less polluting activities compared to the developed countries. A possible solution to this issue may be the imposition of a global emissions tax that will internalize the external cost imposed to the global society. What is important is to assess the social cost of the GHG emissions and each country to pay the corresponding tax. This tax may be low or even negative for some countries with Stiglitz (2006) mentioning that this cost is the difference in the deadweight loss of the tax on emissions and the tax it substitutes.

Barrett (2007) mentions three deficiencies of the Kyoto Protocol. Namely, it deals only with the control of GHG emissions and fails to modify the incentives causing the social costs; it provides only a short-run way of tackling a very long-run problem; and it does not paying attention or even ignoring developing countries.

Figure 1.1: Global effect of Kyoto Protocol on countries' CO_2 environmental efficiency



Source: Halkos and Tzeremes (2011)

Halkos and Tzeremes (2014) in order to capture the influence of countries compliance with Kyoto Protocol Agreement (KPA), conditioned the years a country has signed the agreement until 2007. Their results show that for the first six years after countries signed the Kyoto protocol agreement there is a positive effect on their environmental efficiencies while after that time period it seems that countries avoid to comply with the actions imposed by the agreement. This is shown in Figure 1.1 where it can be seen that countries adopt the agreement for a certain time period (six years) trying to improve environmental performances by reducing CO_2 emissions. But after that, countries are not complying with the Kyoto Protocol and their higher economic growth rates are not associated with the relative reductions on CO_2 emissions implying a negative effect on their environmental efficiencies.

1.3 Damage costs estimates and uncertainties

Carbon dioxide emissions may be considered as the most important anthropogenic effect released into the atmosphere from the change in human land use and the fossil fuels combustion, solid wastes and wood products. But the non-CO_2 gases are also significant. Methane and nitrous oxide are present in the atmosphere naturally. The emissions of CH_4 stem from production and transport of coal, natural gas and oil together with the decomposition of organic wastes while N_2O emissions come from agricultural and industrial activities and from combustion of fossil fuels and solid wastes.

By clearing and cultivating forests, portion of the carbon stored in the woody matter of trees is released directly due to burning while other carbon is emitted more slowly due to decay. In the last two centuries almost 20-25% of the rise in CO_2 concentrations is due to changes in land use like forests' clearing and soil cultivation for agriculture. CO_2 sinks are the oceans (e.g. phytoplankton, coral reefs, various sea plants and animals) and land – sequestration in soil, trees etc. Use of fossil fuels are the source of more than 80% of GHG emissions while more than 10%, and about 12% are due to deforestation and various other changes in the use of land (Hackett, 2011).

Each GHG has different ability to absorb heat in the atmosphere. HFCs and PFCs are the most heat-absorbent while N_2O absorbs 270 times more heat per molecule compared to CO_2 and CH_4 traps 21 times more heat per molecule than CO_2 (Hackett, 2011). Carbon dioxide concentrations have risen more than 25% since the Industrial Revolution and they are steadily increasing (almost 0.5% yearly) (Hackett, 2011). Simultaneously, concentrations of nitrous oxides and methane are rising too. F-gases are expected to increase rapidly due to quick expansion of various emitting industries (semiconductor manufacture and magnesium production) and the substitution of ozone depletion substances (ODSs) like CFCs and HCFCs with HFCs in some applications (aerosols, air-conditioning, foams etc) under the Montreal Protocol.

F-Gases are generated (not naturally) in various industrial processes after the substitution of the Ozone Depleting Substances (ODS, chlorofluorocarbons CFCs and hydrochlorofluorocarbons HCFCs) that were faced out under the Montreal Protocol. They are also emitted from a number of industrial sources such as the use of PFCs in aluminium smelting or in semiconductor manufacture or use of SF_6 as insulating gas in various electrical systems (Halkos, 2010).[9]

1.3.1 Global Warming Potential (GWP)

Global Warming Potential is an index that measures different GHGs emissions with different atmospheric lifetimes and different radiative properties. Maintaining the climate impact constant, GWP measures allow for comparison and substitution among different gases to accomplish the desirable target (Fuglestvelt *et al.*, 2003). CO_2 has a GWP equal to 1 for reasons of comparison. CH_4 and N_2O have GWPs equal to 25 and 298 respectively. Atmospheric lifetimes of PFCs and SF_6 are very long ranging, as can be seen from Table 1.2, from 3,200 years for SF_6 to 50,000 years for perfluoromethane (CF_4). Usually GHGs emissions estimates are expressed in millions of metric tons of CO_2 equivalents (mmt of CO_2e), weighting each pollutant by the value of its GWP.

Specifically, N_2O lasts longer in the atmosphere (approximately 114 years) and is stronger in trapping heat (about 298 times more compared to CO_2). As nitrous oxide has a GWP equal to 298 this implies that it has 298 times more radiative forcing compared to CO_2

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[9] Fluorinated gases (CFC, PCFC, HFC, PFC, SF_6) comprised around 25% of anthropogenic radiative forcing of climate in 1980 and 1990 (IPCC, 1990). This percentage may be attributed to anthropogenic gases CFCs and PCFCs, which were regulated due to their depleting influence on stratospheric ozone by the Montreal Protocol, but were not included in the Kyoto Protocol (Halkos, 2010).

in terms of kgs. **CO_2e** describes different GHGs in a common unit showing the amount of CO_2 that will result to equivalent global warming effect. GHGs quantities are expressed as CO_2e by multiplying the GHG amount by its GWP. For instance 1 kg of N_2O emissions may be expressed as 298 (GWP for 100-years) kg of CO_2e.

At the same time, GHGs have to be treated carefully as they have a long run (LR) character in terms of their effects and at the same time they are accumulating in the atmosphere over the entire world. Scientific predictions indicate that if the current trends continue then the mean temperatures may increase by 2-6^o Fahrenheit in the century.

Table 1.2: Lifetimes and Global Warming Potentials (GWPs) relative to CO_2

		GWP for different time horizon		
	Lifetime (years)	**20-years**	**100-years**	**500-years**
Carbon dioxide (CO_2)		1	1	1
Methane (CH_4)	12	72	25	7.6
Nitrous oxide (N_2O)	114	289	298	153
Trichlorofluoromethane (CFC-11)	45	6,730	4,750	1,620
Chlorotrifluoromethane (CFC-13)	640	10,800	14,400	16,400
Dichlorotetrafluoroethane (CFC-114)	300	8,040	10,000	8,730
Hydrofluorocarbon (HFC-23)	270	12,000	14,800	12,200
Hydrofluorocarbon (HFC-32)	4.9	2,330	675	205
Hydrofluorocarbon (HFC-125)	29	6,350	3,500	1,100
Fluorocarbon 134a (HFC-134a)	14	3,830	1,430	435
Sulphur hexafluoride (SF_6)	3,200	16,300	22,800	32,600
Nitrogen trifluoride (NF_3)	740	12,300	17,200	20,700
Tetrafluoromethane (CF_4)	50,000	5,210	7,390	11,200

Source: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

1.3.2 Integrated Assessment Models (IAMs)

Integrated Assessment Models (hereafter IAMs) can help policy and decision makers. IAMs aim at evaluating climate change control policies, assessing and quantifying how crucial is the climate change and trying to report various dimensions of the climate change problem in a common framework (Kolstad, 1998). Furthermore, as defined by Kolstad (1998) an IAM includes not only human activities but also aspects of physical relationships forcing climate change. IAMs combine world economic activity and the environment providing useful information on policy choices.

According to Parson (1995) an integrated assessment model seeks to provide information for use by relevant decision-makers rather than advanced understanding. Additionally, a substantial characteristic is that an IAM is capable to combine different areas, methods, styles of study or degrees of confidence than would typically characterize a study of the same issue. Similarly and according to Weyant et al. (1996) an IAM is a mathematical tool where the knowledge from different fields is combined for the purpose of dealing with the issue of climate change.

An integrated model includes many definitions and interpretations but these interpretations have elements in common such as the cooperation of different disciplines and fields and the participation of stakeholders (Rotmans, 1998). The first generation of these models focusing on environmental issues emerged in the late 1970s (Nordhaus, 1979; Edmonds and Reilly, 1985). In the next decade the Regional Acidification INformation and Simulation computer model of acidification in Europe was developed (**RAINS**, Alcamo et al., 1990). Models like the Dynamic and Regional Integrated models of Climate and Economy (**DICE** and **RICE**; Nordhaus 1994a, 2007; Nordhaus and Boyer, 2000; Nordhaus, 2008; de Bruin et al., 2009); Global Change Assessment Model (**GCAM**; Edmonds et al., 1994); the Massachusetts Institute of Technology Joint Program on the Science and Policy of Global Change model (**MIT**; Prinn et al., 1996); Model for Energy Supply Strategy Alternatives and their General Environmental Impact (**MESSAGE**; Messner and Strubegger, 1995); Tool to Assess Regional and Global Environmental and Health Targets for Sustainability (**TARGETS**; Rotmans and de Vries, 1997); Integrated Model for the Assessment of the Greenhouse Effect (**IMAGE**; Alcamo et al., 1998); Climate Framework for Uncertainty, Negotiation, and Distribution (**FUND**; Tol, 2002a; Tol, 2005); Asia-Pacific Integrated Model (**AIM**; Kainuma et al., 2002); Policy Analysis of the Greenhouse Effect (**PAGE**; Hope et al., 1993; Hope, 2006; Hope, 2009); model for evaluating regional and global effects of GHG reduction policies (**MERGE**; Manne et al., 1995; Manne and Richels, 2005); TIMES Integrated Assessment Model (**TIAM**; Loulou and Labriet, 2008; Loulou, 2008); Community Integrated Assessment System (**CIAS**; Warren et al., 2008; Mastrandrea, 2010); and World Induced Technical Change Hybrid model (**WITCH**; Bosello et al., 2010) consider at the same time the costs of mitigation and the social costs of carbon.

IAMs can be classified into two different categories. There are ***policy optimization models*** with which, given a certain policy scenario or goal, key policy variables such as carbon emissions control rates are optimized. A further classification of policy optimization models is *cost-benefit (CBA)* and *cost-effectiveness analyses*. In a CBA application the costs of achieving the optimal policy intervention for an environmental target are compared with the resulting benefits given a predetermined constraint (say a specific level of global temperature increase) while in cost- effectiveness the least cost methods of achieving an environmental target are preferred over the more expensive ones.[10] Models such as DICE/RICE, FUND, PAGE, and MERGE are examples of the optimization policy.

The second category of integrated assessment models is referred to policy evaluation models known as ***simulation models***. Applying these types of models environmental economic and social consequences of specific policies can be calculated. These models include greater complexity in terms of regional detail and natural and social processes. Some representative models of this category are the AIM, MESSAGE, IMAGE and CIAS.

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[10] **Discounting** is important. Future costs and damages associated with GHG emissions are expressed in present value (PV) terms. PV of €1 received 25 years from now is the amount we have to invest today to have €1 in 25 years. At 5%, this is almost 30 cents; at 2.5% this is 54 cents. But mitigation cost takes place today, while climate damages appear in the future and thus lower discount rates result to higher mitigation costs. The calculation of PV of net benefits requires estimation of benefits and costs flows from different competitive projects for each year into (a finite time horizon) future. A proper discount rate is chosen and the PV of net benefits is estimated for each year into the future. The PV of the total net benefit (TNB) flows are given as:

$$PV_{TNB} = (B_0 - C_0)/(1+r)^0 + (B_1 - C_1)/(1+r)^1 + \ldots + (B_n - C_n)/(1+r)^n$$

Where C is the total cost in a given time period; B is the total benefit in a given time period; r is the discount rate; and n is the end period of the project in years from the present time. $(B_1 - C_1)$ represents the total net benefits received one year from the present time and $(1+r)^n$ implies that the sum (1+r) is taken to the n^{th} power (end period of project).

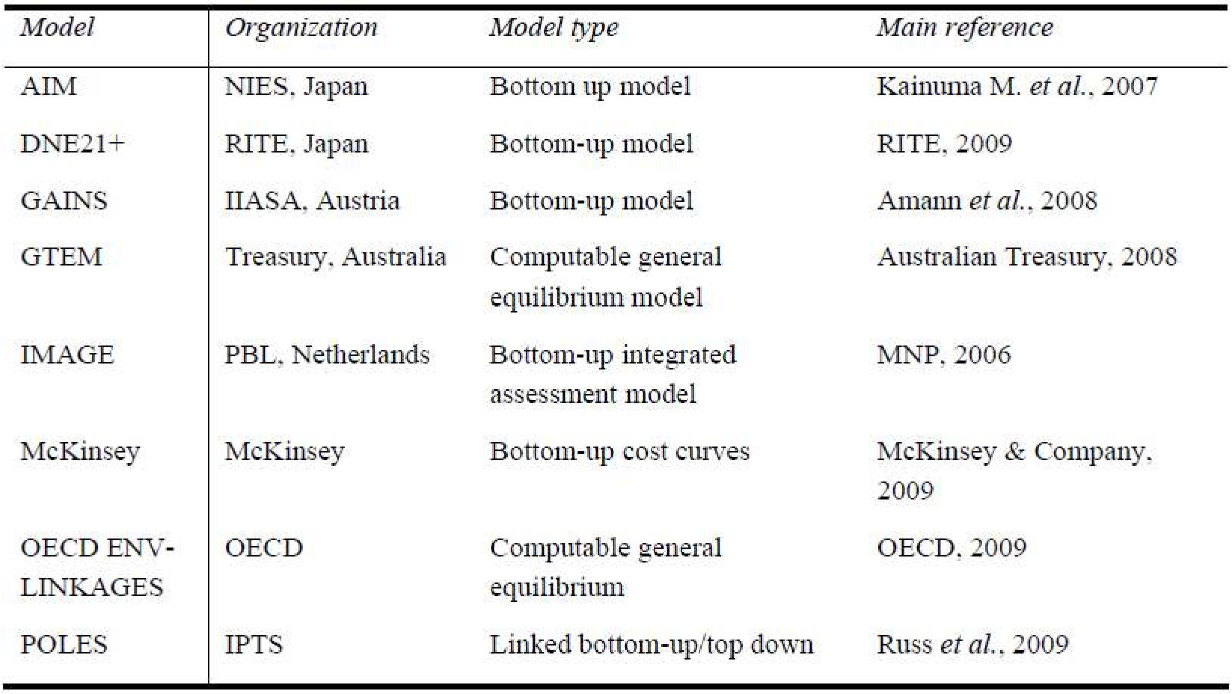
According to Rotmans and Dowlatabadi (1998) integrated assessment models are classified in *macroeconomic-oriented* and *biosphere-oriented models*. Specifically, macroeconomic models are neoclassical models based on a equilibrium framework. At the same time biosphere-oriented models are system based models entailing geophysical and biogeochemical processes. Finally there is a category which combines the characteristics of both orientations known as *hybrid models*. Examples of the tradeoffs of a general equilibrium framework and the dynamic environment are the GCAM and the MIT models.

Recently, models have been developed that incorporate co-benefits for different countries and regions analyses of policies that maximize the benefits between air pollution control and greenhouse gas abatement. An example of these models is the GAINS model (Amann et al., 2008).

Additionally, the following comparisons are considered. Information for greenhouse gas abatement cost is important for the policy makers to apply low cost environmental plans. Yet, statistical sources do not provide such information so it must be combined information derived from economic, social and technological aspects in complex models. Amann et al., (2009) conducted a survey comparing eight different models in order to provide MAC (Marginal Abatement Cost) curves and identifying the key factors that describe the differences of the model estimates. Table 1.3 shows the eight different teams that took part in the quantitative intercomparison.

AIM model which is developed by the National Institute for Environmental Studies combines bottom-up national modules with top-down global modules to evaluate different policies concerning the climate change, the greenhouse gases and their impacts. Another model that was included in the survey was the Dynamic New Earth 21 plus (*DNE21+*) model which has been developed by the Research Institute of Innovative Technology for the Earth. The DNE-21+ represents a bottom up linear programming model that takes into account energy unrelated CO_2 and five kinds of non GHG gases. One more model that applies a bottom-up approach for calculating GHG mitigation potentials and costs, is the Greenhouse gas – Air pollution Interactions and Synergies (*GAINS*) model which has been developed by the International Institute for Applied Systems Analysis (IIASA). Furthermore, bottom up approach uses also the global *McKinsey GHG abatement cost curve,* which was developed since 2006. *OECD* is a recursive dynamic neoclassical general equilibrium mode as well as *GTEM/MMRF* with the aim to address long-term policy issues such as climate change. *IMAGE* belongs to the Integrated Assessement Models and describes long-term dynamics of air pollution, climate change, and land-use change. The latest model included in the survey is the POLES that consists of technologically-detailed modules for energy-intensive sector.

Table 1.3: Participating Models

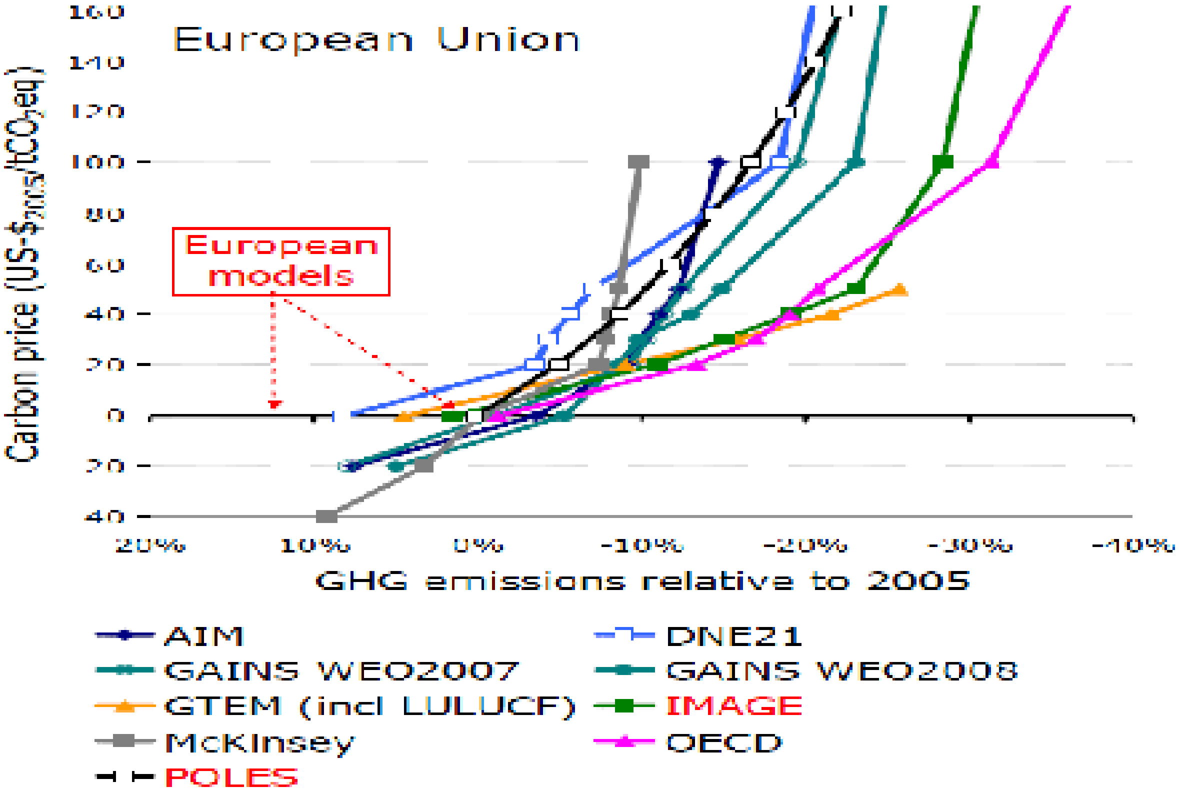


Model	*Organization*	*Model type*	*Main reference*
AIM	NIES, Japan	Bottom up model	Kainuma M. *et al.*, 2007
DNE21+	RITE, Japan	Bottom-up model	RITE, 2009
GAINS	IIASA, Austria	Bottom-up model	Amann *et al.*, 2008
GTEM	Treasury, Australia	Computable general equilibrium model	Australian Treasury, 2008
IMAGE	PBL, Netherlands	Bottom-up integrated assessment model	MNP, 2006
McKinsey	McKinsey	Bottom-up cost curves	McKinsey & Company, 2009
OECD ENV-LINKAGES	OECD	Computable general equilibrium	OECD, 2009
POLES	IPTS	Linked bottom-up/top down	Russ *et al.*, 2009

Adapted from Amann M, Rafaj P, Höhne N (2009) GHG mitigation potentials in Annex I countries. Comparison of model estimates for 2020. Report IR-09-034, September 2009, pp. 2.

The eight modeling teams provided a set of data concerning the emission levels for a range of carbon prices. The combination of the models is represented in the Figure 1.2 below that displays the marginal abatement cost curves for European Union for 2020. Obviously, the cost curves exhibit many differences as there are different assumptions concerning the treatment of the costing perspectives and mitigation potentials.

Figure 1.2: Abatement cost curves for European Union for 2020



Adapted from Amann M, Rafaj P, Höhne N (2009) GHG mitigation potentials in Annex I countries. Comparison of model estimates for 2020. Report IR-09-034, September 2009, pp. 2.

1.3.3 Damage costs

Stern review (Stern, 2007) concludes that serious and early action to control GHGs makes sense with the avoided damage costs to outset the associated costs of achieving the targeted abatement. In summary it can be said that doing nothing to cope with GHGs (Business as Usual, BAU) would imply a climate change damage equal to approximately 10.9% reduction in global consumption per capita. Stabilization at 550 parts per million CO_2e will reduce costs to 1.1% and these costs to stabilize at 550 ppm would be approximately 1%

of gross world product. The Stern review estimated climate change costs by using IAMs and various scenarios for GHGs emissions and concentrations and the associated damage costs corresponding to reduced consumption.[11]

Damage costs estimations can be found also in the various integrated assessment models (IAMs) like DICE, PAGE and FUND. Nordhaus (1994a) presents estimates of percentage losses in world's gross product; Roughgarden and Schneider (1999) moving on in the lines of Nordhaus and various other surveys, present a damage function and its confidence intervals; Heal and Kriström (2002) and Pizer (2006) approach uncertainty by subjective analysis and using experts' opinions. Particularly, Pizer (2003) modified the DICE model (Nordhaus, 1994b) by substituting in a more complex way the quadratic relationship between temperature change and damage. Nordhaus (2008) presents a range of marginal damages of pollutants between \$6 and \$65/t carbon with a central estimate of \$27. In line with the Nordhaus' (2008) estimates, Interagency Working Group on Social Cost of Carbon (2010) cites a mean cost of \$21/t and a \$65/t in the 95th% estimate.

In the case of GHGs air pollution the first cost-benefit analysis is fount in Nordhaus (1991) while Tol (2013) cites 16 studies and 17 estimates of climate's change global welfare impacts (Nordhaus 1994a,b, 2006, 2008, 2011; Fankhauser 1994, 1995; Tol 1995, 2002a,b; Bosello et al. 2012; Maddison 2003; Mendelsohn et al. 2000a,b; Maddison and Rehdanz 2011; Rehdanz and Maddison 2005). Specifically, Tol (2013) applying kernel density estimators to 588 estimates expressed in US\$ 2010 and referring to emissions in the year 2010 offers a list of 75 studies with 588 estimates of carbon emissions' social cost. From these studies, Tol finds a mean marginal cost of carbon equal to \$196 per metric tone of carbon and a mode estimate of \$49/tC; while with 3% and 0% rate of time preference a mean social cost

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[11] Future consumption losses have to be discounted to the present by appropriate consumption discount rates (d) like $d = \rho + g\,\varepsilon$
where ρ is the social discount rate of time preference. g is the growth rate of average consumption and ε the elasticity of the social weight for a consumption change (For more information see Arrow, 2007).

of carbon equal to $25/tC and $296/tC respectively is calculated. Obviously using different rates of time preference lead to high asymmetry in estimates with higher rates of time preference indicating that future climate change costs present a lower present value.

1.3.4 Uncertainties

The associated potential effects of climate change are related among others to energy demand, human health, agriculture, extinction of species and loss of ecosystems etc. The effect of past GHGs on global temperatures is not easy to be estimated. The IPCC (2001) claims that in the 20th century, global temperatures increased in the range of $0,6\pm0,2^{\circ}$ C and provide a number of possible effects of global warming on climate like extreme weather events (with very possible summer droughts in continental areas, higher heat waves, etc), tropical storm intensity (hurricanes, etc), decomposition of methane hydrates, etc.

Climate change uncertainties may be distinguished as parametric and stochastic (Kelly and Kolstad, 1999; Kann and Weyant 2000; Peterson, 2006). The existing IAMs examine mainly the prametric uncertainty attributed to the assumed main parameters like climate sensitivity, damage functions etc in the IAMs. According to Golub et al. (2011) climate sensitivity and damage functions justify the parametric while temperature and economy's performance "unresolved" processes justify the stochastic component of uncertainty. Golub et al. (2011) discuss analytically the discrete uncertainty modeling (DUM) and the special form of real options analysis (ROA) to model climate policy in case of parametric uncertainty while stochasticity is tackled with the use of stochastic dynamic programming (SDP).

Another type of uncertainty stems from the role of clouds, which decrease the solar radiation "reaching" earth's ground by reflecting ultraviolet radiation. This implies that increasing clouds may reduce the effect of greenhouse (McKibbin and Wilcoxen, 2002). At the same time the existence of aerosols in the atmosphere coming from fossil fuels combustion, volcanoes or forests' burning reflect part of the solar radiation and thus reduce climate change. Clouds and aerosols together absorb infrared and this increases warming (McKibbin and Wilcoxen, 2002).

If uncertainty is absent, the efficient control level of emissions may be achieved either by using taxes or tradable permits. But in the case of uncertainty the two instruments are different. If marginal costs are flat (steep) and marginal benefits steep (flat) then permits (taxes) are preferred. Empirical evidence shows that marginal cost curves for controlling GHGs are quite steep with the marginal benefits from controlling emissions being flat. Obviously, uncertainty in cost estimates has to be tackled carefully. Van Vuuren et al. (2007) taking into consideration a number of abatement options, like reductions of non-CO_2 emissions, carbon plantations and various measures in the energy system find that mitigation scenarios end up to lower levels of regional emissions but with increased land use. Cost estimates uncertainty is almost 50%.

1.3.5 Evolution of emissions

We can approximate the evolution of emissions using the concept of the Environmental Kuznets Curve (EKC) hypothesis and the Kaya identity. According to the EKC hypothesis there may be an inverted U-shape relationship between environmental damage and per-capita income. A number of EKC studies consider the factors causing this inverted U-shape pattern (for a brief review see Halkos, 2012).[12]

On the other hand, the Kaya identity connects the main factors that determine the level of human effect with climate in the form of CO_2 emissions. That is

$$CO_2 \text{ emissions} \equiv \text{Population} \times (\text{GDP/c}) \times (\text{Energy intensity}) \times (\text{Carbon intensity})$$

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[12] Various efforts have been done in presenting historical or projected data of CO_2 emissions. Schmalensee et al. (1998) using reduced-form models and country panel data for the time period 1950–1990 projected CO_2 emissions from fossil fuels combustion through to the year 2050 and find evidence of an inverted U-shape relationship between CO_2 emissions and per-capita income with a turning point within the sample. Boden et al. (2012) discuss global, regional and national fossil-fuel CO_2 emissions.

where CO_2 emissions come from the burning of fossil fuels; GDP/c stands for Gross Domestic Product per capita representing the standards of living; Energy intensity is defined as Energy over GDP; Carbon intensity is defined as CO_2 emissions over energy.[13] Thus policies to reduce emissions must concentrate on more energy efficient use (reducing energy per unit of GDP) and fuel switching (reducing carbon intensity of energy).[14]

Table 1.4 presents the indices of CO_2 emissions and Kaya identity's main factors (reference year 1990=100). The average annual change (in %) between the reference year and 2011 is presented in the parentheses. As can be seen the driving forces in the increase of CO_2 emissions globally are population and GDP/c offsetting energy intensity with carbon intensity to remain stable mainly due to the continuous use of fossil fuels and the slow adaptation of low-carbon alternatives.

Table 1.4: Indices of CO_2 emissions and Kaya identity's main factors (reference year 1990=100). In parentheses the average annual change between reference year and 2011.

	CO_2 emissions	**Population**	**GDP/c**	**Energy intensity**	**Carbon intensity**
World	149 (1.9%)	132 (1.3%)	148 (1.9%)	77 (-1.2%)	100 (0.0%)
Annex I Parties	96 (-0.2%)	110 (0.5%)	135 (1.4%)	70 (-1.7%)	93 (-0.3%)
Non-Annex I Parties	261 (4.7%)	138 (1.5%)	220 (3.8%)	77 (-1.2%)	112 (0.5%)
Annex I Kyoto Parties	88 (-0.8%)	104 (0.2%)	132 (1.3%)	70 (-1.7%)	91 (-0.4%)
Annex II Parties	106 (0.3%)	114 (0.6%)	132 (1.3%)	74 (-1.4%)	95 (-0.3%)
Annex II North America	110 (0.4%)	125 (1.1%)	133 (1.4%)	69 (-1.7%)	95 (-0.20%)
Annex II Europe	93 (-0.3%)	110 (0.4%)	132 (1.3%)	74 (-1.4%)	87 (-0.7%)
Annex II Asia Ocania	120 (0.9%)	108 (0.3%)	121 (0.9%)	86 (-0.7%)	107 (0.3%)
Non-OECD Total	194 (3.2%)	135 (1.5%)	198 (3.3%)	68 (-1.8%)	106 (0.3%)
OECD Total	111 (0.5%)	117 (0.7%)	135 (1.4%)	75 (-1.4%)	94 (-0.3%)

Source: Highlights © OECD/IEA (2013).

In more details, Table 1.5 presents the total and per capita CO_2 emissions in million tons and in kg respectively by sector in the year 2011 with the last column to display the

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[13] Kaya identity differs from the IPAT which reflects the impact of human activity on the environment. That is

$$I = P \times A \times T$$

where I is the Human Impact on the environment; P the population; A represents the Affluence; and T stands for Technology.

[14] If we totally differentiate Kaya's Identity then this is expressed as growth rates. That is

$$\%\Delta(CO_2\ \text{emissions}) = \%\Delta(\text{Population}) + \%\Delta(\text{GDP/c}) + \%\ \Delta(\text{Energy intensity}) +\ \%\ \Delta(\text{Carbon intensity})$$

where Δ represents changes in percentage (%). That is the percentage change in emissions equals the sum of percentage changes in population, GDP/c, energy and carbon intensities.

percentage change in CO_2 emissions in the time period 1990-2010. Similarly, Table 1.6 presents CO_2 emissions in the year 2011 per Total Primary Energy Supply (TPES), per GDP in Purchasing Power Parity and per capita with percentage changes in parentheses for the time period 1990-2010.

Table 1.5: Total (in million tons) and per capita (in kg) CO_2 emissions by sector in 2011 (CO_2/c in parentheses)

	Electricity and heat production	Other Energy industry own Use	Manufacturing Industry and Construction	Transport	Other sectors	% Change 1990-2010
Annex I Parties	5589.5 (4324)	663.6 (513)	1956.9 (1514)	3386.6 (2620)	1758.3 (1360)	-3.9
Non-Annex I Parties	7477.2 (1320)	879.3 (155)	4551.7 (803)	2500.9 (441)	1464.6 (259)	160.8
Annex I Kyoto Parties	3234.2 (3606)	384.8 (429)	1290.5 (1439)	1691.2 (1886)	1112.8 (1241)	-12.1
Non-OECD	8154.6 (1426)	857.6 (150)	4740.9 (829)	2557.2 (447)	1577.5 (276)	94
OECD	4912.1 (3960)	685.2 (552)	1767.8 (1426)	3330.2 (2685)	1645.5 (1326)	10.7
USA	2212 (7089)	266 (852)	597.9 (1916)	1638.1 (5250)	573.2 (1837)	8.6
OECD Europe	1353.6 (2439)	182.5 (329)	590.8 (1065)	936.5 (1688)	683.6 (1232)	-5.2
EU-27	1320 (2622)	168 (334)	547.3 (1087)	891.5 (1771)	615.9 (1224)	-12.6
Non-OECD Europe/Eurasia	1399.4 (4121)	138.1 (407)	478.1 (1408)	384.8 (1133)	342.6 (1009)	-31.2
Africa	412.2 (394)	39.9 (38)	163 (156)	245.9 (235)	106.7 (102)	77.7
World	13066.8 (1878)	1542.9 (222)	6508.7 (935)	7001.1 (1006)	3222.9 (463)	49.3

Source: Highlights © OECD/IEA (2013).

Table 1.6: CO_2 emissions in 2011 per Total Primary Energy Supply (TPES), per GDP in Purchasing Power Parity and per capita (% changes in parentheses for 1990-2011)

	CO_2 / TPES (in tons CO_2/terajoule)	CO_2 / GDP PPP (in kg CO_2/US 2005 $)	CO_2/ Population (in CO_2/c)
Annex I Parties	55.3 (-7.0)	0.36 (-35.2)	10.33 (-12.6)
Non-Annex I Parties	57.7 (11.9)	0.52 (-13.8)	2.98 (89.4)
Annex I Kyoto Parties	53.7 (-8.6)	0.33 (-36.1)	8.60 (-15.7)
Non-OECD	57.4 (5.7)	0.55 (-27.7)	3.13 (43.4)
OECD	55.6 (-5.6)	0.33 (-29.6)	9.95 (-5.1)
USA	57.6 (-5.1)	0.40 (-34.6)	16.94 (-12.9)
OECD Europe	51 (-12.5)	0.25 (-36.9)	6.75 (-14.5)
EU-27	51.2 (-13.5)	0.25 (-40.2)	7.04 (-17.9)
Non-OECD Europe / Eurasia	55.7 (-10.1)	0.75 (-40.0)	8.08 (-30.5)
Africa	33 (-0.4)	0.34 (-15.7)	0.93 (7.7)
World	57.1 (0.0)	0.45 (-23.2)	4.50 (13.5)

Source: Highlights © OECD/IEA (2013).

Production using energy creates entropy, which increases when the initial useful energy is turned to redundant energy that cannot be converted into work. The existing mass of living organisms in an area is the biomass. Fossil fuels originate from biomass existing long time before human beings. The existence of biomass and its availability depends on the existence of lands and waters. The necessary areas to supply the required ecological services to maintain life can be assessed by the notion of the ***ECological Footprint*** (ECF). The notion approximates the area needed to supply what a society or an economy needs to consume as well as to absorb the resulting wastes[15].

If we distinguish between renewable and non-renewable energy then the latter are finite and may be exhausted if we have an irrational use.[16] In terms of the ecological footprint and by using the IPAT equation, the total environmental effect can be approximated as:

$$\text{Effect} = \text{Population} \times (\text{GDP/c}) \times (\text{ECF/GDP})$$

In this way it is obvious that ecological footprint must be less than the available area.

1.3.5.1 Impact of financial crisis on emissions projections

Global financial crisis is an interesting issue in terms of affecting emissions projections. Peters et al. (2012) showed that the level of global CO_2 emissions from the combustion of fossil-fuels and the production of cement increased almost 6% in 2010 surpassing 9 billion metric tones of carbon and offsetting more than the 1.4% decrease in 2009. They show that the impact of the financial crisis of the years 2008–2009 on emissions has a short-run character due to the significant increase of emissions in emerging countries and the return to high emissions in developed countries accompanied with higher fossil-fuel intensity globally.

Recently all major organizations (like among others IEA, OECD, McKinsey & Company and IIASA) have updated their projections including the effect of financial crisis on emissions. The results are similar and reveal a modest impact of financial crisis on emissions. Specifically, for 2020 and 2030 emissions projections only about 6% appear to have dropped relative to estimates before the global financial crisis (McKinsey and Company, 2010). This small impact appears to be more significant in developed countries than in developing

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[15] We assume that the total waste emissions are lower that the assimilative capacity of the environment to absorb them. In the case of carbon, economic growth with reduced carbon footprint requires low carbon growth.

[16] For sustainability it is necessary to assume that harvesting rates are lower than the rates of regeneration.

countries. In a by-sector analysis, sectors which are linked to GDP appear to be more affected than sectors which are not linked to GDP. On the one hand, examples of sectors linked to GDP are the power, the industry and the services sectors. On the other hand, sectors such as agriculture, forestry and waste generation are linked with population and not with GDP, therefore they suffer less or no impact from crisis.

There are three reasons for this modest change relative to the pre-crisis results. Firstly, projections are made using long historical time series and consider a large time period towards 2030. Therefore, financial crisis is a relatively small time period. Second, a number of large developing countries such as China, which produce a large amount of emissions, are less exposed to the crisis or their economic systems have been adapted well to the new economic reality. Last, some sectors like agriculture, forestry and waste generation are not linked with GDP and are not affected by the crisis.

The modest reduction in emissions projection has not altered the total abatement potential relative to the pre-crisis period. However, there might be slightly lower abatement costs and lower fossil fuels prices. It is very important for the countries to continue their efforts for emissions reductions as any delay may result in a less abatement potentials in the future.

1.4 Costs of abatement: concepts and methods of calculation

1.4.1 Costs associated with emissions control

Hourcade et al. (1996) distinguish four types of costs associated with emissions control: direct, partial and general equilibrium and nonmarket costs.[17] The first classification of direct costs refers to the abatement unit used to control emissions or insulate houses or substituting high carbon content fuels with low. The partial equilibrium costs include the direct costs but take into consideration the reduction in producer and consumer surpluses

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[17] Jaffe et al. (1995) propose other costs like transaction and government administration.

caused by the increase in GHG emissions which is not traded in the economy. For instance if the price of oil increases both producers and consumers adjust to the increased price by keeping other prices constant.

The general equilibrium costs include all economic costs of GHG emissions abatement. Kolstad and Toman (2005) explain this cost distinction using as an example the sequence of an increase in the price of carbon, the expected fall in the (net of tax) price of oil, the negative effect on the oil industry and the consequences for enterprises supplying inputs to oil industry, to local industry depending on the income workers earn from the oil industry. These secondary impacts from these sectoral effects are not usually elevated in the partial equilibrium costs distinction. Finally, we may have nonmarket costs outside the markets as long run unemployment due to policies that restrict GHG emissions and the human burden of unemployment includes nonmonetary factors (Kolstad and Toman, 2005).

Next let us consider the cost curves for abating emissions, the methods of constructing them before we proceed in the next session to their use in policy making.

1.4.2 Marginal Abatement Cost curves (MAC)

Marginal abatement cost (MAC) curves is a key tool which has been developed since the early 1990s to illustrate the cost associated with carbon mitigation and to contribute to determining optimal level of pollution control (Halkos and Kitsou, 2014; Beaumont and Tinch, 2004; McKintrick, 1999). More specifically, an abatement cost curve as a graph depicts the cost of the emissions reductions. Marginal costs increase as we switch between abatement methods with the abatement rising to the maximum feasible level. In this way the MAC curve is a discontinuous step function presenting a staircase shape with each step representing a specific control method. The level of each step shows the additional cost of an abatement method relative to the maximum incremental amount of the pollutant abated by introducing that method. The sequence of cost-effective abatement methods provides us with the long-run MAC.

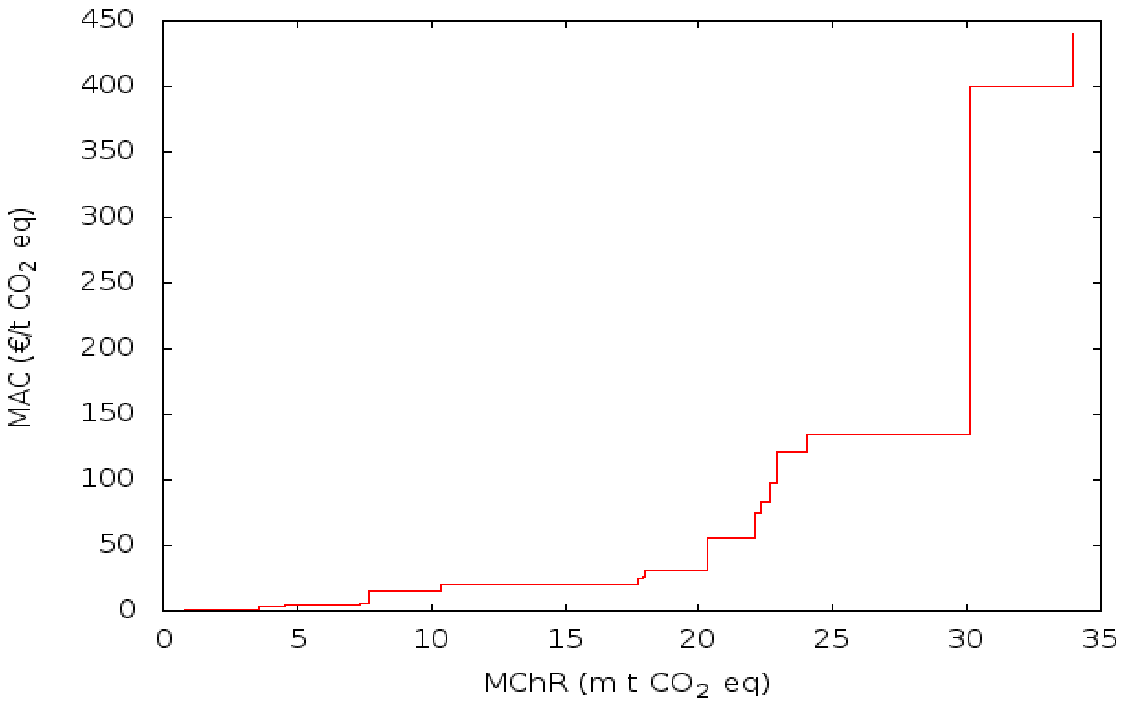
As with any pollutant, the challenge is to reduce GHG emissions in a cost-effective way. Policy makers try to introduce and implement a concrete and consistent policy to achieve the desirable emissions reduction. The authorities or the decisions makers seek to maximize control efforts under their budget constraints. We assume "cost-effectiveness" in the potential application of the abatement techniques, which means that for a given method in a given pollution source, the total annualized cost divided by the annual tonnes of emissions removed is the highest it can be achieved at the lowest cost. This implies that cheaper options have to be preferred compared to more costly ones as it would be inefficient to use the most costly abatement methods first if there are cheaper alternatives.

In this way national abatement cost curves exhibit non-decreasing marginal costs and the most cost-effective techniques will be the appropriate control methods for the national decision maker. The height of each step represents the cost of € per tone of CO_2 abated and the width refers to the magnitude of emission reduction for each mitigation option. Each step of this stepwise curve represents solely one technological option (Halkos, 1992; 1995; 2010).

Control methods may differ in applicability as well as in costs. Abatement costs are independent of the order of application and technologies applied for the abatement of emissions are scale specific. That is constant returns to scale are assumed with fixed abatement coefficients over the abatement range at which each abatement method is efficient. At the same time, both fuel use and costs are assumed given independently of abatement policy with the existence of a competitive market for abatement methods which is accessible to all European countries at the same conditions.Figure 1.3 presents an example of the abatement cost curve for F-gases control for the EU-27 in 2020 (Halkos, 2010).

Moreover, the mitigation options are assessed for a specific year. This approach however includes flaws such as not taking into account neither the potential interdependencies between the options in the system nor the intertemporal dynamics nor the indirect costs such as implementation, search cost or financial costs (Ekins et al., 2011; Kesicki, 2010; Morthorst, 1994).

Figure 1.3: F-gases abatement cost curve for EU-27 in 2020



Source: Halkos (2010).

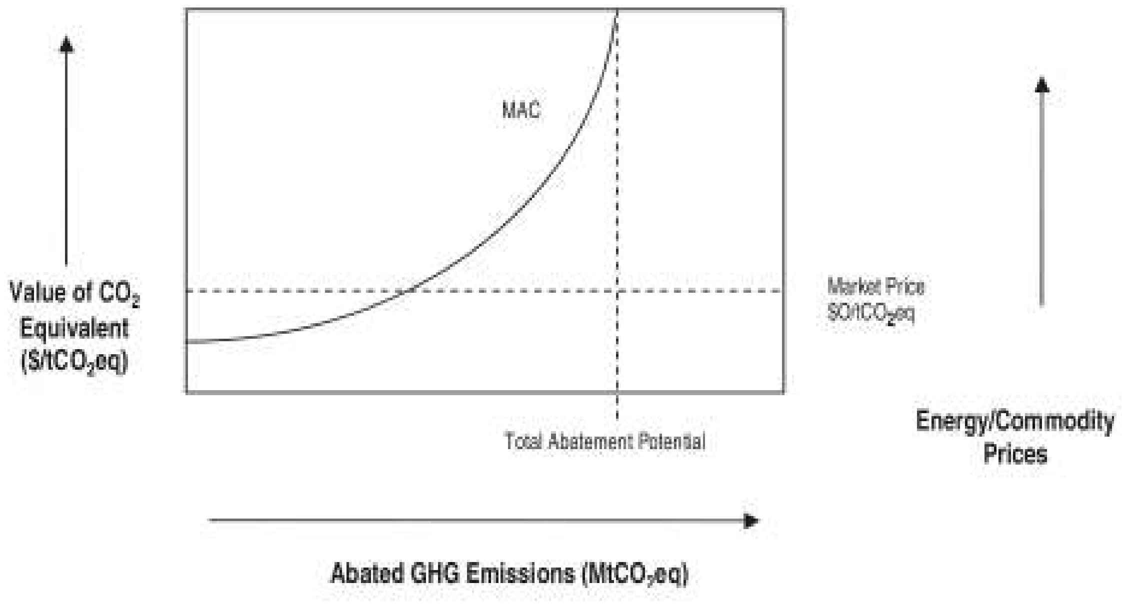
Following Halkos (1992, 1995; 1996a,b), the abatement cost of an emission control method is given by the total annualized cost (TAC) of a control method, including capital and operating cost components. That is:

$$TAC = \left\{ (TCC) \left[\frac{r}{1-(1+r)^{-n}} \right] \right\} + VOMC + FOMC \,,$$

where TCC represents the total capital cost (using investments as a measure for total capital cost); VOMC and FOMC: variable and fixed operational and maintenance cost respectively; $r/[1 - (1 + r)^{-n}]$ reflects the capital recovery factor at a real discount rate r, converting a capital cost to an equivalent stream of equal annual future payments, considering the time value of money (represented by r). Finally, n is the economic life of the asset (in years). For the economic and technical assumptions in cost calculations see Halkos (1992, 1995, 2010). The calculation of annual operating and maintenance costs requires the availability of the pollutant's content in fuel used (e.g. sulphur content in coal used in an industrial unit), the annual operating hours, the assumed abatement efficiency of the adopted abatement unit, as well as country specific conditions like fuel prices, capacity/vehicles utilization and emission factors. Growth in industrial productivity rates and in population are important factors of abatement costs in controlling GHGs.

Alternatively we can use USEPA's (2006) methodology in order to construct Marginal Abatement Curve. In Figure 1.4 the x-axis shows the amount of emissions abatement in MtCO2eq, and the y-axis shows the breakeven price in $/tCO2eq required to achieve the level of abatement.[18]

Figure 1.4: An illustration of a MAC for non-CO_2



Source: USEPA (2006, p. I-13)

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[18] USEPA (2006) defines as the method's breakeven price the carbon price where a method's costs equal to benefits.

The calculation of the breakeven price is presented below (modified from USEPA, 2006):

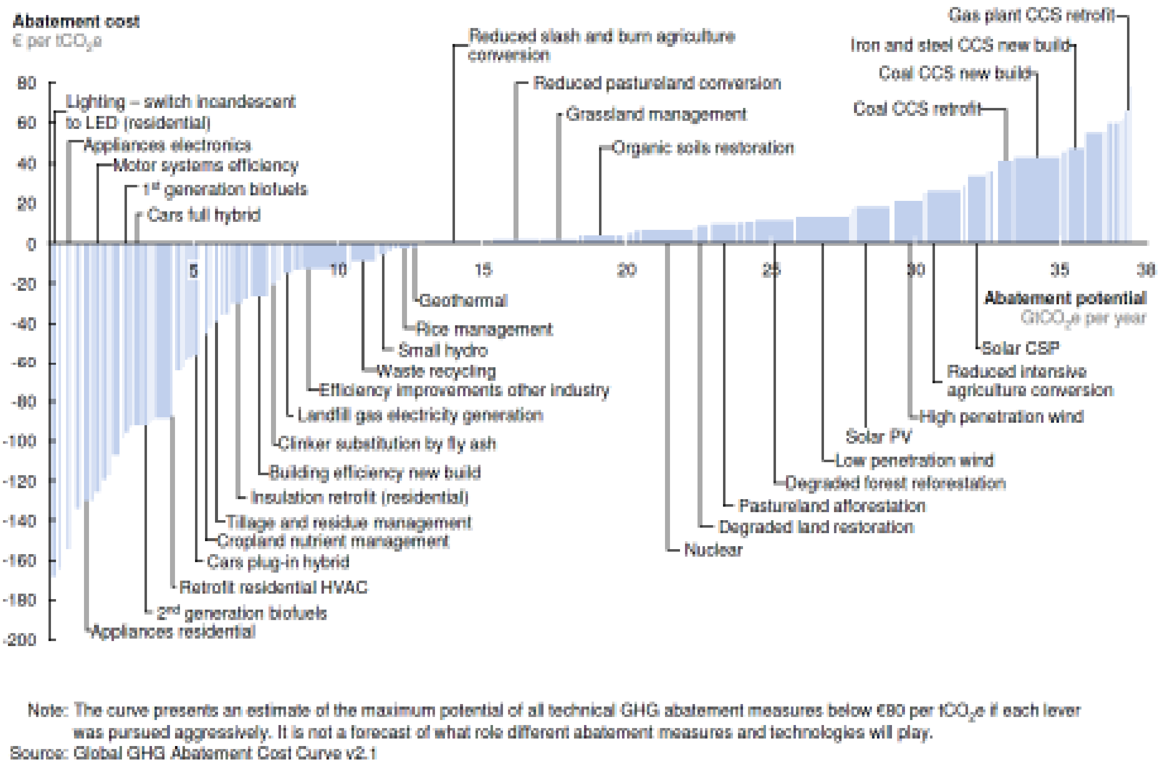
$$P = \frac{CC}{(1-t) * PR * \sum_{n=1}^{N} \frac{1}{(1+d)^n}} + \frac{RC - TR}{PR} - \frac{CC}{n * PR} * \frac{t}{(1-t)},$$

where P represents the breakeven price of the option (\$/tCO2eq); CC is the one-time capital cost of the option (\$);t represents the tax rate (%); PR stands for the pollutant's emissions reduction achieved by the technology (MtCO_2eq); RC is the operating and maintenance cost of the adopted mettod (\$/year); TR reflects the total revenues generated from energy production (scaled on regional energy prices) or sales of abatement by-products or change in agricultural commodity prices (\$); N = the method's lifetime (in years); d stands for the discount rate.

Figure 1.5 presents the McKinsey's and Company global abatement cost curve beyond BAU for the year 2030. Specifically, it presents a calculation of the maximum potential abatement of all possible and feasible control methods. Similarly, Figure 1.6 presents an example of an expert based derived CO_2 abatement cost curve (Kesicki, 2011, p. 3).

The abatement cost curves do not only include positive costs but present also negative costs. As can be seen both Figure 1.5 (McKinsey & Company's abatement cost curve) and Figure 1.6 (Kesicki's abatement cost curve) show significant amounts of negative costs. Many of negative cost opportunities involve energy efficiency measures while some may involve land use, especially in countries with large tropical forest areas. The abatement options with negative cost may be defined in the literature as no regrets mitigation options. The existence of negative costs means that the society benefits from the specified mitigation actions.

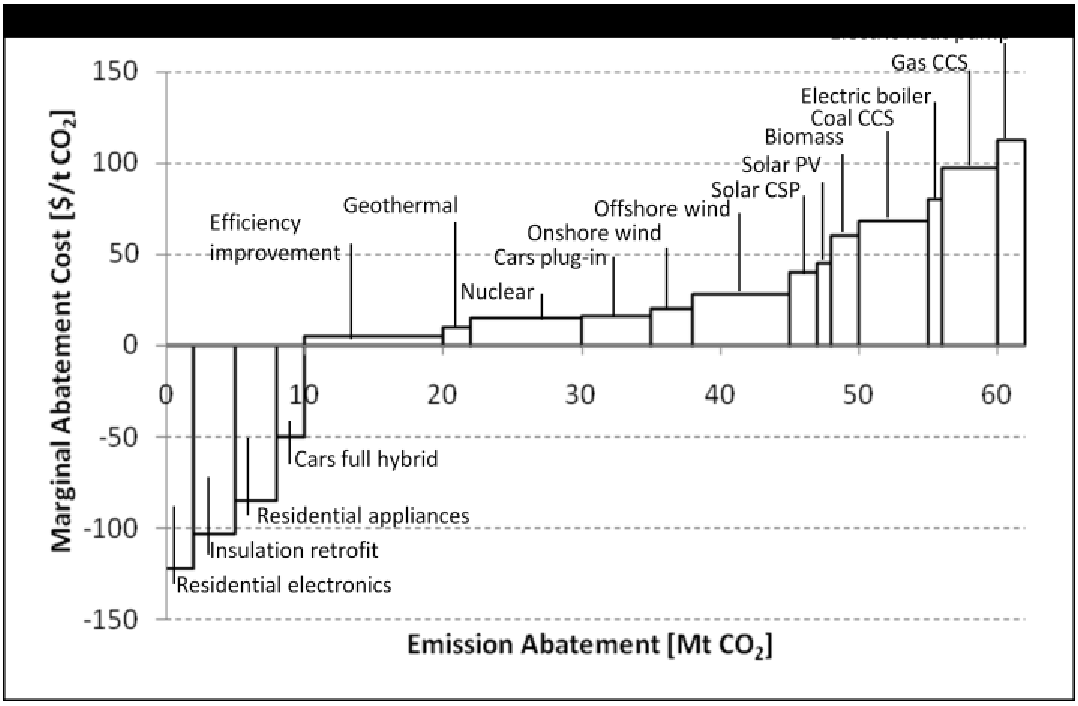
Figure 1.5: McKinsey's global GHG abatement cost curve – year 2030



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: Global GHG Abatement Cost Curve v2.1

Source: McKinsey & Company (2010).

Figure 1.6: CO_2 emissions abatement cost curve



Source: Kesicki (2011).

Ekins et al. (2011) mention that in the case of the McKinsey abatement cost curve as the project costs are correctly estimated, the explanation of these negative costs based on the insufficiently definition of the extensive cost, the implementation of non-financial barriers or inconsistent discount rates. Further, they note that markets are not perfect and suffer from various imperfections. So, the cost curve cannot assume rational agents, perfect information and no transaction costs. Ackerman and Bueno (2011) present an overview of the McKinsey results and discuss the controversy about the meaning of the negative abatement cost. They mention that for this phenomenon McKinsey is not alone as there are bottom-up studies for energy savings and emission reductions which have negative cost options.

In order to avoid the academic controversy about the interpretation of negative cost investment opportunities they offer a new method. Their method obtains estimates which are in some respects comparable to other bottom-up analysis of energy costs. Finally, they note that, according to Brown (2001, p. 1199) there are a range of market failures (like distortionary fiscal and regulatory policies, unprized costs and benefits, imperfect insufficient and inaccurate information) and market barriers (like low priority of energy issues, capital market barriers and incomplete markets for energy efficiency) that explain the existence of the efficiency gap. This disparity is the difference between the actual energy efficiency level of investment and the higher potential cost-beneficial level from the consumer's side.

1.4.3 Methods of constructing abatement cost curves

Two different approaches to energy economy modeling exist.[19] Bottom-up or engineering models and top-down or economic models are the two modeling approaches which lead to very different properties and model results according to the analyses of emissions and abatement costs. Bottom-up modeling is based on disaggregation and technical

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[19] Initially a simplified method is to construct a supply abatement curve. According to Jackson (1991), Naucler and Enkvist (2009) and Kesicki (2010) a supply curve combines the options for supplying energy given demand side options in order to adopt cost effective method of reducing emissions of CO_2.

parameters, whereas top-down modeling is based on aggregation and on macroeconomic principles. Mixture or integrated engineering and economic models may also be used to construct an abatement cost curve.

1.4.3.1 Bottom-up or engineering models

In this case emissions abatement objectives are defined and all potential methods to accomplish this target are listed. For each method, the costs on pollution control installation are estimated together with various other costs like initial investments, fuels used, operation and maintenance, labour and electricity, etc. Next, the total costs imposed to each firm are estimated extracting the total control cost curve.

A bottom-up model as disaggregated model in order to estimate structural changes in the economy is necessary to have available data regarding technologies, the diffusion rate of facilities and the rate of use to capacity. Particularly, bottom-up models describe the demand and supply in a disaggregated way in order to estimate potentials which for example refer to substitution of technologies with low carbon emissions.

The bottom-up approach describes current and potential technologies in detail. It also describes past and present technologies using quantitative data. The purpose is to convert them to desired services and alternative technologies that can provide the same services but with less energy consumption (Wilson & Swisher, 1993; Bohringer & Rutherford, 2009; Loschel, 2002; van Vuuren et al., 2009). More specifically, it investigates how an individual technology can be applied or how can be substituted so as to provide energy services. Bottom-up models are solutions oriented in terms of trying to find a cost-effective strategy to use as little energy as possible to provide a given level of energy services (Wilson & Swisher, 1993).

The analysts of bottom-up modeling propose the substitution of technologies with more energy efficient ones. They also estimate the impacts of these investments on energy demand by developing scenarios that describe cost-effective potentials for implementing energy demand and supply side technologies. The calculation of the potential is based on summing the net costs of technology options. Hence, the technology options are ranked as the costs increase drawing graphically a marginal cost curve or supply curve of emissions reductions or conserved energy. The crucial assumptions of bottom-up modeling to take into account are the costs, total energy consumption of a country, the lifetimes of technologies and alternative technologies, fuel and electricity costs, potential rates of technologies (Wilson & Swisher, 1993).

There are various bottom-up approaches like techno-econometric models, optimization and simulation modelling and accounting frameworks (Jacobsen, 1998). In econometric models socio-economic variables are included endogenously so as to explain the evolution of structural and behavioral changes although unexpected shocks of weather cannot be included and as a consequence the results of the analysis of the econometric relations are biased. Optimization models usually rely on linear programming and various constraints to derive the least cost ways of achieving a targeted energy demand. In this approach consumer choices are included assuming rationality in consumer's behavior and no market imperfections. Simulation modeling imitates energy users and producers using various indications like prices, incomes etc. Its purpose is to simulate variables such as energy prices and technology costs in order to calculate the potentials of energy savings and substitutions.

On the other hand accounting modelling frameworks account explicitly the decision outcomes by considering the effects of various scenarios attaining a certain target like, for instance, the costs and benefits (in energy savings and emission reductions) in using renewable energy sources. But accounting models lack important dynamics and the changes in socio-economic variables are difficult to be assessed and interpreted. Moreover, variables that would be crucial to be circulated endogenously in the model are presumed to be exogenous.

Here we may consider the Long-range Energy Alternatives System (LEAP) as an evolution of the energy system models.[20] LEAP is a flexible modeling environment allowing us to build applications appropriate to specific problems at different geographical levels (cities, countries, regions or globally). The model is based on accounting framework to create appropriate energy demand and supply relying on physical representation of the energy system. It also uses different scenarios to explain the appropriate possible pathways of the evolution of the energy system.

The energy system in many bottom-up models is not necessarily optimal. As a consequence many cost-efficient technologies are not used because of barriers to implement them. Another weakness of this type of approach is that bottom-up models only partially represent the economy and they do not include market responses. Bottom up models characteristic is the representation of technology which allows simulating the actual sector in partial equilibrium setting (Tuladhar et al., 2009; Bohringer & Rutherford, 2008). Additionally this type of models include an excessive number of exogenous variables something that is a factor which can cause deviations from reality. Also there is a difficulty to estimate macro economic costs in terms of GDP. Micro economic costs can be calculated via cost benefit analysis. However there is interdependence between macroeconomic and microeconomic analysis due to interdependence of indicators. These approaches often neglect the macroeconomic impact of energy policies (Tuladhar et al., 2009; Bohriger & Rutherford, 2009; van Vuuren et al., 2009).

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[20] As climate change demands the consideration of very LR time periods (more than a 100 years), researchers started using LEAP model, which has been applied as the standard way in national communications for the UNFCCC reporting. In the supply-side the model uses accounting and simulation approaches in order to provide answers under alternative possible development scenarios to "what-if" type of analysis.

1.4.3.2 Top-down or economic models

These are models relying on aggregate economic variables and their relationships as determined by the economic theory. That is the top-down approach, assuming efficient markets, uses aggregate data to assess the benefits and costs of the impact of emissions control (like GHG mitigation) on income and GDP. It also considers the changes to the economy caused by these mitigation efforts. A number of assumptions are required which may not correspond to real world markets. There are mainly three top-down modeling approaches: macroeconomic, input-output and computable general equilibrium.

Top-down models take into account initial distortions of the market, spillovers and income effects for households or government (Bohringer & Rutherford, 2008; 2009; Wing, 2008; van Vuuren et al., 2009; Jacobsen, 1998). This category of models can be identified into two sub-categories. The first incorporates primal simulations of an aggregate Ramsey growth model with the environmental sector to be based on historical data. For instance, DICE and RICE models belong in this category. The second type of top-down models includes dual computable general equilibrium simulations (CGE) or optimal growth model as for example the MIT Emissions Prediction and Policy Analysis (EPPA) model (Paltsev et al. 2005). CGE models are based on maximization of utility, minimization of cost and market equilibrium for goods. Top-down models greatest advantage is that assess the feedbacks effects between energy system and prices, commodity substitution, income and economic welfare (Wing, 2008).

“Top-down” CGE models divide the world into economically important regions and model demand and supply for commodities in all sectors of economy. Relationships are estimated econometrically or are calibrated. Models are solved for equilibrium before and after a shock (say introduction of carbon tax in the economy). They estimate costs of mitigation by imposing a worldwide carbon tax. Tax causes substitution of low for high carbon fuel with this cost corresponding to mitigation cost. Then by comparing the values of the associated variables in the base and shocked case, cost estimates are derived.

1.4.3.3 Integrated engineering-economic models

Another way to construct abatement cost curves is to rely on cost estimates as extracted by combining engineering and economic models. Recently, there is a wide effort to combine the characteristics of the two approaches into one. Hybrid modeling is the attempt to join a technological bottom-up with a top-down macroeconomic framework, in terms of integrating engineering data and macroeconomic accounts (Hourcade et al., 2006; Bohringer & Rutherford, 2008; Wing, 2008). According to Bohringer & Rutherford (2008) there are three different approaches of hybrid models. Initially bottom-up and top-down models can be combined but the two models are developed independently with the consequence of inconsistencies. Second, bottom-up models can incorporate macro-economic feedbacks or top-down models can incorporate technological explicitness (Hourcade et al., 2006). The last approach represents totally integrated models based on solution algorithms. Research as regards to hybrid modeling include Jaccard et al. (2004), Bohringer (1998), Jacobsen (1998), Koopmans and te Velde (2001), Bohringer et al. (2003), Frei et al. (2003), Kumbaroglu and Madlener (2003), McFarland et al.(2004), Bohringer and Rutherford (2008), Wing (2008).

1.4.3.3.1 Bottom-up versus top-down models

Top-down and bottom-up approaches are different because of the different domain that each approach represents (IPCC, 2001). Top-down estimates of abatement costs are usually high compared to bottom-up as the latter are optimistic in determining feasible cost-effective methods to control GHGs. A number of other factors apart from technological feasibility may increase abatement costs (Kolstad and Toman, 2005; Jaffe et al., 1995). Top-down modeling may be useful in exploring the macroeconomic impact of fiscal environmental policies like environmental taxation while bottom-up modeling helps in exploring specific effects of control methods on different sectors.

GHGs mitigation may lead to benefits from the reduced damages. In Stern’s (2007) review, the high climate scenario among various scenarios shows increasing damages of the climate change in the case of BAU policy. Specifically, by the year 2200 the GNP losses are expected at a level of almost 14%.

Various researchers apply energy economic models to estimate the costs of CO_2 control options (Morthorst, 1994; Maya and Fenhann, 1994; Amous et al., 1994; Mahgary et al., 1994; Halsnses et al., 1994). Mosnaim (2001) applies a bottom-up approach to estimate the costs of CO_2 emissions abatement and sequestration alternatives in Clile. Ribbenhed et al. (2007) using a bottom-up approach rank abatement options to reduce CO_2 emissions in the Swedish iron ore-based steelmaking sector. Hasanbeigi et al. (2010) constructed a bottom-up CO_2 abatement cost curve for the Thai cement industry to determine the potentials and costs of CO_2 abatement, taking into account the costs and CO_2 abatement of different technologies. According to Blok et al. (2001) an integrated modelling analysis of the energy system and the associated emissions with the PRIMES model developed by the National Technical University of Athens (or 'top-down approach'), and an engineering-economic analysis of individual emission reduction options(or 'bottom-up approach'), based on sector studies performed by Ecofys and AEA technology and analysed with the GENESIS database.

Moreover the paper of Novikova (2009) aims to address this gap in knowledge and summarizes the results of research aimed at quantifying the potential to improve electric efficiency and reduce electricity-associated CO_2 emissions from the Hungarian tertiary sector up to the year 2025 as a function of cost of conserved CO_2. To achieve the research purpose, a database of CO_2 mitigation technologies and practices has been created and a bottom-up model has been developed to estimate the baseline final electricity consumption and associated CO_2 emissions from Hungarian tertiary buildings and conduct individual and incremental assessment of mitigation options in terms of their potential for CO_2 emission abatement and costs resulted from deployment of these mitigation options in the sector.

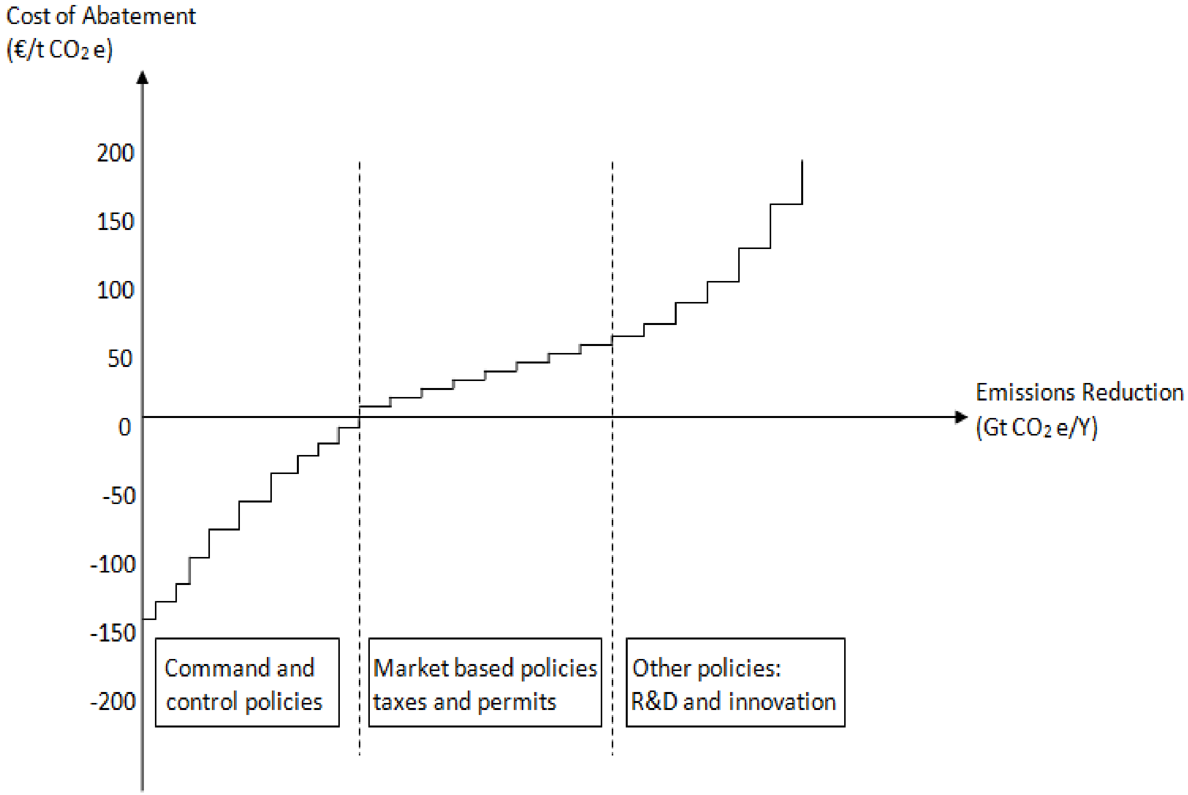
1.5 Basic policy approaches for reducing GHGs

The construction of abatement cost curves increases the environmental awareness of firms in terms of giving insight into the most cost-efficient measures to abate emissions (Beaumont and Tinch, 2004). Furthermore, they provide knowledge regarding command and control regulations to tackle market imperfections in the field of energy efficiency, conservation in buildings, industry and transport (Kesicki, 2010).

GHGs abatement costs are uncertain and differ among countries. Various studies have been carried out determining the marginal abatement cost of controlling GHGs by calculating a carbon tax imposed on the carbon content of the fossil fuels burned. In the USA the carbon tax ranges from \$94 - \$400 /t of carbon (2000 US \$) to reduce GHGs to 93% of 1990 levels by 2010 (satisfying the Kyoto Protocol target) (IPCC, 2001). Similarly in the case of European OECD countries the tax on carbon to reduce emissions ranges from \$25 to \$825 / t of carbon.

Figure 1.7 shows that the derived MAC curve may be used by decision makers to establish effective policies to tackle global warming. The left part of the figure requires attention to coping with market imperfections by imposing appropriate regulations. The middle part of the MAC may lead to the effective policies by the adoption of market-based policies (taxes and tradable permits) while the right part of the curve may require more innovation and R&D.

Figure 1.7: Use of abatement cost curve by policy makers



In general we may have direct regulations, provision of financial incentives, taxation on polluters equivalent to the marginal external social costs (in the concept of Pigou taxation), allocation of property rights (Coasean approach) linked with emissions trading with the economic instruments (carbon tax or tradable permits) necessary to drive to a low carbon economy. A regulatory standard fixes neither however it provides the framework where the firms operate (Ellerman, 2000). Environmental taxes were widely used in order to achieve environmental objectives, but the last years tradable permits are quickly gaining ground. The growing popularity of tradable permits is an outcome of the economic advantages they offer because they have the ability to equalize marginal abatement costs among all controlled sources and they assure least-cost compliance with a particular environmental goal (Egenhofer, 2007). Next we discuss the emissions trading scheme and the experience of their applications so far.

1.5.1 Emissions Trading Scheme

Emissions trading schemes could provide the framework for international cooperation among countries because in the GHG emissions problem the location of the polluter country is irrelevant because it is a cross-border issue. The principal problem of GHG emissions is that they diffuse quickly in the atmosphere, so that a tone of CO_2 emitted contributes the same in global emissions regardless the location of the emitter country (Solomon and Lee, 2000).

In an emissions trading framework, an environmental authority sets a target or a cap on total emissions and then issues emission permits, where the total number of permits equals the cap. In order to establish a market for emissions permits, the environmental authority has to decide about: who will participate in the market, the number of emissions permits that will be available in the market and how the permits will be allocated (Kruger et al., 2007). The last decision can be done either by auctioning or by grandfathering or a combination of them. Emissions trading is used as a means of an interchange and can take two forms which are “allowance-based trading or cap-and-trade” and “credit-based trading”. Allowance-based trading assumes a fixed cap on aggregate emissions and tradable emission rights while Credit-based trading is about trading of emission rights (Ellerman, 2000). Emissions trading can be seen as a means towards the reduction of any possible inefficiency of the defined standards. However, emission permits has received much criticism about their immoral nature. The principal idea behind this objection is that permits gives someone the “right to pollute” and also that zero should be the desirable level of pollution (Ellerman, 2000).

Emissions’ trading scheme is an American institutional innovation in environmental regulation. Among other trading schemes, the American Trading Scheme for SO_2 was the first successful Trading Scheme. The value of SO_2 allowances that issued per year was up to €2.8-8.7 billion while other trading schemes such as American NO_X trading programmes issue allowances up to €1.1 billion (Grubb and Neuhoff, 2006). United States has brought emissions trading into Kyoto Protocol discussions which met the firm opposition from the European Union (Ellerman and Buchner, 2007). However, as we will present later, the EU adopt the emissions trading as its core element of the European environmental policy.

The first major step towards the global adoption of emissions trading schemes was made by the commitment of countries in Kyoto protocol. The commitment that every country has signed in Kyoto protocol is to limit its GHG emissions to some percentage of 1990 emissions on an average annual basis over a five-year First Commitment Period (2008-2012). This commitment can be fulfilled by any means but the protocol favors emissions trading. Although "emission permits" are not referred in the Protocol, it includes "assigned annual amounts" which is basically the same and they may be acquired or transferred. In addition it provides a framework for these permits where Annex-B countries (the countries that signed the Kyoto Protocol) can re-allocate the permits among themselves. Furthermore, as shown in sub-section 2.1, the Protocol promotes two very important mechanisms, the Joint Implementation (JI) and the Clean Development Mechanism (CDM). In JI a country finances an emissions reduction project in another country and in CDM trading can take place with a non-Annex B country.

The European Union Emissions Trading Scheme (EU ETS) is the largest emissions trading scheme and the first large scale emissions trading scheme for carbon dioxide emissions. The EU has committed to reduce the GHGs emissions by 8% according to 1990 levels under the Kyoto Protocol (Bredin and Muckley, 2011). The principal idea of the EU ETS system is an overall cap on total emissions in all 30 member states that is equal to the target of Kyoto Protocol in order to meet the EU commitments. The EU ETS deals with the CO_2 emissions by creating a framework for the energy-intensive industrial plants and electric utilities in EU to trade emission permits for CO_2 (Kruger et al., 2007). These emissions permits are called European Union Allowances (EUAs) and the three main markets for these allowances are: Powernext, Nord Pool and European Climate Exchange (Daskalakis et al., 2009). The EU ETS is a ‘‘bottom-up’’ and decentralized scheme, with each of the member states responsible for the allocations, the registry and the compliance. The EU ETS is covering approximately 13,000 sources and the value of the EUAs distributed is equal to about €22-66 billion (Grubb and Neuhoff, 2006).

The EU ETS is divided into three periods. First is the trial trading period (2005–2007) which is not part of any commitment under the Kyoto Protocol. The second EU ETS trading period (2008–2012) coincides with the first five-year commitment period under the Kyoto Protocol. Finally, in the post-2012 period no commitment has been made but the EU ETS is expected to continue regardless of what happens to the Kyoto Protocol. Anger (2008) studies the possibility to link EU ETS with other non-European schemes such as Canadian, Australian or Japanese. The author argues that this linkage should be the desirable global environmental goal as it would be beneficial for both energy-intensive and non-energy-intensive countries yielding lower adjustment and compliance costs and a larger emissions market. There are some notable differences among the phases such as that in the trial period countries are allowed to auction up to 5% of their total EUAs and 10% during the second phase. In addition, in the trial period the EU ETS only covers CO_2 emissions from large emitters in the heat and power generation industry and in selected energy-intensive industrial sectors (Ellerman, 2008).

The price of the EUAs is defined by the member states and naturally the bigger the share of a country, the bigger the influence it has on the price. The five member states with the highest shares at the trial period are Germany, UK, Poland, Italy and Spain (Convery and Redmond, 2007). The non-compliance with EU ETS results in penalty fines. Thus, enterprises which emit that the EUAs they hold at the end of the accounting period must pay a fine which is 40€ for each metric ton of CO_2 during the trial period and 100€ during the second period (Kettner et al., 2007).

A number of studies investigate the problems and drawbacks of the EU ETS. Jepma (2003) argues that EU ETS has no clear link with the environmental policies of the EU countries. In addition, the author considers the possibility the EU ETS to distort the competition in EU and questions the future perspective of the scheme. Ellerman (2008) signifies the importance of a central coordinating organization for the EU ETS. Additionally, the mechanism should incorporate a number of benefits for compliance in order to encourage the participation in the scheme. Last but not least, the author points to a number of issues such as harmonization, differentiation and stringency. Also, a number of studies question the level of stringency in the mechanism. Demailly and Quirion (2008) investigate the impact of the mechanism's stringency and find that no negative effect emerges from the level of stringency.

The EU ETS covers about 45% of total EU CO_2 emissions (Betz and Sato, 2006). This percentage is not sufficient for EU to meet the Kyoto targets and therefore, member states are encouraged to adopt national environmental strategies in order to accomplish the Kyoto targets (Bohringer et al., 2006). Norwegian environmental policy relies entirely on emissions trading in order to meet the Kyoto targets. The Norwegian Emissions Trading Scheme is a more comprehensive system than the EU ETS because it includes all GHGs. The Norwegian scheme is set to begin at the start of the second EU ETS period at 2008. There is a debate I Norway about the allocation of the permits with quite interesting results. The majority of the parties (six out of eleven) recommended auctioning. The second recommendation was about grandfathering while the third opinion was undecided (Ellerman, 2000).

The United Kingdom Emissions Trading Scheme is also inspired by the Kyoto Protocol but it is not as tied to the UK's obligations as the Norwegian scheme. The UK environmental authorities use additional policies in order to meet the UK objectives such as environmental tax on natural gas, coal and electricity, namely the Climate Change Levy and the Negotiated sectoral Climate Change Agreements (Smith and Swierzbinski, 2007). The Emissions Trading Scheme allows both allowance-based and credit-based emissions trading. The essence of the UK trading scheme is to reduce the environmental taxes and to provide incentives for the emitters to voluntarily take the cap (Ellerman, 2000). The Danish Electricity Sector Emissions Trading Scheme is in effect from 2001 and includes 1/3 of the Danish CO_2 emissions and aims for a 10% reduction in CO_2 emissions below 1988 levels. The mechanism is about electricity generation companies and the emissions permits are grandfathered. The penalty for non-compliers is up-to $22 per ton of carbon (Ellerman, 2000).

In contrast to the aforementioned schemes the Swedish Flex-Mechs Emissions Trading Scheme has started as an open discussion. The mechanism has a very large coverage including almost all sectors and most of the GHGs. The idea of the scheme is to replace the CO_2 tax and to substitute least-cost solution with best-available-control technology. In addition, the system promotes JI and CDM (Ellerman, 2000). French was one of the major countries (along with Germany) which criticize the emission trading schemes. However, a shift in French environmental policy resulted in the French Emissions Trading Scheme. The mechanism incorporates voluntary negotiated five-year agreements between the government and fossil-fuel intensive sectors which is account for 80% of industrial CO_2 emissions and other GHGs. The scheme also promotes JI and CDM. Just like in France, Germany shifted its environmental policy towards an emissions trading scheme. The German Emissions Trading Scheme has limited scope and concerns only large industrial firms. The Dutch Emissions Trading Scheme has also limited scope. It targets JI projects in Central and Eastern Europe.

1.6 Adaptation

Adaptation to climate change may take place locally. Following Burton (1996) and IPCC (2001) a number of adaptation measures can be applied to cope with climate change risks such as bearing, sharing or preventing losses, modifying the threat, encouraging research for new methods and techniques and changing use, location and behavior through education and appropriate regulations. OECD (2009) provides examples of adaptation for various sectors. Specifically in agriculture we may prevent the loss by investing in new capital or removing market distortions and by changing use in crops and altering farming practices; in coastal zones we may prevent losses by upgrading drainage systems, increasing habitat protection and planning land use; in water we may prevent losses by increasing capacity, using water permits and pricing and by encouraging the change in behavior seeking for rational water use or by collecting rainwater.[21]

In general all IAMs pay attention mainly to the relationship between damage caused by climate change and the cost of mitigation with adaptation to be either ignored or considered as part of the damage estimation (Fisher et al., 2007; Fankhauser et al., 1999). The first research modeling adaptation in an IAM's set-up is by Hope et al. (1993) who using PAGE they consider two policies of adaptation: no adaptation and aggressive adaptation. They find that the latter should be used as it is more beneficial.

Tol (2008) models adaptation in the FUND model. Relying on Fankhauser (1994) he uses coastal protection as a continuous decision variable and provides useful information on the dynamics of adaptation showing that adaptation is an important way to tackle the effects of sea level rise. What is important is the adverse relationship in the use of mitigation and adaptation as more mitigation may result to fewer resources left to invest in measures of

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[21] For detailed information see Agrawala e al. (2010).

adaptation. Tol claims that very high abatement levels will more likely lead to adverse influence as less adaptation will be used resulting to higher net climate change degradation.

IPCC has included adaptation in every Assessment Report but took 10 years to organize a workshop on adaptation to climate change in Costa Rica in 1998 (Klein and Maciver, 1999) while it has been proved that adaptation is more difficult to be treated compared to mitigation. Kates (1997) refers to the IPCC 2nd volume of 1995 Assessment Report dedicating a few pages to adaptation (around 4% of the pages of the full report). Kates ascribes this to the presence of two schools of thought: the "preventionists" and the "adaptationists". The former consider adaptation as weakening societies' willingness to control GHGs while the latter believe that little adaptation is needed as climate change takes place slowly for nature and the societies to amend easily (Stern et al., 2013).

Use of adaptation may lead to the so-called maladaptation (Mendelsohm, 2000) with Barnett and O'Neil (2010) to put forward several types of maladaptation like reductions in incentives for adaptation, shift in costs to poor and coexisting emissions of GHGs. Moreover, maladaptation may increase costs with no associated benefits and may result to worse environmental conditions. Smit and Wandel (2006) classify four approaches adopted by researchers in their consideration of adaptation: composite indexes; scenarios and statistical and equilibrium modeling; cost-benefit and cost-effectiveness analyses; and "bottom-up" studies in cases of analysis.[22]

Table 1.7 presents adaptation cost estimates provided by World Bank (2006), Stern (2006), Oxfam (2007), UNDP (2007), UNFCCC (2007) and World Bank (2009). The costs refer to necessary investment levels for adaptation to climate change. The UNFCCC (2007) reported a total cost for global adaptation by 2030 in the range of $49-171 billion yearly. Specifically, for the developed countries the range of the cost is between $22-105 while for

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[22] For more details see Stern et al. (2013).

the developing countries is within $27-66 billion per year. IIED (2009) claims that UNFCCC estimates is perhaps underestimated by a factor of between 2 and 3 for the sectors considered and could be much higher with more sectors included.

Table 1.7: Adaptation cost estimates in developing countries for the years 2010-2015 (in billion US$/year)

World Bank (2006)	9-41
Stern (2007)	4-37
Oxfam (2007)	>50
UNDP (2007)	86-109
UNFCCC (2007)	27-66
World Bank (2009)	75-100

Source: Agrawala and Fankhauser (2008); IIED (2009); Chesney et al. (2013).

SECTION 2

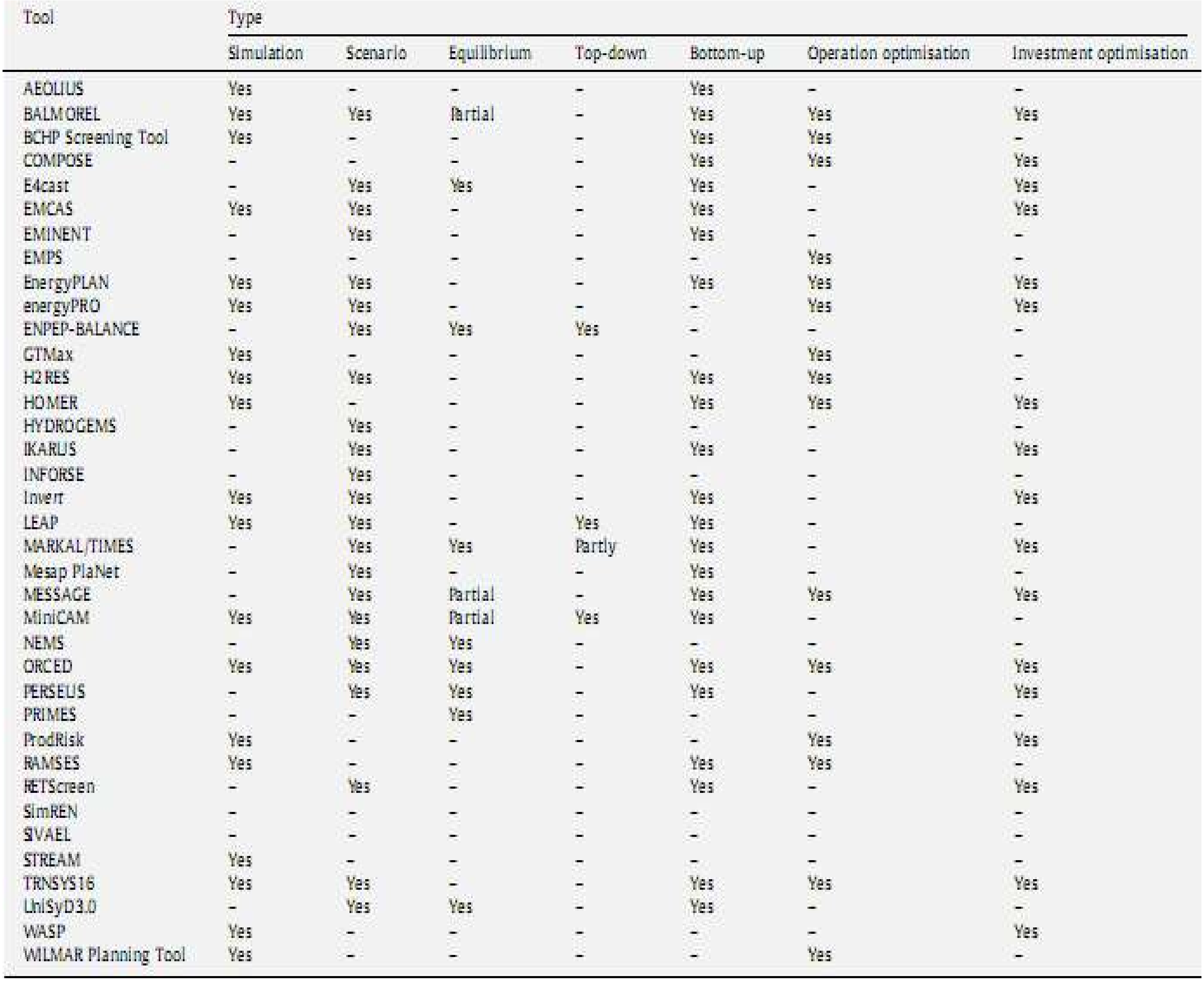
Literature review for GHGs/CO_2 abatement options

2.1 General overview

In recent times more diverse challenges have emerged in societies such as climate change, security of energy supply and economic recession. As a result, the energy sector is being targeted to combat these issues. Often in this transfer, a crucial element is to show coherent technical analysis of how renewable energy can be implemented and what effects renewable energy has on other parts of the energy system. Such analysis requires computer tools that can create answers for these issues by modeling defined energy-systems (Connolly et al., 2010). Some important tools of energy which are used by researchers are presented in Table 1. Additionally, Table 2 presents information on a range of software tools and databases that can be used for sustainable energy analysis.

Between different sectors of the world economy, the industrial sector is one of the most energy-intensive and polluting sectors as it constitutes a significant source of the global greenhouse gases (GHGs) emissions. According to Bernstein et al. (2007), GHGs in the industrial sector include primarily carbon dioxide (CO_2) from energy use, from non-energy use of fossil fuels and from other sources apart from fossil fuels. Additionally, other GHGs are hydrofluorocarbons (HFC-23), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), methane (CH_4) and nitrous oxide (N_2O). Specifically, CO_2 emissions from energy use grew 65% in absolute numbers from 1971 to 2004, at 2.7 Giga tons Carbon (GtC). Developing nations were the biggest polluters in energy related to CO_2 with a global share of 53%, developed economies were in the second place with 35%, while economies in transmission accounted for 11% of the global share. The rest of the global industry CO_2 emission including non energy uses of fossil fuels and non-fossil fuels uses were 0.46 GtC in 2000. The total emissions of the other GHGs, which had much higher Global warming potential than CO_2, were 120 MtC in 2000. To sum up, industry was responsible for 5.3 GtC of total GHGs emissions, 2 GtC from direct emissions and 3.3 GtC from indirect emissions (Bernstein, 2007).

Table 2.1: Tools for modeling energy systems



Tool	Type						
	Simulation	Scenario	Equilibrium	Top-down	Bottom-up	Operation optimisation	Investment optimisation
AEOLIUS	Yes	–	–	–	Yes	–	–
BALMOREL	Yes	Yes	Partial	–	Yes	Yes	Yes
BCHP Screening Tool	Yes	–	–	–	Yes	Yes	–
COMPOSE	–	–	–	–	Yes	Yes	Yes
E4cast	–	Yes	Yes	–	Yes	–	Yes
EMCAS	Yes	Yes	–	–	Yes	–	Yes
EMINENT	–	Yes	–	–	Yes	–	–
EMPS	–	–	–	–	–	Yes	–
EnergyPLAN	Yes	Yes	–	–	Yes	Yes	Yes
energyPRO	Yes	Yes	–	–	–	Yes	Yes
ENPEP-BALANCE	–	Yes	Yes	Yes	–	–	–
GTMax	Yes	–	–	–	–	Yes	–
H2RES	Yes	Yes	–	–	Yes	Yes	–
HOMER	Yes	–	–	–	Yes	Yes	Yes
HYDROGEMS	–	Yes	–	–	–	–	–
IKARUS	–	Yes	–	–	Yes	–	Yes
INFORSE	–	Yes	–	–	–	–	–
Invert	Yes	Yes	–	–	Yes	–	Yes
LEAP	Yes	Yes	–	Yes	Yes	–	–
MARKAL/TIMES	–	Yes	Yes	Partly	Yes	–	Yes
Mesap PlaNet	–	Yes	–	–	Yes	–	–
MESSAGE	–	Yes	Partial	–	Yes	Yes	Yes
MiniCAM	Yes	Yes	Partial	Yes	Yes	–	–
NEMS	–	Yes	Yes	–	–	–	–
ORCED	Yes	Yes	Yes	–	Yes	Yes	Yes
PERSEUS	–	Yes	Yes	–	Yes	–	Yes
PRIMES	–	–	Yes	–	–	–	–
ProdRisk	Yes	–	–	–	–	Yes	Yes
RAMSES	Yes	–	–	–	Yes	Yes	–
RETScreen	–	Yes	–	–	Yes	–	Yes
SimREN	–	–	–	–	–	–	–
SIVAEL	–	–	–	–	–	–	–
STREAM	Yes	–	–	–	–	–	–
TRNSYS16	Yes	Yes	–	–	Yes	Yes	Yes
UniSyD3.0	–	Yes	Yes	–	Yes	–	–
WASP	Yes	–	–	–	–	–	Yes
WILMAR Planning Tool	Yes	–	–	–	–	Yes	–

(**Source:** Connolly et al., 2010, p.1063)

Table 2.2: Software tools and databases for sustainable energy analysis

Name	Scope	Platform	Methodology
Cities for Climate Protection (CCP)	Local (cities, states) climate inventories and action plans	Windows	Physical Accounting
COMPEED XL	Cost-benefit and cost-effectiveness toolbox for private and public decision-makers.	Excel	Physical Accounting
CO_2DB	Database of CO_2 emitting energy technologies	Windows	Database
EnergyPLAN	Simulates and optimizes the operation of an entire national energy system for every hour in a particular year.	Windows	Simulation/ Optimization
Energy Costing Tool	Estimates the amounts and types of energy investments required to meet the Millennium Development Goals (MDGs)	Excel	Accounting
ENPEP	Suite of Models for Integrated Energy/Environment Analysis	Windows	Various
GEMIS	Lifecycle analysis of energy chains	Windows	Physical Accounting
HOMER	Design of off- and on-grid electrification options	Windows	Optimization
LEAP	Integrated Energy/Environment Analysis	Windows	Physical Accounting, Simulation
MAED	Integrated Energy / Environment Analysis	Windows & Linux	Physical Accounting, Simulation
MESSAGE	Final and Useful Energy Demand Projections	Windows	Optimization
REAP	Consumer based emissions and ecological footprint analysis for the UK local authorities and regions	Windows	Environmental extended input-output model of the UK.
RETSCREEN	Energy production, life-cycle costs and GHG emission reductions for various energy efficient and renewable energy technologies	Excel	Physical Accounting
SUPER	Energy Demand and Conservation, Hydrology, Planning under Uncertainty, Hydro-thermal Dispatch, Financial, and Environmental analysis	Windows	Optimization and Simulation
TIMES/ MARKAL	Integrated Energy/Environment Analysis	Windows	Optimization

Source: http://www.energycommunity.org/default.asp?action=71

Moomaw (1996) reported that within the industrial sector, manufacturing has been responsible for approximately 90% of industrial energy demand, and recognized five driving forces of industrial GHGs emissions and possible future reduction. These forces are:

1. The growth of the industrial output and its intensity,
2. Changes in the pattern of industrial growth within the sectors,
3. Reduction in energy volume for production and use of specific products,
4. Replacement of energy intensive materials with less intensive ones, and
5. Redesign of industrial production.

Further, according to Worrell et al. (2001a), the most energy-intensive and GHGs emitters in manufacturing were five subsectors which were iron and steel, cement, petroleum refining, chemical and pulp and paper.

One of the pillars of the modern world and the largest energy consumer manufacturing sector is iron and steel industry. The Organization for Economic Co-operation and Development (OECD, 2001) stated that iron and steel industry accounted for 10-15% of global industry energy consumption and up to 19 exajoules (EJ). Additionally, it was responsible for the 7% of global anthropogenic CO_2 emissions. Furthermore, due to its size, the iron and steel industry was an essential part of international trade. Maestad et al., (2000) reported that 20% of the sea trade and its emissions were attributed to iron and steel industry. Mathiesen and Maestad (2004) signified that half of the global iron and steel production took place in countries which had not sign the Kyoto Protocol. Moreover, 20% of total carbon leakage had been credited to iron and steel industry.

OECD (2001) reported that iron and steel industry is divided into the following five procedures: treatment of raw materials, iron making, steel making, casting, and rolling and finishing. Price et al. (2002) stated that GHGs which had emitted from this sector came mainly from the combustion of fossil fuels. De Beer et al. (2000) reported that there were two available technologies for the production of steel: (a) the integrated steel mills which used iron ores and accounted for the 60% of global steel production and (b) the scrap based mini-mills which used scarp and produce secondary steel and accounted for 30% of global steel production. Ellis and Bosi (1999) presented a number of environmental criteria which the steel and iron industry should meet. These criteria were environmental credibility, transparency, simplicity and low cost, provision of a certain level of crediting certainty to investors and having a great variety of projects. These projects might include an increased energy efficiency of the production, an alternative manufacturing process, or a changing in the input fuel (OECD, 2001).

Cement industry is closely related to construction and economic activity. Cement is an important building material and is produced in almost every country. According to Worrell et al., 2001a, 2001b), cement production consisted of three steps: raw material preparation, clinker making in the kiln, and cement making. Clinker making was the most fuel and energy intensive procedure, accounting 70-80% of the total energy of the production. In 2005, United States Geological Survey (USGS) reported that:

1. Since 1970 the global cement production had been increased by 271%,
2. The world's largest cement producer was China with production of 1000 megatons (Mt) which represented 47% of the global production,
3. Developing countries produced 1560 Mt of cement (73% of the global production) and developed countries 570 Mt (27% of the global production).

Cement industry is highly energy-intensive and a major GHGs emitter, mainly CO_2 from the combustion of fossil fuels and the calcination of limestone.

Petroleum refining is the industrial process where crude oil is processed and refined into more useful products such as gasoline, diesel fuel, kerosene, naphtha, asphalt, heating oil etc. In 2004, the total number of refineries around the world was 735 in 128 countries with distillation capacity of 82.3 million barrels per day (Energy Information Administration, EIA, 2005). The capacity share for US was 20.5% followed by EU25 with 16.4% (EIA, 2005). Furthermore, distillation is considered as the most energy-intensive separation procedure.

Chemical industry is highly diverse due to the large number of companies which produce tens of thousands of products. Levine et al. (1995) stated that the chemical industry was an important part of global economy accounting for 7% of global income and 9% of international trade. The main emitted gas is carbon dioxide which comes from the production of ethylene and other petrochemical products, ammonia and chlorine. Worrell et al. (2000) stated that the chemical industry was responsible for approximately 20% of US industrial energy consumption and an equal amount of GHGs emissions. Bernstein et al. (2007) reported that CO_2 is generated both from energy use and from venting incineration of byproducts. According to Worrell and Galitsky (2004), the US chemical industry was the largest in the world processing almost 25% of the global crude oil production.

Pulp and paper industry is a fast growing and also a highly diverse industry. The Food and Agriculture Organization of the United Nations (FAOSTAT) reported in 2006 that the production of paper and paperboard in developing countries accounted for the 26% of global production. Besides, Szabo et al. (2009) stated that this industry was very energy-intensive because for 1 ton of paper, 5-17 GJ of process heat were required. Direct emissions from this sector were approximately 264 $MtCO_2$ per year. Further, according to Bernstein et al. (2007) a number of mitigation options have been available for this industry, namely the use of biomass fuels, the use of combined heat and power, black liquor gasification and recycling.

Regarding the transportation sector, the majority of GHGs are CO_2 emissions resulting from the combustion of petroleum-based products, like gasoline, in internal combustion engines. According to the United States Environmental Protection Agency[23] (EPA), the

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[23] http://www.epa.gov/climatechange/ghgemissions/sources/transportation.html

largest sources of transportation-related GHGs emissions include passenger cars and light-duty trucks, including sport utility vehicles, pickup trucks and minivans. These sources account for over half of the emissions from the sector. The remainder of GHGs emissions comes from other modes of transportation, including freight trucks, commercial aircraft, ships, boats, and trains as well as pipelines and lubricants.

According to the latest estimates of the International Energy Agency (IEA), the transport sector contributes 23% of the total CO_2 emissions in the world. The transport sector's direct emissions from combustion fuels from 1971 to 2006 represented a rising share of total global emissions. Road transport was responsible for the highest share of emissions globally. Within road transport, automobiles and light trucks produced well over 60% of emissions, but in low- and middle-income developing countries, freight trucks (and in some cases even buses) consumed more fuel and emitted more CO_2 than the aforementioned light-duty vehicles. Schipper et al. (2009) reported that road transport was also associated with emissions of criteria air pollutants, such as carbon monoxide (CO) and oxides of nitrogen (NO_x), as well as particulate matter (PM). These emissions had a high negative impact on human health, particularly in densely populated urban areas.

In European Union (EU), the road transport contributed about one-fifth of the EU's total emissions of CO_2. Particularly, CO_2 emissions from road transport increased by nearly 23% between 1990 and 2010, and without the economic downturn growth it could have been even bigger. Transport is the only major sector in the EU where greenhouse gas emissions are still rising[24].

The literature review for GHGs/CO_2 abatement options follows for each one of the energy, industry and transportation sectors. Within each sector, special reference is given to the literature review concerning long projections with and without using the Long Range

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[24] http://ec.europa.eu/clima/policies/transport/vehicles/index_en.htm

Energy Alternatives Planning (LEAP) system. The LEAP system is a widely-used software tool for energy policy analysis and climate change mitigation assessment, which was developed at the Stockholm Environment Institute. Up to now, LEAP has been adopted by thousands of organizations in more than 190 countries worldwide, and has become, especially in the developing world, the de facto standard for countries undertaking integrated resource planning, greenhouse gas (GHG) mitigation assessments, and Low Emission Development Strategies (LEDS). Besides, many countries have also chosen to use LEAP as part of their commitment to report to the U.N. Framework Convention on Climate Change (UNFCCC[25]).

2.2 Energy Sector

Halkos (1995) developed theoretical and empirical representations (using mathematical models) of economic incentives for implementing pollution control strategies for Europe. The results showed that:

1. The imposition of charges implied a higher emissions reduction compared to the case where simple standards in the form of ecosystem sensitivity thresholds would have been applied, and
2. A high uniform charge rate achieved a high emissions reduction but this result might be due to the fact that for some major polluters it was cheaper to abate than to pay the charge.

Halkos (2003) examined the hypothesis of the inverted U-shaped relationship between environmental damage from sulphur emissions and economic growth as expressed by GDP. Using a large database of panel data consisting of 73 OECD and non-OECD countries for 31 years (1960–1990), the author applied for the first time random coefficients and Arellano-Bond Generalized Method of Moments (A–B GMM) econometric methods. He found that although the Environmental Kuznets Curve (EKC) hypothesis was not rejected in the case of

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[25] http://www.energycommunity.org/default.asp?action=47

the A–B GMM, there was no support for an EKC in the case of using a random coefficients model.

Unander et al., (2004) examined residential energy use in the Scandinavian countries: Denmark, Norway and Sweden, over the period 1973–1999. The paper used a decomposition approach to investigate differences in residential energy demand structure and end-use intensities and discussed both differences in absolute levels of energy use and differences over time. Comparisons were also made to other countries that had been analyzed in the IEA energy efficiency indicator project. The analysis showed that, in contrast to Denmark and Sweden, Norway saw a growth in total residential energy use between 1973 and 1999. This can be partially explained by the fact that Norway started from a lower per capita income level in the early 1970s but had since then enjoyed a rapid income growth that drove up house area and consequently put a pressure on energy use. But the analysis also showed that Denmark and Sweden achieved significant reductions of residential energy intensities between 1973 and 1990, while the reductions in Norway were negligible. After 1990, the picture changed; there was a strong decline in residential energy intensities in Norway and a high rate of energy savings compared to most other countries analyzed by the IEA, while energy savings in Denmark and Sweden more or less came to a halt.

Larsen and Nesbakken (2004) analyzed two methods for end-use estimation which could be applied to household data for appliance holdings, as well as, to demographic and economic variables. The first method was the engineering model ERAD. This model was used to decompose household electricity consumption into different end uses. The second method was an econometric conditional demand model applied to data from the same survey. The drawbacks of the ERAD model seemed to be hard to eliminate. However, their econometric analysis indicated that there was potential for improvements of end-use results by conducting surveys designed for analyzing end-use consumption econometrically.

Bruvoll and Larsen (2004) decomposed the actually observed emissions changes in Norway, and used an applied general equilibrium simulation to look into the specific effect of carbon taxes. This study was made for the period 1990-1999 to reveal the driving forces behind the changes in the three most important climate gases; CO_2, methane and N_2O. From 1990 to 1999, the Norwegian CO_2 emissions increased by 19%. This growth was significantly lower than the GDP growth of 35%. In other words, average emissions per unit GDP was reduced by 12 percent over the period. The authors found that the most important emission-reducing factors were (a) more efficient use of energy and (b) a substitution towards less carbon intensive energy. The energy intensity and energy mix components contributed to a reduction in CO_2 emissions over the period by 14 percent. The effect of carbon taxes on these emission-reducing components had been small. The model simulations indicated that the carbon tax contributed to a reduction in emissions of 2.3%. Also, the effect of the carbon taxes in Norway was strongly dominated by the Norwegian oil and gas sector. For onshore sectors only, the carbon tax effect on emissions was 1.5%.

Diakoulaki et al. (2006) presented a decomposition analysis of CO_2 emissions in Greece for the period 1990–2002 which was split into two equal time intervals. The proposed analytical procedure relied on the refined Laspeyres model and followed a bottom-up approach starting from the major energy consuming sectors and aggregating the obtained effects for estimating their relative impact at the country level. Different indicators, either monetary or physical, were used in each sector in order to more accurately approximate the real activity related with energy consumption and emission generation. In addition, the analysis was extended as to take into account the effect of the varying electricity mix in the overall responsibility of the final demand sectors. The main finding of this research was that in the case of Greece economic growth and the ensued social welfare were still strongly coupled with energy consumption and atmospheric emissions. The only encouraging signs against this general trend were the relative improvements in the energy mix and technical efficiency of electricity generation and industry, as well as the advances in car technology pulling down energy intensity in road transport. However, these signs were not enough to meet the restriction imposed by the Kyoto target. In addition to the increasing activity levels, energy intensity was growing in all final demand sectors except industry, mostly with a growing rate in the second period. On the other side, changes in the energy mix were only marginal in the examined period since the development of urban networks of natural gas had started after 2000, while advances in the development of renewable energies were very slow compared to the mounting use of fossil fuels.

Lenzen et al. (2006) appraised sustainable household consumption from a global perspective. Using per capita energy requirements as an indicator of environmental pressure, the authors focused on the importance of income growth in a cross-country analysis. Their analysis was supported by a detailed within-country analysis encompassing five countries, in which they assessed the importance of various socioeconomic-demographic characteristics of household. In other words, the authors approached the EKC by combining the life-cycle approach to consumption with a cross-country analysis, involving both industrialized and developing countries. The following conclusions were drawn:

1. The hypothesis of a Kuznets curve for household energy requirements was not supported as this curve increased monotonically with household expenditure and a turning point was not observed,
2. Uniform cross-country relationship between energy requirements and household expenditure was not supported as elasticities varied across countries, even after controlling for socioeconomic-demographic variables,
3. Significant differences in average energy requirements were observed, even at equal income with the causes of these differences to be attributed to geographical conditions

and population density, energy conservation and technology, and consumer lifestyles (Climatic conditions appeared to play a minor role in the overall picture), and

4. Brazil, India and Japan provided some exceptions from the general result that socioeconomic-demographic factors generally had similar influences on energy requirements as each country featured a different selection and sequence of significant driving factors, which demonstrated the importance of country-specific circumstances for explaining energy requirements.

Halicioglu (2009) examined empirically the dynamic causal relationships between carbon emissions, energy consumption, income, and foreign trade in the case of Turkey using time-series data for the period 1960–2005. The author tested the interrelationship between the variables using the bounds testing to cointegration procedure. The bounds test results gave two forms of long-run relationships between the variables. In the case of first form of long-run relationship, carbon emissions were determined by energy consumption, income and foreign trade. In the case of second long- run relationship, income was determined by carbon emissions, energy consumption and foreign trade. An augmented form of Granger causality analysis was conducted amongst the variables. The long-run relationship of CO_2 emissions, energy consumption, income and foreign trade equation was also checked for the parameter stability. The empirical results suggested that income was the most significant variable in explaining the carbon emissions in Turkey which was followed by energy consumption and foreign trade. Moreover, a stable carbon emissions function was observed. The results also showed that Turkey should design new environmental policies to reduce environmental degrading.

Oh et al. (2010) analyzed the specific trends and influencing factors that had caused changes in emissions patterns in South Korea over a 15-year period, from 1990 to 2005. Using the Log Mean Divisia index method with five energy consumption sectors and seven sub-sectors in terms of fuel mix, energy intensity, structural change, and economic growth, the aims of this work were to investigate: (a) sectoral trends of energy-related CO_2 emissions, (b) the effects of the main factors of CO_2 emissions in each sector and (c) the main drivers of such changes in terms of energy policy and socio-economic features. The results showed that economic growth was a dominant explanation for the increase in CO_2 emissions in all the sectors. The results also demonstrated that fuel mix caused CO_2 reduction across the array of sectors with the exception of the energy supply sector. CO_2 reduction as a function of structural change was also observed in manufacturing, services and residential sectors. Furthermore, energy intensity was an important driver of CO_2 reduction in most sectors except for several manufacturing sub-sectors. Based on these findings, it appeared that South Korea should implement climate change policies that would consider the specific influential factors associated with increasing CO_2 emissions in each sector.

Using time series data, **Halkos and Tzeremes (2011)** explored China's carbon emissions for the period 1960-2006. Particularly, the authors investigated the direct role of growth and in connection to trade and the value added by various sectors such as agriculture, industry and services. The authors' empirical results indicated the presence of an inverted U-shaped curve between CO_2 emissions and growth represented by the GDP per capita. Trade seemed to be an important determinant in this relationship. The empirical findings provided evidence for policy implications regarding the role of growth, trade and the value added by the various sectors of the economy on environmental degradation.

Shahbaz et al. (2011) explored the existence of a long run equilibrium relationship among CO_2 emissions, financial development, economic growth, energy consumption, and population growth in Pakistan. ARDL bounds testing approach to cointegration was implemented to the data for 1974-2009. The results confirmed a long run relation among these variables. Financial development appeared to help reduce CO_2 emissions. The main contributors to CO_2 emissions however were: economic growth, population growth and energy consumption. Besides, the authors' results also lent support to the existence of Environmental Kuznets Curve for Pakistan. Based on the findings they argued that policy focus on financial development might be helpful in reducing environmental degradation.

Hussain et al. (2012) examined the relationship among environmental pollution, economic growth and energy consumption per capita in the case of Pakistan. The per capital carbon dioxide (CO_2) emission was used as the environmental indicator, the commercial energy use per capita as the energy consumption indicator, and the per capita gross domestic product (GDP) as the economic indicator. The investigation was made on the basis of the environmental Kuznets curve (EKC), using time series data from 1971 to 2006, by applying different econometric tools like ADF Unit Root, Johansen Co-integration, VECM and Granger causality tests. The Granger causality test showed that there was a long term relationship between these three indicators, with bidirectional causality between per capita CO_2 emission and per capita energy consumption. A monotonically increasing curve between GDP and CO_2 emission was found for the sample period, rejecting the EKC relationship, implying that as per capita GDP was increasing a linear increase would be observed in per capita CO_2 emission. The authors supported that these empirical findings would guide policy makers in Pakistan to develop new standards and monitoring networks for reducing CO_2 emissions.

Hossain (2012) investigated empirically the dynamic causal relationships between CO_2 emissions and energy consumption, economic growth, foreign trade and urbanization of Japan through the co-integration and causality analysis. The bounds testing approach was applied for co-integration in order to examine the existence of long-run equilibrium relationship between CO_2 emissions and its determinants. Also, the Johansen-Juseliues co-integration test was applied in order to find the existence of co-integration equations as the robustness of bounds test. Furthermore, the Granger causality test was applied with VEC model to investigate the causal linkage between different pairs of variables. Short-run unidirectional causalities were found from energy consumption and trade openness to carbon dioxide emissions, from trade openness to energy consumption, from carbon dioxide emissions to economic growth, and from economic growth to trade openness. The test results also supported the evidence of existence of long-run relationship among the variables. It was also found that over time higher energy consumption in Japan gave rise to more carbon dioxide emissions. But in respect of economic growth, trade openness and urbanization, the environmental quality was found to be normal good in the long-run.

Safdari et al. (2013) investigated the Environmental effects of energy consumption and economic growth by using annual time series date (1971-2008), as well as, applying the Johansen-Juselius co-integration approach in Iran. The Findings showed that if the consumption energy intensify increased one percent, this would lead to incline carbon dioxide gas emission near to 0.877 percent on average. Meanwhile, increasing per-capita gross domestic product by one percent, this would cause the increase of per-capita carbon dioxide gas emission by about 1.29 percent on average. Moreover, the results gained from Engel Granger Causality test demonstrated a mutual causality between the Iranian economic growth and volume of CO_2 emission at 5 percent level of significance.

2.2.1 A review of long-term projections without using the LEAP system in the Energy Sector

Lee and Ryu (1991) presented the results of two long-term scenarios for energy use and CO_2 emissions in Korea for the year 2025. The two scenarios were subject to the same set of assumptions about changes in a range of economic, demographic and socioeconomic variables, but are distinguished in terms of the opportunities for fuel substitution and energy-efficiency improvements. The low-emissions scenario relied less heavily on carbon-intensive fuels and achieved greater strides in improving efficiency than the high-emissions scenario, and thus managed to constrain the growth of energy-related greenhouse gases. The results indicated that by improving energy efficiency through technological progress, fuel switching and related policies, Korea could begin to make the necessary transition to a less carbon-intensive future.

Nakata and Lamont (2001) examined the impacts of using carbon and energy taxes to reduce carbon emissions from the Japanese energy system. Using META-Net, a partial equilibrium model of the Japanese energy sector was developed to forecast changes in the energy system out to the year 2040. The META-Net economic modeling system developed at the Lawrence Livermore National Laboratory Net is a partial equilibrium modeling system that allows for explicit price competition between technologies, and can constrain or tax emissions. The model of the current work accounted for the changes in energy technology capacities, fuels, and consumption in response to policy initiatives, such as taxes. The authors found that carbon and energy taxes would decrease carbon dioxide emission to a proposed target. The total cost in terms of supplying energy would be similar for either approach.

However, the model also indicated that carbon taxes would cause a shift in resources used from coal to gas. Integrated coal gasification combined cycles (IGCCs) would not penetrate the market in carbon tax case. Since energy security was a primary concern to Japan, maintaining a diverse base of resources was very important. Policies that would eliminate coal, and efficient coal-based technologies, might not be desirable. The development of clean coal technologies and advanced transportation technologies suitable for Japan's energy systems should be the next target to overcome the limit of carbon taxes.

Gielen and Changhong (2001) analyzed the optimal set of policies for reduction of SO_2, NO_x and CO_2 in Shanghai for the period of 2000–2020. The analysis was based on a linear programming MARKAL model for the Shanghai energy system. The results showed that the relevance of no-regret options was limited because Shanghai had improved its energy efficiency significantly in recent years. The model calculations suggested that this trend would persist if current policies were sustained. This energy efficiency improvement and the planned introduction of natural gas would have important benefits from a GHG emission point of view. These benefits had received little attention as yet. Local air pollution reduction could result in additional GHG emission reduction up to 2010. After 2010, however, its CO_2 emission co-benefits would be limited. Dedicated abatement technology would be the most cost-effective way to reduce local air pollution. An additional incentive of 100 Yuan/t CO_2 emission reduction (12.5 Euro/t) would result in an additional emission reduction of 11% (22 Mt CO_2), and it would result in a significantly different technology mix than stand-alone local air pollution policies. The total potential for GHG emission reduction would amount to 66 Mt in 2010 and to 49 Mt in 2020 compared to base case levels without policies.

ZhiDong (2003) developed an integrated econometric model consisting of macroeconomic sub-model, energy sub-model, and environment sub-model, named as 3Es-Model, to perform a long-term simulation study for China by 2030. The analysis showed that in the coming 30 years, the potential of GDP growth would be around 7% annually and the continuation of rapid economic growth could result in insurmountable difficulties for energy security, air protection, and CO_2 emission reductions. For the sustainable development, more comprehensive measures should be adopted, including improvements in energy efficiency, more rapid energy switching from coal to natural gas and renewable energy sources, imposing carbon tax, development of clean coal technology, establishment of strategic petroleum stockpiling, and enforcement of air protection.

Gan and Li (2008) developed a comprehensive econometric model to study the long-term outlook of Malaysia's economy, energy and environment to 2030. The authors' purposes were to analyze future fossil fuel demand and supply positions, and hence energy security issues, as well as, pollutants emissions of Malaysia. The integrated econometric model consisted of a macroeconomic sub-model and an energy–environment sub-model. The macroeconomic sub-model was designed to provide indicators influencing energy supply and demand and related pollutants emissions consistently. The energy–environment sub-model was designed to determine energy flows in stages and relating pollutants emissions consistently with the consideration of relating economic and price indicators obtained in the macroeconomic sub-model. A reference scenario that assumed a continuation of existing trends and policies implemented up to the end of 2004 was developed for the projection of Malaysia's economy, energy and environmental outlook to 2030. The projections under the reference scenario indicated that Malaysia's gross domestic production (GDP) was expected to average 4.6% from 2004 to 2030, and total primary energy consumption would triple by 2030. Coal import would increase following governmental policy of intensifying its use for power generation. Oil import was predicted to take place by 2013 and would reach 45 Mtoe in 2030. Hence, for the coming years, Malaysia's energy import dependency would rise. Carbon emissions will triple by 2030. On the other hand, the projections under an alternative renewable energy (RE) scenario showed that the utilization of RE would a strategic option to improve the long-term energy security and environmental performance of Malaysia. However, substantial governmental involvements and support, as well as the establishment of a regulatory framework would be necessary.

Ko et al. (2010) analyzed a series of carbon dioxide (CO_2) emissions abatement scenarios of the power sector in Taiwan according to the Sustainable Energy Policy Guidelines, which was released in June 2008. The MARKAL-MACRO energy model was adopted to evaluate economic impacts and optimal energy deployment for CO_2 emissions reduction scenarios. This study included analyses of life extension of nuclear power plant, the construction of new nuclear power units, commercialized timing of fossil fuel power plants with CO_2 capture and storage (CCS) technology and two alternative flexible trajectories of CO_2 emissions constraints. The CO_2 emissions reduction target in reference reduction scenario would be back to 70% of 2000 levels in 2050. The two alternative flexible scenarios would be back to 70% of 2005 and 80% of 2005 levels in 2050. The results showed that nuclear power plants and CCS technology would further lower the marginal cost of CO_2 emissions reduction. Gross domestic product (GDP) loss rate in reference reduction scenario would be 16.9% in 2050, but 8.9% and 6.4% in the two alternative flexible scenarios, respectively. This study also showed the economic impacts in achieving Taiwan's CO_2 emissions mitigation targets and revealed feasible CO_2 emissions reduction strategies for the power sector.

Tsai and Chang (2013) presented the results on the simulations of different technology development scenarios under the same emission reduction goal, utilizing the MARKAL model to evaluate emissions reduction on Taiwan's electricity, industry, buildings, and transportation sectors. The empirical results showed that Taiwan could potentially reduce 56%–60% of greenhouse gas emissions relative to the BAU scenario in 2025, and 15% relative to the 2005 levels. The accumulated incremental cost would be an increase by 1.2%–1.96% of Taiwan's GDP.

de Lima and Veziroglu (2001) proposed a program of electrolytic hydrogen generation for Brazil through the assistance of photovoltaic cell panel. The generated hydrogen would serve as an energy carrier and would be used in every application where fossil fuels were being used that time. Three scenarios were considered: fast hydrogen introduction, slow hydrogen introduction, and no hydrogen introduction. The results showed that hydrogen introduction (1) would increase the energy consumption, (2) would increase the gross national product per capita, (3) would reduce pollution, and (4) would increase the quality of life in Brazil. Fast hydrogen introduction would bring the benefits by 20 years earlier.

de Lucena et al. (2010) applied an integrated resource planning approach to calculate least-cost adaptation measures to a set of projected climate impacts on the Brazilian power sector. By using a parametric long-term energy demand projection model (MAED – model for analysis of energy demand), and an energy supply optimization model (MESSAGE – model for energy supply strategy alternatives and their general environmental impact), the authors identified the least-cost options for compensating the projected impacts, based on premises about each energy technology's technical-economic characteristics and the country's resource endowments. This methodology had the advantage of finding optimal solutions that took into consideration the whole energy chain and the interactions between energy supply and demand. Results pointed in the direction of an increased installed capacity based, mostly, on natural gas, but also sugarcane bagasse, wind power and coal/nuclear plants, to compensate for a lower reliability of hydroelectric production, amongst other impacts. The indirect effect of these results would be the displacement of natural gas from other consuming sectors, such as industry, in favor of its use for power generation. Results obtained were, however, based on the techno-economic premises used in the simulation, which might vary in the long term.

Cai et al. (2008) developed a large-scale linear programming model (University of Regina Energy Model, UREM) for supporting energy systems planning in the Region of Waterloo, Canada. In UREM, energy production, supply and consumption, scenario developing process, and policy analysis are integrated into a general modeling framework. Developing four scenarios (including a reference case), the authors (a) tackled the dynamic, interactive and complex characteristics of the energy management system in the Region of Waterloo, (b) identified characterize and developed a number of site-specific scenarios, including regional development plans, renewable energy options and sustainable development strategies for in-depth analysis of energy supplies/demands, technologies, emissions and relevant policies, (c) searched for optimal patterns of energy generation, conversion, transmission and consumption under the least economic and environmental costs, (d) generated a number of compromise decision alternatives under varying system conditions, allowing comprehensive analysis of trade-offs between environmental, social and economic objectives and (e) applied the proposed UREM for supporting the Region's long-term energy system planning and address issues concerning plans for cost-effective allocation of energy resources and services. The results indicated that the Region would attain a comparatively stable energy structure if its energy management practices continued to be based on the existing policy.

A higher energy supply/demand projection associated with a higher system cost would be realized if the plans for economic expansion and re-urbanization were prioritized among the Region's policies. Also, a higher system cost and a lower GHG emission would be obtained if solar energy was introduced into the existing energy management system. Moreover, a lower system cost and a lower energy demand/supply would be observed if the Region's policy was conservative on energy consumption. The results indicated that regional development plans, sustainable development strategies and renewable energy options could significantly affect energy management through their effects on energy demand/supply and related technologies in residential, commercial and transportation sectors.

Through a case study on long-term CO_2 emission reduction in the Netherlands, **Gielen (1995)** showed that integrated energy and materials studies could give significant new policy options for energy savings and CO_2 emission reduction through materials system improvements. An integrated energy and materials system MARKAL model was used for this analysis. The results showed that, on one hand, CO_2 emission reduction costs would be significantly reduced in the integrated approach, and, on the other hand, the material system would be significantly influenced by CO_2 emission reduction. Consideration of dynamic interactions would result in better understanding of future developments in both energy and material systems.

Biesiot and Jan Noorman (1999) described the results of several research programmes that together aimed at the development and application of methodologies that would enable the study of long-term environmental effects (mainly related to the total household energy demand) of household consumption in relation to other economic sectors. This is usually described as the household metabolism approach. In this work, the authors used energy consumption and CO_2 emissions as proxies for long-term impacts on the environment. The major long-term environmental effects of several hundred Dutch household consumption categories were determined by means of the hybrid energy analysis methodology. Total energy consumption and related CO_2 emission data were calculated as a function of household income and family type. Past trends were studied by a time series (1950–1990) analysis. Technical reduction potentials were calculated for mid and long-term scenarios. It was concluded that the set of methodologies described would form a useful tool for the analysis of unsustainable trends in household consumption patterns and associated energy requirements in the past and the present. The results indicated that present trends would lead towards unsustainability. However, reversal of these trends would be feasible if this started in the immediate future and if it was maintained for decades.

Mirasgedis et al. (2004) presented a baseline projection until 2020 of the future energy supply and demand situation in Greece, the associated trajectories of greenhouse gas (GHG) emissions, and the effects of an environmental tax equivalent to \$40/t of carbon dioxide (CO_2). The latter scenario represented a rough estimation of the GHG emissions abatement potential in the country's various energy sectors. The energy market and emissions forecasts were developed using the ENergy and Power Evaluation Program (ENPEP), a bottom-up, integrated supply and demand simulation framework. Driven by a growing population, an increasing per-capita income, and a 3.3 % growth in the overall economy, Greece's final energy consumption was projected to rise from 19.3 to 29.0 million tons of oil equivalent (Mtoe) over the next 20 years. While the country's primary energy production was expected to be relatively stable, net imports were shown to surge substantially, thus increasing Greece's energy import dependency. The forecasts predicted substantial changes for Greece's power system with the generation mix shifting away from oil and lignite to natural gas.

Energy consumption patterns were also forecasted to change, driven by underlying structural changes in the economy. Notable changes were projected for the services and transportation sectors. Projected fuel shifts in final consumption were induced by expected price developments and government policies. As a result of the projected growth and shifts in energy production and consumption and fuel mix, baseline GHG emissions in 2010 were forecast to exceed 1990 levels by 47.2%. By 2020, emissions were projected to exceed 1990 levels by 70.3%. The environmental tax scenario showed significantly lower GHG emissions, primarily a result of emissions reductions in the power sector, as well as the industrial and residential sectors.

Ioakimidis et al. (2012) presented a roadmap with the modeling of the main technologies associated to the Carbon Capture and Storage (CCS) and its implementation into the Greek energy system considering existing National and International Strategic energy plans under different scenarios. The implementation of CCS technologies would have a large influence on the national electrical power production, having the responsibility for large shares of the emissions reduction that can potentially achieved in this sector. For this purpose, TIMES (The Integrated MARKAL/EFOM System) was chosen as the principal tool for building a technoeconomic model of the Greek energy system and its possible evaluation over time (2040). The implementation of CCS to the new licensed power plants from 2010 and onwards could reduce significantly the use of lignite production which would be replaced either by cheaper imported electricity and/or higher penetration of renewables, especially from wind and CSP. The cost of a CCS energy policy implementation under a CO2 tax issue would add an extra 6.25 B€ up to 10.2 B€ to the electricity generation cost compared to the BAU scenario while completing the suggested energy mixture targets of the Greek Ministry of Environment, Physical Planning & Public Works and the CO2 emissions reduction according to the EU regulations.

The study of **Paltsev et al. (2009)** focused on energy markets in Russia. The authors looked at the recent developments in the world energy market and in the Russian natural gas, oil, and electricity sectors. Then, by using the MIT Emissions Prediction and Policy Analysis (EPPA) model (which is a general equilibrium model of the world economy), the authors considered different scenarios for a potential development of energy markets, both for Russia and for the Russian trading partners. The results showed that energy use in Russia would increase in 2050, while electricity use would be nearly doubled in 2005. The energy system would continue to rely heavily on traditional fossil energy. The long-run reference projection for oil price would have a continuous increase until 2050 and the same would hold for natural gas.

Cinar and Kayakutlu (2010) provided a general overview of creating scenarios for energy policies using Bayesian Network (BN) models. BN is a useful tool to analyze the complex structures, which allows observation of the current structure and basic consequences of any strategic change. Under BN, the authors proposed a decision model that would support the researchers in forecasting and scenario analysis fields. The proposed model would be implemented in a case study for Turkey. The choice of the case was based on complexities of a renewable energy resource rich country. The results showed that in the case of a stable scenario, renewable investment would overcome the nuclear investment. For the pessimistic scenario nuclear investment seemed to be a better choice than renewable investment according to the decision variables (greenhouse emission and energy import). On the other hand, in the case of the optimistic scenario, there was a tie between these two alternatives.

Using the modeling tool ELESA (Econometric Lifestyle Environment Scenario Analysis), **Chitnis et al. (2012)** described forecast scenarios to 2030 for UK household expenditure and associated (direct and indirect) greenhouse gas (GHG) emissions for 16 expenditure categories. Using assumptions for (a) real household disposable income, (b) real prices, (c) exogenous non-economic factors (ExNEF), (d) average UK temperatures, and (e) GHG intensities, three future scenarios were constructed. In each scenario, real expenditure for almost all categories of UK expenditure would continue to grow up to 2030; the exceptions being 'alcoholic beverages and tobacco' and 'other fuels' (and 'gas' and 'electricity' in the 'low' scenario) would lead to an increase in associated GHG emissions for most of the categories in the 'reference' and 'high' scenarios other than 'food and non-alcoholic beverages', 'alcoholic beverages and tobacco', 'electricity', 'other fuels' and 'recreation and culture'. Of the future GHG emissions, about 30% was attributed to 'direct energy' use by households and nearly 70% attributable to 'indirect energy'. UK policy makers therefore would need to consider a range of policies if they wished to curtail emissions associated with household expenditure, including, for example, economic measures such as taxes alongside measures that would reflect the important contribution of ExNEF to changes in expenditure for most categories of consumption.

Labriet et al. (2005) developed a new version of the advanced multi-region World MARKAL model and calibrated to the AlB scenario of IPCC over a 50-year time horizon. The analysis of the base and CO_2 constrained cases confirmed and refined several conclusions observed by other models. Amongst them:

1. The level of non-emitting electricity generation in the base case would be a crucial assumption for defining CO_2 reduction opportunities,
2. CO_2 capture and sequestration would compete directly with renewable electricity generation and would contribute to a major reduction in the marginal cost of CO_2,
3. The primary consumption of coal might be increased in the long term when associated with the capture of flue gas CO_2 at power plants,
4. In transportation, the substitution of oil by biomass would be robust and much preferred to the other alternative technologies,
5. The price-induced reduction of elastic demands would also contribute to the emissions reduction,
6. The resulting annualized cost of CO_2 policies would remain under 1% of the GDP in 2050 for the stabilization of CO_2 concentration at 550 ppmv (AlB base case),
7. Hydrogen production and end-uses technologies, CO2 capture and sequestration, as well as non-C02 greenhouse gases would deserve more attention, and
8. Future work would focus on the modeling and comparison of the cooperative and non-cooperative international frameworks.

Using ACROPOLIS, **Das et al. (2007)** formulated four case studies considering policies and measures on (a) renewable portfolio schemes and internationally tradable green certificates, (b) emissions trading and global GHG abatement target, (c) energy efficiency standards and (d) internalization of external costs (with 15 energy models). The ACROPOLIS initiative, supported by the European Commission and the International Energy Agency, used up to 15 energy models to simulate and evaluate selected policy measures and instruments and then compared their impacts on energy systems essentially in terms of costs of greenhouse gas emissions (GHG) reduction and energy technology choice. From a large set of results, ACROPOLIS concluded that the Kyoto targets (and their continuation beyond 2010 in specific scenarios) could be achieved through global emissions trading at a cost around 1% of the GDP. It was also indicated that this flexibility mechanism was a more cost-effective instrument for GHG mitigation than meeting the goal domestically without trade. The study demonstrated also that internalized external costs through a price increase would reduce local pollutants (SO_x, NO_x, and others) and would produce other benefits such as triggering the penetration of clean technologies.

2.2.2 A review of long-term projections with the LEAP system in the Energy Sector

Bala (1997) presented projections of rural energy supply and demand and assessed the contributions to global warming. The output of a dynamic system model was used in the LEAP model and overall energy balances were then compiled using a bottom-up approach. Biomass fuels constituted the major energy sources for rural people. A major share of fuel was consumed for cooking using traditional stoves which had efficiency less than 10%. Most of the biomass came from crop wastes. Conservative estimates showed tremendous pressure on rural forests for fuelwood. As a result, there was overcutting of rural forests resulting in environmental degradation. Further, the simulation results showed that the major supply source would be biomass. Bangladesh would contribute a very small amount of CO_2 on a per capita basis but could be seriously affected by climate change. Deforestation and other changes in land use would be important contributors to increased CO_2 emissions in Bangladesh. The emphasis in the country for lowering CO_2 emissions should be on: (i) more efficient use of non-commercial as well as commercial energy; and (ii) reduction in deforestation and a substantial increase in afforestation.

Shin et al., (2005) analyzed the impacts of LFG (landfill gas) electricity generation on the energy market, and the cost of generating electricity and greenhouse gases emissions in

Korea using the LEAP model and the associated 'Technology and Environmental Database'. In order to compare LFG electricity generation with existing other generating facilities, business as usual scenario of existing power plants was surveyed, and then alternative scenario investigations were performed using LEAP.

Different alternative scenarios were considered, namely, the base case with existing electricity facilities, technological improvement of gas engine and LFG maximum utilization potential with different options of gas engine (GE), gas turbine (GT), and steam turbine (ST). The analysis showed that in the technological improvement scenario, there would be 2.86GWh or more increase in electricity output, decrease of 45 million won (Exchange rate (1$=1200 won)), and increase of 10.3 thousand ton of CO_2 in global warming potentials due to same period (5 year) of technological improvement. In the maximum utilization potential scenario, LFG electricity generation technology would be substituted for coal steam, nuclear and combined cycle process. Annual cost per electricity product of LFG electricity facilities (GE 58MW, GT 53.5MW, and ST 54.5MW) would be 45.1, 34.3, and 24.4 won/kWh, and steam turbine process would be cost-saving. LFG utilization with other forms of energy utilization would reduce global warming potential by maximum 75% with compared to spontaneous emission of CH_4.

Lee et al., (2008) estimated the future mitigation potential and costs of CO_2 reduction technology options to the electricity generation facility in Korea. The monoethanolamine (MEA) absorption, membrane separation, pressure swing adsorption, and O_2/CO_2 input system were selected as the representative CO_2 reduction technology options. In order to analyze the mitigation potential and cost of these options, the LEAP system was used for setting future scenarios and assessing the technology options implication. The baseline case of energy planning scenario in Korea was determined in a business-as-usual (BAU) scenario. A BAU scenario was composed of the current account (2003) and future projections for 20 years. Alternative scenarios mainly dealt with the installation planning options of CO_2 reduction technology (exogenous capacity, planning time, and existing electric plants). In each alternative scenario analysis, an alternation trend of existing electricity generation facilities was analyzed and the cost of installed CO_2 reduction plants and CO_2 reduction potential was assessed quantitatively. Specially, the CO_2 emission amount of existing power plant-based coal steam utilization in alternative scenario I was 0.856 kg/kWh in the BAU scenario while the CO_2 emission amount in the new power plant-based coal steam utilization with introduced CO_2 capture after 2006 had an expected average of 0.180 kg/kWh (MEA), 0.369 kg/kWh (membrane), 0.211 kg/kWh (PSA), and 0.089 kg/kWh (O_2/CO_2 recycle). In the case of alternative scenario II, the CO_2 emission amount of existing power plant-based oil steam utilization was 0.7 kg/kWh in a BAU scenario while the CO_2 emission amount in the new power plant-based oil steam utilization with introduced CO_2 capture after 2006 had an expected average of 0.150 kg/kWh (MEA), 0.309 kg/kWh (membrane), 0.176 kg/kWh (PSA), and 0.074 kg/kWh (O_2/CO_2 recycle). In an alternative scenario III, the CO_2 emission amount of the existing power plant-based combined cycle utilization was 0.856 kg/kWh in a BAU scenario while the CO_2 emission amount in the new power plant-based combined cycle utilization with introduced CO_2 capture after 2006 had an expected average of 0.154 kg/kWh (MEA), 0.205 kg/kWh (membrane), 0.117 kg/kWh (PSA), and 0.049 kg/kWh (O_2/CO_2 recycle). According to alternative scenario IV, the CO_2 emission amount of existing power plant-based coal, oil steam and combined cycle utilization was 0.774 kg/kWh in a BAU scenario. But the CO_2 emission amount in the new power plant based coal, oil steam and combined cycle utilization with introduced CO_2 capture after 2006 had an expected average of 0.177 kg/kWh (MEA), 0.283 kg/kWh (membrane), 0.201 kg/kWh (PSA), and 0.085 kg/kWh (O_2/CO_2 recycle). The results also showed that the CO_2 emission amount per unit electricity generation in comparison with each alternative scenario would contribute to the proportion of the CO_2 emission of power plant-based coal steam utilization.

Kim et al. (2011) summarized the recent trends in the ROK (Republic of Korea) energy sector, including trends in energy demand and supply, and trends in economic, demographic, and other activities that under-lied trends in energy use. The assembly of a model for evaluating energy futures in the ROK (ROK 2010 LEAP) and results of several policy-based scenarios focused on different levels of nuclear energy utilization were described, as well as, their impacts on energy supply and demand in the ROK through the year 2030 were explored, along with their implications for national energy security and long-term policy plans. Nuclear power continued to hold a crucial position in the ROK's energy policy, but aggressive expansion of nuclear power alone, even if possible given post-Fukushima global concerns, would not be sufficient to attain the ROK's ''green economy'' and GHG emissions reduction goals. The authors' analysis of recent trends of national and sectoral energy use implied that securing energy supplies would not really the crucial issue to be addressed by the ROK's future energy policies.

During the decade from 2000 to 2010 annual TPES growth in the ROK slowed to less than 5% / yr from 8% to 14% annually in the 1990s, and the growth rate of primary energy use was projected to stabilize at around 2% annually in the coming decade. Recent trends and projections suggested that natural gas and electricity would continue to substitute for the direct use of other fossil fuels, and the shares in total final energy use of these fuels were expected to continue to increase through 2030. A major challenge in the ROK's energy future was how to manage (a) future natural gas supplies which would be crucial in fueling both end-use demand and for the generation sector, and (b) the evolution of the fuel mix for electricity generation including the capacity and availabilities of nuclear and renewable power, both of which would face an uncertain future for different reasons.

Park et al., (2013) analyzed the energy, environmental and economic influences of three electricity scenarios in Korea by 2050 using the LEAP system. The reference year was 2008. Scenarios included the baseline (BL), new governmental policy (GP) and sustainable society (SS) scenarios. The BL and GP scenarios were based on nuclear power and coal-fired power, and the SS scenario was based on renewable energy. The growth rate of electricity demand in the GP scenario was higher than that of the BL scenario while the growth rate in the SS scenario was lower than that of the BL scenario. Greenhouse gas emissions from electricity generation in 2050 in the BL and GP scenarios were similar with current emissions. However, emissions in 2050 in the SS scenario were about 80% lower than emissions in 2008, because of the expansion of renewable electricity in spite of the phase-out of nuclear energy.

While nuclear and coal-fired power plants accounted for most of the electricity generated in the BL and GP scenarios in 2050, the SS scenario projected that renewable energy would generate the most electricity in 2050. It was found that the discounted cumulative costs from 2009 to 2050 in the SS scenario would be 20% and 10% higher than that of the BL and GP scenarios, respectively. However, the cost increase was thought to be reasonable considering (a) that income would increase by about three times by 2050 and (b) the existence of co-benefits, such as the reduction of GHG emissions, harmful environmental effects and energy dependence on foreign countries.

Limmeechokchai and Chaosuangaroen (2006a) developed energy policy measures in order to promote the renewable energy utilization and increase energy efficiency in the consumption sectors of Thailand. To estimate the potential of energy saving, the projection of energy demand was grouped into two cases: the base-case or business as-usual (BAU) scenario and the energy efficiency case or alternative scenario. The authors' analysis showed that since non-electricity was the main form of energy that was consumed in the residential sector, the efficiency improvement of cooking stove would result in the largest amount of energy savings. The total energy saving in the residential sector was 7,291.6 ktoe, accounting for 29.42% of total residential final energy consumption in 2020. This scenario also helped in the reduction in the largest amount of carbon dioxide emission.

Mulugetta et al., (2007) constructed power sector scenarios for Thailand in order to represent the range of opportunities and constraints associated with divergent set of technical and policy options. The authors included Business-As-Usual (BAU), No-New-Coal (NNC), and Green Futures (GF) scenarios over a 20-year period (2002–2022). The results showed that in the BAU scenario, the GHG emissions would increase steadily with the construction of new coal-fired and natural gas plants until about 2015 when GHG emissions would reach their zenith. Over this period (2002–2015), GHG emissions would be increased by 94% from 58 to 112.6 tCO_2 at a rate of about 5.2% increase per year. From 2015 onwards, the trend would show a decline in GHG emissions reaching 101.6 million tCO_2 eq. This declining trend could be explained by the increasing efficiency with which natural gas would be converted into electricity towards the latter years of the study period, and to a lesser extent the modest expansion of Thailand's renewable energy programme. Nonetheless, the BAU scenario had significantly higher emissions than the other NNC and GF scenarios, largely to do with the higher contribution of coal-fired generation to the overall electricity balance. In the alternative scenarios, the NNC scenario showed an increasing trend in emissions until 2015, stabilizing thereafter until 2022. In contrast, the emissions in the GF scenario followed a leveling and gradually declining trend starting in 2005, which would be consistent with what could be expected as more and more renewable energy-based generation systems come on stream to replace the outgoing coal-fired plants. Both alternative scenarios therefore would offer better environmental performance than the BAU path with respect to global air pollutants. The avoided emissions over the study period amounted to 325 and 692 million tons of CO_2

equivalent for the NNC and GF scenarios, respectively, which represented reductions of about 17% and 36% relative to the BAU path. Further, the authors' analysis showed that the CO_2 reduction costs of the NNC and GF over the study period were estimated at \$11.55/tCO_2 and \$4.55/tCO_2, respectively.

Limmeechokchaia and Chawana (2007) presented the strategies to overcome barriers to the adoption of improved cooking stove (ICS) and small biogas digester (SBD) technologies in Thailand. Firstly, to obtain the appropriate strategies to implement the ICS and the SBD, a pattern of energy consumption in the residential sector was investigated. Then the potential of reduction of energy consumption and corresponding emissions by the ICS and the SBD was assessed. The identification and ranking of barriers to the adoption of the ICS and the SBD technologies were also investigated. In order to assess the energy consumption and the corresponding emissions reduction, the LEAP system was used in this study. Then, the Analytic Hierarchy Process (AHP) model was used to identify and rank the barriers. Results from the LEAP model showed that the cumulative total energy consumption and corresponding emissions reductions during the period 2002–2030 by the ICS were 27,887.7 ktoe and 10,041.0 thousand tons of CO_2 equivalent, respectively. An average emissions reduction cost per ton of CO_2 equivalent per year was US\$ 0.95 for a fuel wood cooking stove and US\$ 0.35 for a charcoal cooking stove. Regarding the SBD, the cumulative total liquefied petroleum gas (LPG) consumption reduction and CO_2 mitigation were 5780.9 ktoe and 1548.8 thousand tons of CO_2 equivalent during the period 2002–2030, respectively. Results from AHP analysis of ranking of barriers showed that the three most important barriers in the adoption of the ICS were (i) high investment cost, (ii) lack of information, and (iii) lack of financial sources. For the SBD, the three most important barriers were (i) high investment cost, (ii) lack of financial sources, and (iii) lack of experts and skilled manpower. The sustainable energy triangle strategy (SETS) was implemented to overcome barriers in the adoption of the ICS. Results showed that the traditional cooking stoves were successfully replaced (more than 20% per year). Regarding the SBD, the biogas pool project (BPP) was implemented to resolve the over-supply of biogas. Results also showed that the BPP was a proper strategy.

Wangjiraniran and Eua-Arporn (2010) examined the impact of utilizing gas, coal and nuclear energy for long-term power generation on generation cost, emission and resource availability. A scenario-based energy accounting model was applied for creating long-term future scenarios. A baseline scenario was created on the basis of the existing power development plan (PDP). Three alternative scenarios of coal, nuclear and gas options were projected for the period beyond the PDP, i.e. 2022-2030. The results indicated that nuclear energy would have high potential for GHG mitigation and cost reduction. For the coal option, the benefit of cost reduction would be diminished at carbon prices above 40 USD/ton. However, clean technology development as well as the momentum of global trends would be the key factor for coal utilization. The results also showed the need of fuel diversification, in terms of depletion of the natural gas reserves depletion. It was clearly seen that the natural gas supply in Thailand would inevitably depend very much on the LNG imports in the long term. Hence, the attraction of natural gas in terms of cheap domestic resource utilization would vanish.

Foran et al., (2010) explored options for efficiency improvements in Thailand's residential sector, which was consuming more than 20% of Thailand's total electricity consumption of 150 TWh/year. The authors constructed baseline and efficient scenarios for the period 2006–2026, for air conditioners, refrigerators, fans, rice cookers, and compact fluorescent light bulbs. They drew on an appliance database maintained by Electricity Generating Authority of Thailand's voluntary labeling program. For the five appliances modeled, the efficiency scenario resulted in total savings of 12% of baseline consumption after 10 years and 29% of baseline after 20 years. Approximately 80% of savings came from more stringent standards for air conditioners, including phasing out unregulated air conditioner sales within 6 years. Shifting appliance efficiency standards to existing best-in-market levels within 6 years would produce additional savings. The authors discussed institutional aspects of energy planning in Thailand that had limited the consideration of energy efficiency as a high-priority resource.

Phdungsilp (2010) presented an integrated approach to study energy utilization and development in Bangkok. The LEAP system was used to simulate a range of policy interventions and to predict how these would change energy and carbon development from 2000 to 2025. The planning period was assumed to start in 2005, and 2000 was used as the baseline year. Sustainability of the sixteen proposed policies and scenarios was analyzed using a multi-criteria decision- making approach. The study began by developing an understanding of the energy use patterns, and followed with the application of energy modeling and decision support in future energy planning. These methods were helpful tools for energy planners as well as city administrators to develop their energy plans with regard to sustainability. Results revealed that the most significant energy savings would be in the transport sector relative to the BAU scenario.

The scenario analysis showed that the implementation of a modal shift from private passengers to mass transit systems would have the potential to greatly reduce energy demand, CO_2 emissions and to reduce the level of local air pollutants. This scenario had potential energy savings of 6614 ktoe in 2025. In the industrial sector, the improvement of energy efficiency showed savings of 736 ktoe in 2025. Electricity savings under the promotion of high efficiency appliances scenario in the residential sector and the potential of savings under the efficient HVAC systems scenario in commercial building were expected to be 111 and 12.3 ktoe in 2025, respectively. These energy savings would be important to Bangkok, since the city was dependent on imports of both electricity and fuels. However, if all of the strategies on the demand side were simultaneously implemented, the highest potential energy savings in 2025 would be expected to be 7947 ktoe, while on the supply side the renewable electricity scenario would show a significant reduction in CO_2 of 1757 kt CO_2-equivalent by 2025.

Further, policy options were assessed using a multi-criteria framework. In the residential sector, promoting high efficiency appliances policy would have the highest score, while the utilization of day lighting as a lighting system would provide the best improvement in the commercial sector. Energy efficiency policy received the highest score in the industrial sector. In transport sector, the modal shift policy got the best score among four transport policies. These policy options might be used as a basis for priority policy planning in the reduction of energy consumption CO_2 emissions, and local air pollutants.

Wangjiraniran et al. (2013) explored the possible scenarios under the constraint of nuclear and coal-fired power development. In addition, the consequence on the overall cost, greenhouse gas and diversification index of Thailand power generation system was also investigated. The reference scenario was created on the basis of the power development plan (PDP2010). Three alternative scenarios with the repeal of nuclear power plant (NPP), coal-fired power and their combination were comparatively simulated. The results showed that the overall cost for the worst case without NPP and coal-fired power would increase significantly the overall cost up to 33.8 percent in 2030 compared to the reference scenario. This would be caused by the replacement with higher price technology of natural gas combine cycle together with the higher fuel price due to the LNG import. In addition, diversification index would be doubled in this case. In term of the environmental concern, the GHG emission would possibly increase by 25.1 percent for the case of coal replacing NPP.

Zhang et al., (2007) estimated external costs of electricity generation in China under different scenarios of long-term energy and environmental policies. The LEAP software was used to develop a simple model of electricity demand and to estimate gross electricity generation in China up to 2030 under these scenarios. Because external costs for unit of electricity from fossil fuel would vary in different government regulation periods, airborne pollutant external costs of SO_2, NOx, PM_{10}, and CO_2 from fired power plants were then estimated based on emission inventories and environmental cost for unit of pollutants, while external costs of non-fossil power generation were evaluated with external cost for unit of electricity. The developed model was run to study the impact of different energy efficiency and environmental abatement policy initiatives that would reduce total energy requirement and also would reduce external costs of electricity generation. It was shown that external costs of electricity generation might reduce 24–55% with three energy policies scenarios and might further reduce by 20.9–26.7% with two environmental policies scenarios. The total reduction of external costs might reach 58.2%.

Cai et al., (2007) projected the energy consumption and CO_2 emissions from China's electricity sector through the employment of three different scenarios based on the LEAP system. The baseline scenario, the current policy scenario, and the new policy scenario sought to gradually increase the extent of industrial restructuring and technical advancement. Results implied that energy consumption and CO_2 emission in China's electricity sector would rise rapidly in all scenarios until 2030—triple or quadruple the 2000 level; however, through structural adjustment in China's electricity sector, and through implementing technical mitigation measures, various degrees of abatement could be achieved. These reductions would range from 85 to 350 million tons CO_2 per year—figures that correspond to different degrees of cost and investment. Demand side management and circulating fluidized bed combustion (CFBC) (ranked in order) were employed prior to use to realize emissions reduction, followed by supercritical plants and the renovation of conventional thermal power plants. In the long term, nuclear and hydropower would play the dominant role in contributing to emissions reduction. It was also suggested that a ‘‘self-restraint’’ reduction commitment should be employed to help contribute to the reduction of emission intensity, an avenue that would be more practical for China in light of its current development phase. Setting the year 2000 as the base year, the intensity reduction target could possibly range from 4.2% to 19.4%, dependent on the implementation effectiveness of various mitigation options.

Zhou and Lin (2008) evaluated the impact of a variety of scenarios of GDP growth, energy elasticity and energy-efficiency improvement on energy consumption in China’s commercial buildings using a bottom-up energy model. The authors also evaluated the existing energy statistics and made adjustments on sectoral energy consumption. The results suggested that:

1. Commercial energy consumption in China’s current statistics was underestimated by about 44% and the fuel mix was misleading,
2. Energy-efficiency improvements would not be sufficient to offset the strong increase in end-use penetration and intensity, particularly of electricity applications, in commercial buildings,
3. Higher equipment efficiency and stronger policies could together act to slow down the growth of energy consumption in buildings, and
4. Different GDP growth and elasticity scenarios could lead to a wide range of floor area growth and therefore, to a degree dependent on rates of penetration of various energy technologies, could significantly impact energy consumption in commercial buildings.

Davoudpour and Ahadi (2006) evaluated the twin impacts of price reform and efficiency programs on energy carriers’ consumption and GHGs mitigation in the Iranian housing sector. For this purpose, the demand functions for energy carriers were developed by econometrics process models. The results revealed that price elasticity for electricity demand in the Constant Elasticity Model for the short-run and the long-run were respectively -0.142 and -0.901. In the Variable Elasticity Model, the 250% increase in electricity rates in the short-run resulted in a price elasticity change from -0.02 to -0.475, hence the 250% increase in electricity pricing for the long-run resulted in the price elasticity changed from -0.15 to -2.0.

Finally, aided by a Scenario-Based Approach, the impact of fuel pricing and efficiency improvement in trends of energy demand and GHGs emission were assessed in a Scenarios Base, developed on two different cases of Business-as-Usual (BAU) and Management. The results indicated that in the BAU case between 2000 and 2011, the energy demand and CO_2 emission would increase with an annual growth rate of 7.5% and 6.8%, respectively. Comparatively, if the energy carriers' price was increased to border price and energy efficiency programs were implemented, they would stimulate carriers' demand and CO_2 emissions growth rate decreases to 4.94% and 3.1%, respectively.

Kadian et al., (2007) applied the LEAP system for modeling the total energy consumption and associated emissions from the household sector of Delhi. Energy consumption under different sets of policy and technology options were analyzed for a time span of 2001–2021 and emissions of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x), nitrous oxide (N_2O), total suspended particulates (TSP) and sulfur dioxide (SO_2) were estimated. Different scenarios were generated to examine the level of pollution reduction achievable by application of various options. The business as usual (BAU) scenario was developed considering the time series trends of energy use in Delhi households. The fuel substitution (FS) scenario analyzed policies having potential to impact fuel switching and their implications towards reducing emissions. The energy conservation (EC) scenario focused on efficiency improvement technologies and policies for energy-intensity reduction. An integrated (INT) scenario was also generated to assess the cumulative impact of the two alternate scenarios on energy consumption and direct emissions from household sectors of Delhi. Maximum reduction in energy consumption in households of Delhi was observed in the EC scenario, whereas, the FS scenario would seem to be a viable option if the emission loadings were to be reduced.

Wijaya and Limmeechokchai (2009) examined utilization of geothermal energy scenarios for future electricity supply expansion in Java-Madura- Bali (Jamali) system as the largest electricity consumer in Indonesia by using the LEAP system from 2006 to 2025. The authors used three scenarios of geothermal utilization to maintain reserve margin of 30% according to the government plan in 2025. In the first scenario they added 50 MW of geothermal power plant, in the second scenario, 100 MW of geothermal power plant was added and in the last scenario, 124 MW was added in the endogenous capacity. They found that in the end of the period, by implementing the first scenario, the geothermal capacity generation would be increased by 5.7 GW. The second scenario implementation would increase 8.2 GW and for the last scenario increases would be about 10 GW. The authors also found that in 2025 emission reductions of each scenario would be 12.9%, 21.5%, and 25% respectively, compared to the BAU scenario. Additionally, in the end of projection the costs of each scenario would be 6.6 Billion USD, 6.8 Billion USD and 7.1 Billion USD respectively, compared to 6.3 Billion USD in the BAU scenario.

Tanoto and Wijaya (2012) studied the nuclear power plant development in Java-Madura-Bali area in the Indonesian Long-term electricity planning perspective. Indonesian electricity demand had continuously risen year by year particularly in the Java-Madura-Bali area, or often known as “JaMaLi” area. Holding the largest share for economic activities in the country, it was served by the largest electricity grid in Indonesia called the JaMaLi interconnection system. It was found that the electricity demand in JaMaLi area would increase to 308 TWh in 2025, of which the demand would be dominated by the household sector with 131 TWh or 42% of total electricity consumption. To meet this future demand, a total of 66 GW of installed power plant capacity had to be developed, being fuelled by various energy resources available in Indonesia, excluding nuclear. Hence, the authors explored the possibility of long-term electricity expansion planning in the JaMaLi area by including nuclear power plant in order to meet the future demand and environmental protection concern as well as to increase the supply security up to 2027. During the study period, the potential of energy resources available for JaMaLi area along with two electricity supply scenarios based on nuclear and non-nuclear sources were assessed. At the end of the projection, the nuclear power plants might contribute to the reducing of the fossil power plants requirement such as coal and natural gas by 2 GW and 1.9 GW respectively. Meanwhile, the total emission reduction achieved by nuclear scenario was estimated 16.8 million tons of CO2 equivalent.

Mustonen (2010) presented in a scenario analysis of rural energy consumption, how energy services in different sectors of a village economy could contribute to the achievement of the UNDP Millennium Development Goals. In a rural village in Lao People’s Democratic Republic, household energy demand and energy uses were surveyed immediately prior to the electrification of the village. Based on the situation preceding electrification of the village, the development of village electrification was studied by simulating the village energy system, accounting for all village energy uses but transportation. To study the potential development of electricity demand in the village, three scenarios were constructed using the LEAP model: ‘‘residential demand’’, ‘‘income generation’’ and ‘‘public services’’. Energy demand in each scenario was analyzed with reference to the Millennium Development Goals. The results showed that in the residential demand scenario, the benefits would arise from electrification increasing the lighting efficiency and decreasing the lighting costs for an average village household. Increases in demand could be achieved through the income generation scenario, where electrically powered productive activities would increase daytime electricity demand in the village power system. More equitable development could be achieved through the public services scenario, where residential and income generating uses of electricity were included.

Yophy et al., (2011) described the assembly of a first version of Taiwan's LEAP model, and used it to compare the energy demand of BAU (assuming current trends and government plans), GOV (enhancing energy efficiency by over 2% annually through 2025), FIN (a sensitivity case assuming the financial tsunami's far-reach- ing negative effects on Taiwan's economic growth), RET (assuming that the existing three nuclear power plants are retired as scheduled, but not replaced), and ALL (all of the above three cases combined). The authors found that the retirement of existing nuclear power plants as scheduled (RET) would have a negative impact on energy supply (increasing the need for coal, for example) and would result in an increase in CO_2 emissions. The rest of the scenarios would result in significantly reduced energy demand by 2030, in which the ALL case (combining energy efficiency with an assumption of lower economic growth) would result in the greatest reductions, followed by the GOV case. The FIN case had less effect on energy consumption than the GOV or ALL cases, indicating that lowered economic growth would be likely to have less effect on energy demand than aggressive policies to change energy consumption behavior patterns. Finally, in terms of carbon dioxide emissions projections for 2030, the ALL case showed the least emissions followed by the GOV case, while the carbon dioxide emissions in the RET would be higher than in the BAU case.

Pereira et al., (1997) presented a summary of the technologies and practices that could be implemented in Venezuela in order to contribute to both climate change mitigation and national development efforts. The mitigation analysis concentrated on options to reduce CO_2 emissions generated from the energy sector and land-use change. From the mitigation options analyzed for the energy sector it was determined that the most effective were those in the transportation sector (switching to larger capacity vehicles, reduced private vehicle share, and switching fuels for public transportation from gasoline to natural gas), both in terms of contribution to emissions reduction and costs. Regarding the options for industry, boilers conversion from liquids to natural gas showed negative cost, but to a considerably lower extent that for the transportation sector.

Efficiency improvement of natural gas boilers, which presented close to zero cost, was more effective in reducing emissions than boiler conversion. Increase in hydro power generation was the alternative with the highest total cost but it was very effective in reducing emissions. Finally, from the mitigation options analyzed for land-use change, it was established that the forest sector had a considerable potential for reducing CO_2 emissions through the adoption of sustainable forest practices, especially by slowing the rate of forest loss and degradation. Maintenance of already existing biomass in natural forests should be the first priority of forest measures to reduce the amount of carbon released to the atmosphere. Forest protection and management of native forest represented the two options with the highest carbon conservation potential and the lowest carbon unit cost. Expansion of the forest cover through the development of intensive forest plantations also presented a high potential to offset carbon emissions in Venezuela.

Morales and Sauer (2001) investigated the use of DSM (demand-side management) measures that might lead to reduction in fossil fuel demand and thus mitigate GHG emissions in Ecuador. Technical and economic assessments were carried out through construction of scenarios with the LEAP system. Results showed attractiveness of measures based on both substitution of energy sources and energy efficiency. Particularly, the authors found that minimizing biomass consumption, through efficiency improvement and substitution by LPG would avoid emissions and might avoid net greenhouse emissions.

Using a cost-benefit analysis, **Islas et al. (2003)** analyzed three Mexican power sector scenarios for the period 1996-2025: base (using fuel oil), official (introducing natural gas) and transition (incorporating renewable energy). Providing that no technological change was assumed from that current time until the year 2025, the following were observed: (a) the second scenario would be always better than the first scenario, (b) the third scenario would be better than the first scenario for natural gas prices, (c) the second scenario would be economically more favorable than the third scenario for natural gas prices, but the third scenario would be economically more favorable than the second scenario for discount rates larger than 24%, and (d) for lower prices of natural gas, the second scenario would always be economically more favorable. On the other hand, if technological change was assumed from that current time until the year 2025, the third scenario would be economically more favorable than the second one.

Islas and Grande (2008) assessed the abatement costs of several SO_2-control options (including flue-gas desulphurization technologies, hydro treatment of fuel oil, and the substitution of high-sulfur by low-sulfur content fuels) in the Mexican electric-power sector. For this reason the authors evaluated the implementation of such options in 10 selected power-plants—the main SO_2 emitters in the Mexican Electric Power Sector (MEPS)—with the aim of suggesting solutions for SO_2-emissions reduction and estimating the corresponding abatement, investment and total costs during the analyzed period. The results indicated that the best SO_2-abatement-costs route might account for a reduction of 41% of MEPS SO_2-emissions and would require investment and total costs of $841 and $477 million, respectively. This meant that an important reduction in the national SO_2-emissions might be achieved with a relatively small effort.

Ghanadan and Koomey (2005) developed and analyzed four energy scenarios for California that were both exploratory and quantitative. The business as-usual scenario represented a pathway guided by outcomes and expectations emerging from California's energy crisis. Three alternative scenarios represented contexts where clean energy would play a greater role in California's energy system: Split Public would be driven by local and individual activities; Golden State would give importance to integrated state planning; Patriotic Energy would represent a national drive to increase energy independence. Future energy consumption, composition of electricity generation, energy diversity, and greenhouse gas emissions were analyzed for each scenario through 2035. Energy savings, renewable energy, and transportation activities were identified as promising opportunities for achieving alternative energy pathways in California.

A combined approach that brought together individual and community activities with state and national policies would lead to the largest energy savings, increases in energy diversity, and reductions in GHG emissions. Critical challenges in California's energy pathway over the next decades identified by the scenario analysis would include dominance of the transportation sector, dependence on fossil fuels, emissions of GHG, accounting for electricity imports, and diversity of the electricity sector. Finally, the authors presented a summary of important policy lessons, opportunities, and policy implications that would emerge from the scenario analysis.

McCarthy et al., (2008) described preliminary results from an ongoing assessment of the interactions between hydrogen and electricity. As a first step, the authors used the LEAP system to evaluate different scenarios for hydrogen and electricity demand and supply in California in terms of primary energy use and GHG emissions. Supply scenarios (two electricity supply scenarios and five hydrogen supply scenarios) were developed to compare the impacts of various hydrogen and electricity production options on a statewide level. The authors found that hydrogen production relying on grid electricity might actually increase GHG emissions compared to the reference cases (i.e., no hydrogen penetration).

Chedid and Ghajarb (2004) examined the merits of implementing energy efficiency policies in the building sector in Lebanon following the approach normally adopted in Climate Change studies. At first, the authors examined the impact of the energy sector on the Lebanese economy, and then assessed the feasibility of implementing suitable energy efficiency options in the building sector. For this purpose, a detailed analysis of the building sector in Lebanon was presented with emphasis on the thermal characteristics of building envelopes and the energy consuming equipment. The long-term benefits of applying energy efficiency options in the building sector were then assessed using a scenario-type analysis that compared these benefits against those of a baseline scenario that assumed no significant implementation of energy efficiency policies. Finally, feasible options were highlighted and recommendations to remove the major barriers hindering the penetration of energy efficiency options in the Lebanese market were provided. The results reported by the authors showed that fluorescent lamps and solar water heaters represented win–win energy efficiency options and yielded substantial energy savings over the whole planning horizon. Although, electric heaters consumed electric energy most, their use was on the decrease as a result of market dynamics, which gradually would lead to their replacement by the more efficient fuel boilers and heat pump air-conditioners.

Dagher and Ruble (2011) modeled and evaluated possible future paths for Lebanon's electricity future. The baseline scenario (BS) reflected the business-as-usual state of affairs and thus described the most likely evolution of the power sector in the absence of any climate change-related or other policies. Two alternative scenarios were examined in contrast to the

BS; the renewable energy scenario (RES) and the natural gas scenario (NGS). Using the LEAP system, the authors conducted a full-fledged scenario analysis and examined the technical, economic, and environmental implications of all scenarios. From an economic standpoint as well as from an environmental perspective both alternative scenarios were superior to the baseline. Hence, the results of the simulation showed that the alternative scenarios were more environmentally and economically attractive than the BS. These scenarios would help Lebanon to meet its social, environmental, and economic development goals, while at the same time to provide other unquantifiable benefits.

Tavin et al., (2009) developed the LEAP energy planning system for South Africa, with 2005 to be the base year and with a limited number of plausible future scenarios that might have significant implications (negative or positive) in terms of environmental impacts. The system quantified (a) the national energy demand for the domestic, commercial, transport, industry and agriculture sectors, (b) the supply of electricity and liquid fuels, and (c) the resulting emissions. A comprehensive analysis of indicators that were used internationally and in South Africa was done and the available data was accessed to select a reasonable number of indicators that could be utilized in energy planning. A consultative process was followed to determine the needs of different stakeholders on the required indicators and also the most suitable form of reporting. The authors (a) demonstrated the application of Energy Environmental Sustainability Indicators (EESIs) as part of the developed tool, which would assist with the identification of the environmental consequences of energy generation, and (b) used scenarios and thereby promoted sustainability, since environmental considerations could then be integrated into the preparation and adoption of policies, plans, programs and projects.

Papagiannis et al., (2008) presented the results of an analysis on the economic and environmental impacts of the application of an intelligent demand side management system, called the Energy Consumption Management System (ECMS), in the European countries. The ECMS can be applied for the control of individual, widely distributed electric loads, using the power distribution network as the command communication channel. The system can be applied in public lighting, in the tertiary and residential sectors, as well as in the industry. A top-down analysis investigated the possible penetration levels in each application area. The long-term impacts following the application of system were evaluated using the LEAP 2006 platform. The WASP IV model was also used for the optimization of the power generation expansion and the corresponding calibration of LEAP2006. Several operational strategies combining variable market penetration of the ECMS and expected energy savings were examined. Results showed that, under a logical market penetration, a reduction of 1–4% in primary energy, 1.5–5% in CO_2 emissions and a 2–8% saving in investment costs for power generation expansion would be expected for the EU-15. The results also justified that innovative devices might be attractive to end users and also would help in the implementation of global energy-saving policies.

Giatrakos et al., (2009) evaluated for the island of Crete the present electrical energy status, and examined the possibility of further penetration of sustainable energy. Various energy modeling software solutions were examined and evaluated, in order to form scenarios according to the governmental and EU directives for renewable energy sources (RES), as well as to the planned conventional power plant upgrades and LNG transition. The authors developed different scenarios of load unfolding, results of which would be used to predict annual minimum and maximum loads, in order to model the additional technologies for the power production and transmission. The business-as-usual (BAU) scenario represented changes that would be likely to occur in the future, in absence of any new policy measures. Besides, two scenarios would be formed, which were differentiated by the degree of DSM (demand side management) penetration. Both scenarios exploited any energy saving potential by adopting the available practices and technologies. The more austere, ‘‘extended DSM’’ scenario also complied with the main EU targets. Analysis showed that even the most modest and realistic RES implementation scenarios, combined with a partially successful demand restriction, could indeed contract the island’s environmental footprint. RES penetration in Crete’s electric seemed to be able to surpass 30% by 2020, surpassing even the optimistic EU targets for 20% RES by 2020.

Roinioti et al., (2012) built energy scenarios for the future Greek energy system– with a focus on the electricity production system – and explored how these scenarios could be reflected in economic, environmental terms and in terms of energy efficiency. The main tool which was used in the scenario analysis was the LEAP system. From an environmental perspective, the Green scenario (low emissions - high growth), followed by the Blue scenario (low emissions - low growth) were the most favorable. Results revealed that the Green scenario offered the highest decrease in CO_2 emissions, but also had the highest capital cost. In the Orange scenario (high emissions - high growth) the final energy demand was increased by 82% in 2030 compared to 2009. This might endanger both the development of a cohesive energy policy and healthy energy market. The Orange scenario was the most emissive scenario. From an economic standpoint, the Red scenario (high emissions - low growth) was the most favorable. However, it was also the second most emissive scenario. The Reference scenario (reflecting the business-as-usual state of affairs and including the programmed integration/withdrawal measures of thermal units and the aimed RES expansion for 2020) seemed to be at a middle point: It was more favorable economically than the Orange and Green scenarios, but it was also more emissive than the Green and Blue scenarios. However, it would lead to lower emissions than the Orange and Red scenarios. Moreover, it was important to note that the Green scenario was the only scenario which would achieve the goal of 40% RES in electricity production in 2020. Nonetheless, all the scenarios included considerable increase in RES installed capacity. In the Reference scenario the RES participation in electricity production would reach 38% and in the Blue scenario the corresponding share would be 35%. Thermal solar systems were also introduced in the system, with 255 MW in the Orange scenario and 510 MW in the Green scenario, in 2030. The Green scenario assumed a remarkable small hydro exploitation, while the photovoltaics would gain an important share in the electricity production system in the Green (5,000 MW in 2030) and Orange scenario (3,833 MW in 2030)

Kuhi-Thalfeldt et al. (2010) created a model for Estonia's energy system in LEAP software for the period 2000-2030 and designed eight different electricity generation scenarios based on the long term development plans. For creating the Estonian energy system model, statistical data for the years 2000-2006 was inserted and final energy consumption data (all primary fuels, electricity and heat) by different sectors (industry, agriculture, transport, commercial and households) were used. The production units for electricity, heat, oil shale mining and shale oil production were created in LEAP and their production was optimized to represent the real situation. This meant that a reference model was built, where the production from generating units would be at the same level as the actual numbers in 2000-2006.

Thereafter the development of final energy consumption in 2007–2030 was predicted and for each scenario changes in the production capacities (closing of plants and building of new ones) were made. Based on analyzed CO_2 and SO_2 emissions, it was evident, that all scenarios would show a reduction of emissions compared to Scenario 0, where continuation of current situation was assumed. Closing down of old oil shale PFBC (pressurized fluidized bed combustion) units would have a significant impact on pollution reduction. The new CFBC (circulating fluidized bed combustion) units would have lower emissions; particularly the SO_2 emissions would be over 100 times lower.

2.3 Industry Sector

In this section we present a review of works related to GHGs/CO2 abatement options for the following industrial sectors: iron and steel, cement, petroleum refining, chemical, and pulp and paper.

Examining the Japanese iron and steel industry, **Gielen and Moriguchi (2001a,b,; 2002)** found out that it emitted 13% of total nation GHGs emissions which was considered as very high compared to other countries. However, the efficiency of Japanese industry was considered among the highest in the world. Using GAMS, the authors constructed a STEAP (Steel Environmental strategy Assessment Program) model from the industrial ecology perspective and examined a number of GHGs emission reduction strategies, such as an increase in the energy efficiency, the alternation of coal with other fuels, an increased recycling rate, the removal of CO_2 and sea disposal, an increased efficiency of the materials and the beginning of ambitious projects like Clean Development Mechanism (Gielen, 1999). As stated by Gielen and Moriguchi (2001a,b), some of these options were of zero or negative cost and therefore they could have be implemented and promoted the competitiveness. However, technologies such as blast furnace had not been fully developed and further it was difficult to implement such technologies those times. Additionally, the STEAP model indicated the necessity for a change from integrated steel mills production to scrap based mini-mills production

Worrell et al. (2001a) investigated the iron and steel industry in USA. Considering 1994 as the base year, it was shown that for steelmaking, physical energy intensity and CO_2 intensity had been reduced by 27% and 39% respectively. The authors examined 47 energy efficient technologies, which had been presented in Worrell et al. (1999). These technologies could be categorized in commercially available technologies and advanced technologies which had not been available for wide commercial use. Then, they applied bottom-up energy conservation supply curves in order to rank the conservation technologies. Their results pointed out that the two technologies had a potential of energy efficiency improvement of 18% and 19% reduction of CO_2 emissions respectively.

Kim and Worrell (2002) studied the steel and iron industry in three developing countries (Brazil, China, India), two newly industrialized countries (Mexico and South Korea and one industrialized country (USA). The authors extended the methodology of Worrell et al. (1997) and used physical indicators to make an intra-sector trend decomposition analysis of CO_2 emissions. The results indicated significant differences among countries. Some common features were the increased volume of the production which had a negative effect on increasing CO_2 emissions and the improved energy efficiency which had a positive effect on reducing pollution intensity. However, the net effect appeared to be towards an increase in CO_2 emissions.

Mathiesen and Moestad (2004) examined the effect of a carbon tax on CO_2 emissions using the SIM model (Steel Industry Model), which is a numerical partial equilibrium model. Assuming a carbon tax of $25 per ton CO_2, the authors found that the total steel production would be reduced by 3.2% and at the same time emissions would be reduced by 7.8% due to the carbon tax. Moreover, the authors highlighted that it would be common for a climate policy to be enforced only at a few countries, usually industrialized ones, and would have zero or negative effect on global emissions. This was also the case for iron and steel production because a stringent climate policy could cause relocation of the production towards an industrialized country with a less stringent policy. The findings demonstrated that the combination of a carbon tax with border tax adjustments, such as import taxes and export subsidies between the country which would adopt the climate policy and the country which would fail to comply with this policy, might be proved to be a very powerful instrument.

Demailly and Quirion (2008) examined the effect of European Emission Trading Scheme (ETS) on competitiveness (measured by production and profitability) of iron and steel industry. Additionally, they checked for the robustness of their results with various assumptions, e.g. marginal abatement cost curve, elasticities of trade and demand, pass-through rates etc. The results indicated that the losses of the sector had been insignificant and the arguments against ETS were not justified.

According to the United States Geological Survey (USGS, 2006), the Indian cement industry was the second bigger cement industry in the world with a production of 130 Mt. The TATA Energy Research Institute (1999) conducted a study about the available in commerce energy-efficient technologies for Indian cement industry. It was found that all these technologies combined had a potential of improvement in energy efficiency around 33%. In addition, future technologies had a potential of 48% energy reduction and 27% CO_2 emissions reduction but with relatively high cost.

Martin et al. (1999) analysed the US cement industry. They pointed out that US cement plants was relatively old. Furthermore, coal and coke had replaced natural gas as the most widely-used fossil fuel in the sector. The authors underlined the decreases in energy intensity (30%), CO_2 intensity from fuels (25%) and total CO_2 intensity (17%). They applied an energy conservation supply curve in order to assess 30 technologies according to energy efficiency, energy savings, CO_2 abatement, and various costs including investment, operation and maintenance. The results showed a potential of 11% in energy savings and 5% in CO_2 emissions. Additionally, they proposed the use of blended cement which would have a positive impact both in energy savings (18%) and in CO_2 abatement (16%).

Worrell et al. (2001b) studied the global cement industry and proposed a range of opportunities for CO_2 abatement. These options included the following: (a) improvements in energy efficiency, (b) changes towards a more energy efficient procedure (e.g. from wet to dry process), (c) change of high carbon with low carbon fuels or renewable fuels, (d) CO_2 removal, and (e) blended cements. The options of blended cement, improvement of energy efficiency and more efficient procedures were promising for immediate results in short term for CO_2 abatement. In long term, the use of alternative cement types such as mineral polymers from kaolin and also CO_2 removal could achieve further reduction of CO_2 emissions.

Gandalla et al. (2006) examined the potential reductions in crude oil distillation units. They demonstrated a number of energy saving and emission abatement opportunities. The alternation of process conditions, the changing of fuel mix and the additional equipment were considered as potential opportunities. The authors constructed a model to assess CO_2 emission from boilers, furnaces and turbines. This model was used in combination with a short cut model (Gandalla et al., 2003a,b) to optimize the process and minimize the CO_2 emissions. The results revealed that with the existing structure a 22% CO_2 emission reduction was achievable. Moreover, the introduction of a gas turbine could lead to a 48% CO_2 emission reduction.

Using marginal abatement cost curves, **Holmgren and Sternhufvud (2008)** investigated the abatement opportunities and costs in Swedish oil refineries. Evaluating the cost effect of the European Union Emissions Trading Scheme (EU ETS), the authors pointed out that the inclusion of Swedish refineries or any other firm or industry at the EU ETS would offer additional incentives for CO_2 reductions. The authors also found that it was possible abatement options to be implemented within 5 and 6 years with significant CO_2 reduction results. Particularly, they examined two refineries and the abatement potential was 8% and 22% respectively.

Analysing the Japanese chemical industry, **Gielen and Moriguchi (2001a,b)** underlined the rapid growth of the industry due to the growth of plastic packaging market. The authors recognized CO_2 emissions, energy consumption and wastes as important environmental problems arising from this growth. They also argued that immediate steps towards a more sustainable growth were required. The authors applied linear programming models in order to assess the impact of recycling ordinances, taxes and subsidies. They found that a CO_2 tax could result in waste reduction while a material tax could result in emissions reduction.

Bloemhof-Ruwaard et al. (1996) examined abatement options in European paper and pulp industry. More specifically, the authors examined the effect of paper recycling on environmental pollution. Additionally, if the recycling was reducing environmental degradation, the authors examined if maximal paper recycling was the best abatement technique for the sector. The findings revealed that a high population region could achieve significant pollution reduction with recycling and boost the production of paper products. Furthermore, a region which produced large amount of graphical product should focus on a cleaner production with energy recovery. Based on their analysis, the authors proposed that the best technique was a combination of recycling, cleaner pulp production and energy recovery.

Joelsson and Gustavsson (2008) assessed two innovative mitigation technologies about CO_2 emissions and oil use in pulp and paper industry. The authors compared two technologies: (a) Black liquor gasification with electricity and motor fuels in chemical pulp mills, and (b) increased energy efficiency in thermochemical pulp mills. These two technologies were evaluated according to net CO_2 emissions, oil use, primary energy consumption, biomass consumption and cost. The results indicated that black liquor gasification with motor fuels would be more efficient than electricity. Additionally, both technologies appeared to have significant mitigation potentials.

2.3.1 A review of long-term projections without using the LEAP system in the Industry Sector

In this section we review the long term studies which concern the industrial sector. We start with global studies or studies which concern more than one country and then continental studies.

de Beer et al. (2000) examined the opportunities for CO_2 abatement in iron and steel industry. Initially, the authors presented a number of abatement techniques which were: energy efficiency improvement with new or existing techniques, change from primary to secondary iron and steel production, CO_2 recovery from blast furnace, charcoal-based blast furnace, and decrease of iron ore and iron oxide. The following four scenarios were projected into the future: (a) the "frozen scenario" which assumed constant efficiency and emission at 1985-1995 levels and represented the worst case scenario, (b) the "moderate change scenario" which was the business as usual scenario, (c) the "accelerated change scenario" which assumed increased efficiency and implementation of new techniques and (d) the "wonderful world scenario" which assumed the immediate shift of developing countries' industry to meet the western standards. Results indicated that under the "frozen scenario" global CO_2 emissions would increase by 440 Mt per year and under the "moderate change scenario" the emissions would increase by 250 Mt per year. In the "accelerated change scenario" the emission would stabilize at 1995 levels and only in the "wonderful world scenario" there would be emission abatement of 200 Mt per year.

Hidalgo et al. (2005) studied an ISIM model (Iron and Steel Industry Model) which examined the evolution of the industry in the period 1997-2030. The authors took into account a business as usual scenario and three alternative scenarios which assumed the establishment of an emission trading system with different country coverage (EU15, EU27 and Annex B countries). In the reference case the industrial output would be increased by

75%. It was expected that developing countries, such as China, would rise their part in global production and consumption. On the other hand, OECD countries would decrease their consumption by 22% while global energy consumption was expected to decrease by 29% in 2030. Global CO_2 emissions would be decreased by 15% until 2030. This result happened due to lower global energy consumption which resulted from a shift towards cleaner and cheaper technologies. In the alternative scenarios, bigger country coverage would result in lower compliance costs and lower CO_2 emissions. In the EU-15 scenario the cost of compliance with Kyoto targets would be reduced at half while in the EU-27 scenario there would be further reductions up to two thirds. In the Annex B scenario the reductions would continue to rise and compliance costs would drop by 71%.

To study the pulp and paper industry in 47 global regions and to project three scenarios by 2030, **Szabo et al. (2009)** constructed a bottom-up PULPSIM model with particular focus on energy consumption and CO_2 emissions. In the business as usual scenario, the value of carbon would rise from 0 to 30 euro per ton of carbon in Europe and would remain zero in the rest of the world, while total emissions would rise from 220 $MtCO_2$ to 400 $MtCO_2$. However, the alternative "climate commitment scenario" revealed a high mitigation potential up to 30%-40% compared with the BAU scenario. In this alternative scenario, the value of carbon would be raised by 140 euro per ton of carbon in Europe and in the rest of the world. Furthermore, there would be significant constraints in resource availability and a change in forestry management practises. Besides, the results designated the significant potential of fibrous resource inputs and the effect of increased waste wood and black liquor based heat generator. The authors suggested that carbon taxes and emission permit systems would be effective ways for emission mitigation compared with other approaches.

For the US iron and steel industry, **Ruth and Amato (2002)** adopted **Ruth et al. (2000)** model. This model uses econometric forecasting combined with a reduced-form partial equilibrium model in order to study the implications of alternative CO_2 policies by the industry. The authors investigated a baseline scenario and three alternative ones. For the reference case, iron and steel production was assumed to be constant. The projections showed a 24% reduction of total emissions by the year 2020. Additionally, electric arc furnace (EAF) would be increased by 53% implying a change towards cleaner practices. The alternative three scenarios assumed that the cost of carbon was \$25, \$50 and \$75 respectively, and that improvement policies would have been implemented by the year 2000. These carbon costs would lead to decreases in the use of energy and carbon emissions. On the other hand, for the three alternative scenarios, EAF would be increased by 55%, 57% and 59% respectively.

Liu et al. (1995) examined the case of China's cement industry. The authors studied the projections of three scenarios, a business as usual scenario (scenario 1) with low-cost vertical kilns without advanced technology, moderate scenario (scenario 2) with moderate-cost advanced vertical kilns and an expensive scenario (scenario 3) with high-cost state of art precalciner kilns. The results indicated that with scenarios 2 and 3 the Chinese industry would become efficient but the authors seriously doubted about the likelihood of these scenarios. Instead, the authors proposed that technical training, financial incentives, efficiency standards and environmental regulation might lead to the right direction.

Zhu et al. (2010) analysed the energy consumption and CO_2 emissions in Chinese chemical industry. The authors examined three scenarios for the whole industry and six sub-sectors, ammonia, calcium carbide, caustic soda, coal-based methanol, sodium carbonate and yellow phosphorus. The first scenario was the business as usual scenario where levels and structures of each sub-sector remained constant to 2007 level. Two alternative scenarios were provided, the low technological improvement rate scenario and the high technological improvement rate scenario. The results indicated a 12% CO_2 emissions reduction in the low alternative scenario and a 26.8% reduction in the high alternative scenario. Moreover, it was pointed out that regulation and policy administration would play a significant role in CO_2 emissions abatement.

Zhang et al. (2009) applied a bottom-up model and linear programming optimizing methods to study the Chemical Oxygen Demand (COD) emissions in Chinese pulp industry. The authors analysed various scenarios with the time horizons to be extended to years 2010, 2020 and 2030. Particularly, three scenarios were considered; a BAU scenario, a "reduction policy" scenario and a "without reduction policy" scenario. Results indicated an increase in COD to 2.2 million tons (representing a 50% rise) in the BAU scenario. In the "reduction policy" scenario there was a significant reduction of COD to 1.21 million tons while in the "without reduction policy" scenario the abatement was 10% higher than that of the "reduction policy" scenario. Extending the work of Zhang et al. (2009), Zhang et al. (2012) studied three pollutants in Chinese paper and pulp industry; COD, ammonia-nitrogen (NH4-N) and absorbable organic halides (AOX). The authors examined a BAU and five alternative scenarios. The results revealed great reduction potentials. In particular, the closing of small pulp and paper mills in favour of more technologically advanced mills and the changing towards cleaner techniques would be effective pollution abatement options.

Langley (1986) studied the iron and steel industry in United Kingdom. The author examined 44 subsectors and took into account any structural changes. He considered 1980 as the base year and showed that energy consumption had been reduced by 40% since 1956. Further reductions could have been achieved by applying additional conservation measures, such as heat recovery from coke ovens and sinter plants, blast furnace, Basic Oxygen Steel-making (BOS) furnace, electric arc furnace (EAF) and the continuous casting in finishing operations. The author examined two scenarios, a high scenario by which total output would be increased by 18 million tons by 2000, as well as, further improvements would be introduced and a low scenario by which total output would remain constant at around 12 million tons. The findings indicated that in the high scenario the energy consumption would be reduced by 23.5% and in the low scenario by 17.6%.

Demailly and Quirion (2006) investigated the allocation of emission allowances using two methods: (a) the "grandfathering" method in which the number of free allowances for an enterprise does not depend on its current behaviour and (b) the "output-based allocation" method in which enterprises get their allowances relative to their current production level. The authors studied the EU27 cement industry for the period 2008-2012 and applied the bottom-up CEMSIM-GEO model following Brander (1981) and Brander and Krugman (1983), and assuming a Cournot oligopoly. This model concentrates on fuel and technologies. The authors assumed a business as usual scenario where no policy was enforced and two alternative scenarios for "grandfathering" and "output-based allocation". The results for grandfathering revealed a high level of CO_2 abatement in EU, namely, around 25%, but at the same time a high degree of leakage around 50%. The results for output-based allocation showed an insignificant drop for CO_2 emissions but also an insignificant rate of leakage.

2.3.2 A review of long-term projections with the LEAP system in the Industry Sector

Ackerman and de Almeida (1990) examined the case of Minas Gerais in Brazil, a state where steel industry would use the obsolete technology of charcoal-based iron and steelmaking. The authors stated that charcoal was the primary wood for fuel use and its consumption level was far above the sustainable levels, threatening the wood shortages. LEAP baseline scenario revealed an increasing gap between supply and demand for wood and as a result an on-going wood crisis. The authors proposed a change through less charcoal intensive technologies, introduction of more efficient improvements and a rise in wood supply through actions such as reforestation.

Wang et al. (2007) used LEAP software to analyse Chinese iron and steel industry from the base year 2000 up to 2030. The authors generated a BAU scenario and two alternative scenarios to investigate the CO_2 potential in the industry. In the BAU scenario, only the policies which had been adopted prior to 2000 were considered. The second scenario, which was the "current policy" scenario, considered adopted policies from 2000 to 2005. The third scenario, which was the "mitigation" scenario, took into account more ambitious targets and technologies than alternative scenario 2, such as energy management, structural adjustment, the application of larger scale operations and more advanced plants, and specific energy conservation technologies. The "current policy" scenario had a mitigation potential of 51 million tons, while the "mitigation" or "new policy" scenario had a mitigation potential of 107 million tons.

Atabi et al. (2011) developed four scenarios for CO_2 emissions in Iranian cement industry. Particularly, the authors used LEAP to construct a BAU scenario and three other alternatives using the 2005 as the reference year and projecting the scenarios until 2020. The first alternative scenario was based upon the substitution of heavy oil with natural gas, the second was based upon the introduction of energy efficient policies and the third was based upon the reduction of integrated emissions. In the BAU scenario, the CO_2 emissions would reach 61 million tons, while in the case of the three alternative scenarios there would be reductions of 4.9%, 9.8% and 13% respectively.

Ke et al. (2012) examined CO_2 emissions and energy consumption in the Chinese cement industry for the period 2011-2030. Based on historical trends, the authors constructed three output projections; a Building and Infrastructure Contraction-based (BIC) projection, a Peak Consumption per Capita-based (PCPC) projection, and a Fixed Assets Investment-based (FAI) projection. The authors recognized two possible abatement methods for CO_2 emissions and energy savings; a best practise savings potential which was based on one-time improvement to the world’s best practise and a continuous improvement potential. Furthermore, they developed four scenarios to study the implications of different abatement policies and measures; a frozen scenario which was the BAU scenario, a best practise scenario, a reference scenario which was a continuous improvement scenario, and an efficiency scenario which reflected a faster improvement than the reference scenario. The results revealed that under the best practise scenario there would be a potential of 20% reduction in energy consumption and total CO_2 emissions, while under continuous improvements scenarios, energy related reduction would have a potential to reach 22%-49%, and CO_2 reductions to reach 31%-54% compared to the best practise scenario.

Park et al. (2010) investigated the CO_2 mitigation potential in the Korean petroleum refining industry for the period 2008-2030. The authors evaluated four new technological advancements; crude oil distillation units, vacuum distillation units, light gas-oil hydro-desulfurization units and vacuum residue hydro-desulfurization process. Then, to study CO_2 abatement options the authors developed a BAU and five alternative scenarios which were related to the technological advancements. The most effective scenario for CO_2 abatement was that one which used overhead vapor waste heat recovery in the vacuum residue. At the same time, the scenarios related to vacuum distillation units, light gas-oil hydro-desulfurization units and vacuum residue hydro-desulfurization process demonstrated slight decreases in CO_2 emissions. On the other hand the scenario related to crude oil distillation units was the worst one and would lead to an increase in CO_2 emissions.

Song et al. (2007) studied the chemical industry in Korea for the period 2002-2015. Particularly, the authors studied chemical absorption which is a process of CO_2 removal using chemical reactions. They constructed a BAU and an alternative scenario where various technological advancements were considered. The two scenarios were compared based on CO_2 abatement potential, as well as, on capital and operation & maintenance costs. Relatively to the CO_2 mitigation potential, the authors estimated a 5% reduction from 2005 to 2010, a 10% from 2011 to 2014 and a 15% in 2015. Regarding costs, results revealed that technological advancements would not only increase CO_2 mitigation potential but also would decrease the costs.

Cai et al. (2008) examined China's mitigation options by studying five sectors of the economy; iron and steel sector, cement sector, pulp and paper sector (the 3 industrial sectors), electricity sector and transport sector. The authors developed three scenarios for each sector: a "Pre-2000 Policy" scenario which was based on policies which had been implemented before 2000, a "Recent Policy" scenario which was based on policies which had been implemented prior to 2006 and an "Advanced Options" scenario which was based on various technological advancements about GHGs mitigation. In 2010, the "Recent Policy" scenario had a potential of 5% CO_2 reduction while the "Advanced Options" scenario had a potential of 11% CO_2 reduction compared to the "Pre-2000 Policy" scenario. Projections for 2020 showed a 7% reduction under the "Recent Policy" scenario and 19% under the "Advanced Options" scenario.

Considering a time-horizon until 2020, **Limmeechokchai and Chaosuangaroen (2006b)** evaluated for Thailand the energy efficiency programs in small commercial and industrial sectors. The authors developed a BAU and four alternative scenarios about energy efficient options. Particularly, for the industrial sector, they considered improvements in lighting system, in heating device, in electric motor, in cooling device, and in boilers and other efficiency improvements. The results indicated that efficiency improvements in boilers and furnaces would have a significant potential of 9.87% CO_2 reduction.

Another study about Thailand's industrial sector is that one of **Phdungsilp and Wuttipornpun (2011)** which was referred to the period 2005-2030. The authors analysed a BAU and an alternative scenario which considered a number of technological improvements about industrial efficiency, alternation to natural gas, combined heat and power in designate factories, process integration, integrated policy and efficient electricity end-use devices. The results indicated a potential of 79.02-117.94 $MtCO_2$ reduction by 2030.

2.4 Transport Sector

Papagiannaki and Diakoulaki (2009) presented a decomposition analysis of the changes in carbon dioxide (CO_2) emissions from passenger cars in Denmark and Greece, for the period 1990–2005 based on the logarithmic mean Divisia index I (LMDI I) methodology. Denmark and Greece had been selected based on the challenging differences of specific socio-economic characteristics of these two small EU countries, as well as on the availability of detailed data used in the frame of the analysis. The analysis examined the implication of six factors in CO_2 levels, namely, the population, the vehicles in use per capita, the average distance traveled by car and the shares of cars by fuel type used, engine size and engine technology. The comparison of the results disclosed the differences in the transportation profiles of the two countries and revealed how they would affect the trend of CO_2 emissions.

Specifically, in the case of Greece, decomposition analysis led to very clear conclusions. Among the factors examined, ownership of passenger cars was by far the most influential one. The relative contributions of the remaining factors were quite lower. A shift to bigger and more powerful cars with greater energy consumption was observed, while the advantage of the improvement in engine technologies was offset partly by a certain delay regarding the renewal of the fleet. On the other hand, a regular reduction of the annual mileage had been assumed following the remarkable increase of new car registrations. Diesel cars constituted only a small fraction of the fleet of passenger cars, mainly used as taxis which were traveling at least six times more than gasoline cars. The much higher mileage of diesel cars cut the advantage of the lower fuel consumption compared to gasoline cars, therefore, the decreasing share of diesel cars contributed to reducing CO_2 emissions.

Additionally, **Papagiannaki and Diakoulaki** mentioned that in Denmark vehicles ownership tended to increase at a much lower pace than in Greece, thus affecting total emissions accordingly. Therefore, CO_2 emission increases were found to be lower in comparison with the Greek case, except for the period 1990–1995 which was marked by the particular increase of the average annual distance covered by passenger cars, as reported in relevant databases. In the next two 5-year periods, the upward trend of emissions was restricted by the continuous reduction of mileage and by the engine technology effect, related mostly to the faster, compared to Greece, penetration of cars with EURO standards, especially from year 1995 to 2000. The authors said that quite important, also, was the contribution of the growing share of diesel cars, which was responsible for the largest part of CO_2 increase between 2000 and 2005, because of the higher CO_2 intensity attributed to diesel cars. Finally, the shift towards cars with greater cylinder capacity was much more intense in the case of Denmark and, therefore, the consequent size effect had a higher contribution in total CO_2 changes. In conclusion, the findings of the decomposition analysis suggested that in front of the new more ambitious targets of the EU to reduce CO_2 emissions by 20% in 2020, more systematic efforts should be undertaken in both countries towards a more sustainable road transport system, including policy measures and technological support.

Utlu et al. (2004) analyzed sectoral energy and exergy utilization in Turkey between 1999 and 2000. Total energy and exergy utilization efficiencies were calculated to be 43.24 and 24.04% in 1999, and 44.91 and 24.78% in 2000, respectively. In order to calculate these efficiency values, the authors sub-grouped Turkey into four main sectors, namely utility, industrial, transportation and commercial-residential. They found that energy efficiency values were 23.88% in 1999 and 23.71%, in 2000 for the transportation sector while the exergy efficiency values were obtained to be 23.80% in 1999, and 23.65% in 2000 for the same sector.

Ediger et al. (2007) examined energy and exergy efficiencies in Turkish transportation sector. The authors used the energy consumption values in tons-of-oil equivalent for eight transport modes of four transportation subsectors of the Turkish transportation sector, including hard coal, lignite, oil, and electricity for railways, oil for seaways and airways, and oil and natural gas for highways. For each mode of transport, the weighted mean energy and exergy efficiencies were calculated by multiplying weighting factors with efficiency values of that mode. They were then summed up to calculate the weighted mean overall efficiencies for a particular year. Although the energy and exergy efficiencies in Turkish transport sector were slightly improved from 1988 to 2004, the historical pattern was cyclic, as stated. The energy efficieny was found to range from 22.16% (2002) to 22.62% (1998 and 2004) with a mean of 22.42±0.14% and exergy efficiency to range from 22.39% (2002) to 22.85% (1998 and 2004) with a mean of 22.65±0.15%. Overall energy and exergy efficiencies of the transport sector consisted mostly of energy and exergy efficiencies of the highways subsector in percentages varying from 81.5% in 2004 to 91.7% in 2002. The rest of them consisted of other subsectors such as railways, seaways, and airways. In conclusion, in this study the authors showed that airway transportation should be increased to improve the energy and exergy efficiencies of the Turkish transport sector.

Using the partial least square regression method (PLSR), **Zhang et al. (2009)** forecasted the transport energy demand for 2010, 2015 and 2020 under two scenarios. Based on GDP, urbanization rate, passenger-turnover and freight-turnover, the authors found that the total transport energy demand for 2020 would reach to a level of about 433.13 Mtce for scenario 1 and about 468.26 Mtce for scenario 2. The forecasting results showed that the transport energy demand in 2020 would be 2.33–2.51 times of that in 2006. Those figures for 2020 were very close to estimates obtained by Energy Research Institute of China.

Wu et al. (2011) summarized the vehicle control strategies and policies in Beijing since the mid of 1990s in order to reduce the impact of vehicle emissions on urban air quality. These strategies were classified into seven categories:

1. Emission control on new vehicles,
2. Emission control on in-use vehicles,
3. Fuel quality improvements,
4. Alternative fuel and advanced vehicles,
5. Economic policies,
6. Public transport, and
7. Temporal traffic control measures.

Evaluating the emission profiles of Beijing's vehicle fleet between 1995 and 2009, the authors discussed potential future strategies for Beijing's vehicle fleet and explored long-term mechanisms for vehicle emission control in Beijing and the rest of China. The results showed that the fleet-average emission rates of CO, HC, NO_X, and PM_{10} by each major vehicle category would be decreasing over time. For example, gasoline cars would have decreased fleet-average emission factors by 12.5% for CO, 10.0% for HC, 5.8% for NO_X, and 13.0% for PM_{10} annually since 1995, and such a trend would be likely to continue. The authors also found that the total emissions for Beijing's vehicle fleet would be increased from 1995 to 1998 with a clear and steady decrease between 1999 and 2009. In 2009, total emissions of CO, HC, NO_X, and PM_{10} would be 845000t, 121000t, 84000t, and 3700t, respectively with reductions of 47%, 49%, 47%, and 42%, relative to 1998.

Westerdahl et al. (2009) investigated the impacts of emissions from transportation on air quality and community concentrations in Beijing in 2007. They characterized the Beijing air quality under different microenvironments, i.e., on-road, roadside and ambient. The results demonstrated a strong traffic impact on the carbon monoxide, black carbon, and ultrafine particle concentration. Specially, for on-road light-duty vehicles the carbon monoxide, black carbon and ultrafine particle number emission factors were derived to be 95g kg^{-1}-fuel, 0.3g kg^{-1}-fuel and $1.8x10^{15}$ particles kg^{-1}-fuel, respectively. While the emission factors for on-road heavy-duty vehicles were 50g kg^{-1}-fuel, 1.3g kg^{-1}-fuel and $1.1x10^{16}$ particles kg^{-1}-fuel, respectively.

Huo et al. (2012) measured HC, CO, NO_x, and $PM_{2.5}$ emissions from 175 diesel trucks of different sizes and technologies in five Chinese cities during 2007 and 2011, and generated emission factors on the basis of the measurements. The results showed that the HC, CO, and $PM_{2.5}$ emission factors had been reduced significantly as the emission standards become more stringent from Euro 0 to Euro IV, but the NO_x emission factors had changed differently. Euro II trucks had 3-6% higher NO_x emission levels than Euro I technologies and Euro III trucks failed to show a reduction as regulated by the standards. More stringent NO_x requirements (e.g. Euro IV) for diesel vehicles needed to be enforced. Finally, more measurement studies needed to be conducted to further understand real-world emission levels of diesel trucks in China as the comparison between the measurement results from this study and emission factors used in recent emission inventory studies showed that inventories studies might have underestimated NO_x emissions and overestimated $PM_{2.5}$ emissions from diesel trucks for late years (2006-2009).

2.4.1 A review of long-term projections without using the LEAP system in the Transport Sector

Limanond et al. (2011) presented a project for future transport energy consumption in Thailand for the next 20 years. The study developed log-linear regression models and feed-forward neural network models, using as independent variables the national gross domestic product, population and the numbers of registered vehicles. The models were based on 20-year historical data between years 1989 and 2008 and were used to project the trends in future transport energy consumption for years 2010–2030. The final log-linear models included only gross domestic product, since all independent variables were highly correlated. It was found that the projection results of this study were in the range of 54.84–59.05 million tons of oil equivalent and 2.5 times the 2008 consumption. The projected demand was only 61–65% of that predicted in a previous study, which had used the LEAP model. This major discrepancy in transport energy demand projections suggested that projects related to this key indicator should have taken into account alternative projections, because these numbers would greatly affect plans, policies and budget allocation for national energy management.

Ceylan et al. (2008) proposed a new method for estimating transport energy demand using a harmony search (HS) approach for the period 2006-2025. The authors developed Harmony Search Transport Energy Demand Estimation (HASTEDE) models taking as an input population, gross domestic product and vehicle kilometers. These models were applied to Turkish Transportation sector energy consumption. Results showed that HS algorithm might be used for energy modeling, but sensitivity analysis (SA) was required to obtain best values of the HS parameters. The quadratic form of HASTEDE would overestimate transport sector energy consumption by about 26% while linear and exponential forms would underestimate by about 21% when they were compared with the MENR (Ministry of Energy and Natural Resources) projections.

Boies et al. (2009) investigated the motor vehicle greenhouse gas emissions in a non-California State, Minnesota, for the period 2005-2030. The authors modeled several technology and policy options for reducing GHGs from motor vehicles in Minnesota. They concluded that Minnesota would have a viable approach to meeting its stated GHG reduction targets (15% by 2015 and 30% by 2025, relative to year 2005) only if advancements were made in all three areas, that is, vehicle efficiency, carbon content of fuels, and VKT (vehicles-kilometer travelled). If policies focused on only one or two areas, potential improvements might be negated by backsliding in another area (e.g., increasing VKT offsetting improvements in vehicle efficiency).

Dray et al. (2009) used the Aviation Integrated Model, which was under development at the University of Cambridge, to assess the impact of an open emissions trading scheme on the US and Indian air transport systems. The analysis was based on three internally consistent projections of per capita GDP, population, oil price, and carbon price until 2050. In each projection three different stabilization targets of atmospheric CO_2 concentration were examined, ranging from 450 ppm to 750 ppm. Significant reductions in air travel demand, fuel use, CO_2 emissions and required airport capacity growth before 2050 were only observed relative to a reference case in the most stringent scenario of stabilizing the atmospheric CO_2 concentration, i.e. at 450 ppm – an extremely challenging task. The air transport system response was found to increase if non- CO_2 emissions from aviation were considered in the trading scheme. This study also suggested that any given stringency level would have differing effects on short- and long-haul traffic. A comparison between the domestic aviation system impacts in the US and India suggested a generally smaller response of the Indian air traffic system to a given CO_2 emissions trading scheme due to lower price elasticities and average trip distance.

Fontaras and Samaras (2010) investigated the future characteristics of the European passenger car in order to meet the new average CO_2 emissions limit which was introduced in EU in 2009 (average CO_2 emissions reduction to 130 g/km until 2015). The authors studied possible changes in vehicle characteristics for meeting this limit taking into account the average European passenger car of 2007–2008. For this purpose first the most important factors affecting vehicle fuel consumption over the reference cycle (NEDC) were identified. At a second step, the CO_2 benefit from the optimization of these factors was quantified, through simulations of 6 different passenger cars commonly found in the European fleet. For the simulations Advisor 2002 was employed and validated against published type approval data. The analysis indicated that substantial reductions in vehicle weight, tire rolling resistance and engine efficiency were necessary to reach even the 2008 target. A 10% reduction in average vehicle weight combined with 10% better aerodynamic characteristics, 20% reduced tire rolling resistance and a 7.5% increase in average powertrain efficiency could lead to CO_2 reductions of approximately 13% (about 138 g/km based on 2007–2008 fleet-wide performance). So, the authors found that the complying with the 130 g/km within the next six-year timeframe would be a rather difficult task and additional technical measures should be necessary.

Zachariadis and Kouvaritakis (2003) presented a long-term 'business as usual' outlook of energy use and CO_2 emissions from transport in the 10 states of Central and Eastern Europe (CEE) which had acquired the status of 'accession countries' to the European Union. This was done with the aid of macroeconomic and demographic forecasts taken from international organizations and adjusted in order to account for recent developments, and moderate projections of fuel prices that had considered both the path of convergence of CEE economies towards EU standards and the potential future development of crude oil prices. The results of the study showed that public transport modes (buses and trains), which were expected to experience little or moderate growth after their collapse in the beginning of the 1990s, would lose much of their share in both passenger and freight transportation mainly to cars and trucks, while after 2015 aviation was expected to be the most booming mode. Car ownership, which was still at low to medium levels in most CEE countries, would grow rapidly up to 2015–2020 and then would gradually approach saturation. Despite considerable improvements in energy efficiency in all modes and especially in cars, transportation energy use was expected to almost double in 2030 compared to 2000, with private road transport (cars and trucks) being constantly responsible for about 80% of the total, while accounting for almost 60% of total passenger kilometres and tone kilometers respectively. As a result of potential future EU legislation the authors mentioned that, a rising fraction of automotive gasoline and diesel blends would be produced from biomass, so that biofuels would be foreseen to account for approximately 5% of total transportation fuel use by 2030. In conclusion, CO_2 emissions from transport were expected to be 70% higher in 2030 in comparison to 2000, even when biofuels would be treated as CO_2-neutral and not considering indirect CO_2 emissions of electric vehicles and trains.

Can and Price (2007) used integrated assessment models to project both baseline and mitigation greenhouse gas emissions scenarios. The authors examined sectoral energy consumption trends for 10 world regions using historical data for the period 1971–2000 and projected data for the period 2000–2030 based on the A1 and B2 scenarios of the Special Report on Emissions Scenarios (SRES). The major driving forces of past and future energy demand and CO_2 emissions included demographic and economic variables, such as population and GDP. The SRES scenarios provided information on their assumptions for these two variables with storylines describing the context of economic and social development. The A1 scenario predicted very rapid economic growth and low population growth, while the B2 scenario foresaw more moderate economic and population growth. The A1 storyline saw a rapid introduction of new and more efficient technologies with increasing convergence among regions. The B2 storyline portrayed an emphasis on sustainable development with less regional integration but more local development. The results of the study showed that the transportation sector would account for 22% of global primary energy use and 27% of global CO_2 emissions in 2004. Petroleum products consumption would represent 94% of the energy use in this sector, while natural gas would represent 3%, and electricity and biofuels would represent 1% each.

Road vehicles would account for about 83% of all transportation energy use, while aviation would represent 12%, rail 3% and navigation 2%. Transport energy demand in developed countries would represent the bulk of the world transport energy use with a share of 65%. However, energy use in transport had grown considerably faster in developing countries during the 1971–2000 period, at an annual rate of 5% compared with 2.1% for developed countries. Primary energy consumption in the transport sector would represent 22% of total primary energy consumption in the world in 2000, an annual increase of 2.5% since 1971. So, they said that this sector was expected to grow in all regions but most intensively in developing. The A1 and B2 scenarios projected an annual growth rate of 3% and 2.1%, respectively, for the period 2000–2030. Finally, the authors said that as transportation would be the fastest-growing source of CO_2 emissions globally both scenarios forecasted transportation related emissions from industrialized countries to continue to grow at a slower pace over time.

Conversely, developing countries in both scenarios were expected to grow rapidly, albeit much more rapidly in the A1 scenario. In absolute terms, they mentioned that the additional CO_2 emissions per year in 2030 versus 2000 would be higher in developing countries. However, their contribution would be lower in the B2 scenario, where the growth in emissions from developing countries would only represent 60% of total global growth, compared with 80% in the A1 scenario.

2.4.2 A review of long-term projections with the LEAP system in the Transport Sector

Islas et al. (2007) investigated the use of bioenergy in Mexico. Three different scenarios were created for electricity generation, transportation and residential sectors within a time frame from 2005 to 2030. In the base scenario fossil fuels were assumed as the dominant source of energy, whereas in the two alternative scenarios (ethanol and biodiesel production), the substitution of fossil fuels by biomass fuels was analyzed in all selected economic sectors. Simulation results obtained from the LEAP program and indicated that the use of ethanol, biodiesel and electricity obtained from primary biomass might account for 16.17% of the total energy consumed in the high scenario for all selected sectors. CO_2 emissions reduction, including the emissions saved from the reduction in the non-sustainable use of fuelwood in the rural residential sector, would be equivalent to 87.44 million tons of CO_2 and would account for 17.84% of the CO_2 emitted by electricity supply and transportation sectors when the base case and the high scenario were compared by 2030.

Specially, for the transportation sector the authors showed that in the high scenario, ethanol and biodiesel consumption would reach 30.8 PJ in 2015, increasing up to 1101.4 PJ in 2030. The contribution of these biofuels to the total amount of energy used by the transportation sector would be 1.02% in 2015 and 20.17% in 2030. Furthermore, biofuels would participate with 1.28% and 21.95% of the share in diesel and gasoline vehicle sectors by 2015 and 2030. Avoided emissions of non-biogenic CO_2 would amount to 1.95 million tons of CO_2 in 2015 and 59.65 million tons in 2030. This would represent a reduction of 1.28% and 21.95% by 2015 and 2030.

Palencia et al. (2012) examined the impacts of using hybrid vehicles, plug-in hybrid vehicles and fuel cell vehicles together with vehicle lightweighting using high-strength steel, as measures to reduce carbon emissions from light-duty vehicle fleet, considering jointly energy and materials flows. Direct effects of vehicle use and indirect effects linked to vehicle production and disposal were accounted using a model developed in LEAP. The model was used to study the evolution of light-duty vehicle fleet in Colombia until 2050 under six scenarios that represented different choices regarding powertrains, fuels, and materials for vehicle manufacturing. Under the considered scenarios, the authors found that energy demand and CO_2 reductions in 2050 could be reduced up to 108 PJ and 4.1 Million Tonne-CO_2 respectively with more efficient powertrain penetration accounting for the largest part of the reductions. In terms of vehicles production and disposal, the impact would be limited to the increment of waste material from retired vehicles, since new vehicles would be imported or assembled in the country using mainly imported components.

Bauer et al. (2003) investigated the link between transport and energy demand in Mexico for the period 1980-2030. The authors used the LEAP system (SEI-Boston) to model the gasoline demand in Mexico, under three GDP growth scenarios. The programmed fuel chain model used GDP which was expected to grow from 97.2 million in 1999 to 128.9 million in 2030 and population as drivers to derive the evolution of the income per capita in the three scenarios. The Three ''Rapid Automobile Growth (RAG)'' scenarios, A, B and C, with GDP annual average growths of 3.7%, 5.2% and 6.2%, respectively, used the Gompertz curve to yield the number of automobiles as a function of income per capita and, correspondingly, as a function of the year in which such income would be attained. The results of the study showed that the rapid automobile growth phenomenon might induce serious environmental impacts in the urban concentrations where most of the private vehicles circulated daily. Not only the gasoline consumption would increase, but also the average cruising speed would be further reduced. The limited success of current environmental policies in the main cities might thus be reversed if these policies were not revised in a systemic way: improvements in the quality of fuels, promotion of alternative fuels and hybrid cars, better and more extensive public transport, enforcement of the emission controls, coordination of traffic signals, variable working schedules to lower traffic peaks and education of drivers.

Bose (1998) presented a transport simulation model for the four Indian metropolises, namely Delhi, Calcutta, Mumbai and Bangalore, during the period 1990-2011 using LEAP program in order to analyze energy use and emissions in meeting the travel requirements of the residents of India under two transport strategies. The two strategies were: (a) the strengthening of public transport to reduce urban congestion (scenario 1) and (b) the promotion of cleaner and alternative fuels and improved engine technologies (scenario 2). The results from his analysis showed that both strategies could reduce the emissions of CO, HC, TSP and Pb in these cities as follows: 28-75% for CO, 28-80% for HC, 21-59% for TSP and 31-83% for Pb in 2010/2011. Reduction potential of SO_2 emissions in Delhi, Calcutta and Mumbai would be 24%, 46% and 27%, respectively, while in Bangalore this would be increased by 5%. Reduction potential of NO_x would be 15% and 22% in Delhi and Mumbai, while in Calcutta and Bangalore this would be increased by 12% and 16%, respectively.

Saisiritat et al. (2010) created energy demand model in Thailand transportation sector with validation against total energy consumption using the LEAP program, during the period 2008-2022. In order to analyze energy use pattern in transportation sector with capability to predict energy demand, bottom-up approach was undertaken due to its capability in accounting for the flow of energy based on simple engineering relationship, such as traveling demand, fuel consumption and vehicle numbers. The aim of their study was to assess the possibility of using ethanol as diesel substitute by recourse to energy demand model in Thai transportation sector. The authors mentioned that ethanol had been technically proved as diesel substitute in compression-ignition (CI) engine in two ways. First, low-blend of ethanol in diesel with emulsifier could be used in conventional CI engine. On the other hand, a high-blend of ethanol could be used in a modified CI engine. The results of the research suggested that the ethanol bus after 10 year period could reduce CNG (compressed natural gas) fuel demand by 550 thousand tons. Moreover, the CO_2 emission could be reduced by more than 32 thousand tons per year.

Zhang et al. (2008) developed dynamic vehicle emission factors to project vehicle emission inventories of CO, VOCs, NO_x, PM_{10}, and CO_2 more accurately in Hangzhou, China during 2004–2030, considering several factors such as regulated emission limits, regulated fuel economy, vehicle deterioration of emission factors, and fuel economy deterioration. The stocks of vehicles and fuel consumption from 2004 to 2030 were forecasted with upgraded LEAP model according to the growth of population and GDP of Hangzhou. The projected results showed that regulated vehicle emission limits of National I and II standard of China would not be effective to reduce the emission factors of vehicles except motorcycles, and only National III and National IV of Vehicles Emission Limits could apparently reduce overall emission factors of all type vehicles with both gasoline and diesel. The results also showed that emission factors would continue to decrease after 2010. Up to 2030, the total emission inventories of CO, VOCs, NO_x, and PM_{10} would increase by 467.52%, 61.44%, 8.31%, and 78.35%, respectively.

However, emission inventory of CO_2 would grow continuously to 2030 with 770.54% growth rate. Additionally the authors suggested that for reducing emissions of vehicles, Hangzhou could either increase the effective year of stricter National regulated limits or improve vehicles emission control technology to reduce vehicle deterioration or would do both. In the mean-time, vehicle amount and fuel economy would have great influence on emissions, especially on the emission of CO_2 that would not decrease by reduction of vehicle deterioration, and would practice of stricter regulated limits. Therefore, to reduce the vehicle growth rate and fuel consumption, the decrease of vehicle emission inventories would be vital. To achieve these goals the authors mentioned that, Hangzhou would need to improve its public transport system including construction of subway and reduce vehicle fuel economy.

Lin et al. (2010) developed a detailed LEAP model to assess the effectiveness of urban energy conservation and GHG mitigation measures and applied it to analyze the future trends of energy demand and GHG emissions in Xiamen city. Four end-use sectors were included in the model: the household sector, the industrial sector, the transport sector, and the commerce sector. The reduction potentials in energy consumption and GHG emissions were estimated for a time span of 2007–2020 under two different scenarios. The 'Business as Usual' scenario assumed that the government would do nothing to influence the long-term trends of urban energy demand. An 'Integrated' scenario, on the other hand, was generated to assess the cumulative impact of a series of available reduction measures: clean energy substitution, industrial energy conservation, combined heat and power generation, energy conservation in building, motor vehicle control, and new and renewable energy development and utilization. The calculation results in Xiamen showed that the clean energy substitution measure would be the most effective in terms of energy saving and GHG emissions mitigation, while the industrial sector would have the largest abatement potential.

Zhang et al. (2010) developed a LEAP model in order to project the fuel consumption in China until 2030 under three energy consumption decrease scenarios which were: (a) 'business as usual' (BAU), (b) 'advanced fuel economy' (AFE), and (c) 'alternative energy replacement' (AER). The results from their analysis showed that fuel consumption would reach 992.28 Mtoe (million tons oil equivalent) with the BAU scenario by 2030. In the AFE and AER scenarios, fuel consumption was predicted to be 734.68 and 600.36 Mtoe, respectively, by 2030. In the AER scenario, fuel consumption in 2030 would be reduced by 391.92 (39.50%) and 134.29 (18.28%) Mtoe in comparison to the BAU and AFE scenarios, respectively. Hence, the authors proposed that the government of China should also implement policies to encourage the development and usage of biomass-diesel, which could reduce diesel consumption by 204.126 Mtoe (43.77%) compared to the BAU scenario. Finally, gasoline and diesel consumption could be decreased further by replacing diesel with CNG as the fuel for buses, or by increasing the proportion of diesel PCs.

Kumar et al. (2003) evaluated the greenhouse gas mitigation potentials of different biomass energy technologies in Vietnam for the period 1995-2020. Using the LEAP model, different scenarios were considered, namely the base case with no mitigation options, replacement of coal stoves by biomass stoves, substitution of kerosene and LPG stoves by biogas stoves, substitution of gasoline by ethanol in transport sector, replacement of coal by wood as fuel in industrial boilers, electricity generation with biomass energy technologies and an integrated scenario including all the options together. In the case of scenario 1, where the coal stoves would be substituted by biomass cooking stoves, the abatement cost ($/Mg of CO_2 reduced) was positive and would increase over the study period. This was because the cost of wood was more than coal in the case of Vietnam. In scenario 2, replacement of LPG and kerosene would be also unattractive as the abatement cost was again positive. In 2005, a new oil refinery would be established in Vietnam. This would make kerosene and LPG cheaper so that the abatement cost was expected to increase further. In scenario 3, replacement of gasoline by ethanol could be realized in a few more years. At that time, the cost of ethanol was more than gasoline; this would result in a positive abatement cost. The cost of ethanol was expected to decrease in the future which would result in the decrease of abatement cost.

Scenario 4 considered the substitution of coal by biomass in the industrial boilers. In this option, the abatement cost was significantly affected by the resource cost. As stated, wood in Vietnam was more expensive than coal, which made this option unattractive. In scenario 5, the substitution of fossil fuel power plants by packages of biomass energy technologies was the most attractive option among the abatement scenarios. Finally, the authors mentioned that the substitution of fossil fuel fired plants by packages of BETs would have a negative abatement cost. So, if this option was implemented, this would result in mitigation of 10.83 Mt CO_2 in 2010.

Dhakal (2003) estimated and analyzed the historical and future trends of energy demand and environmental emissions from passenger transportation of the Kathmandu Valley, Nepal covering CO_2, CO, HC, NO_x, SO_2, total suspended particles (TSP) and lead (Pb). The authors used the LEAP framework for constructing future scenarios up to year 2020 and analyzing their implications. These scenarios mainly dealt with traffic improvement measures, promotion of public transportation and electric vehicles. The results estimated a four-fold increase in energy demand for the period 1988–2000. TSP increase of 4.5 times in this period was the major concern since high particulate concentration was already above World Health Organization guidelines. Under the non-intervention scenario, energy demand in 2020 was estimated to be 2.7 times of that in the year 2000. Similarly, 2.5 times increase of TSP in 2020 from the year 2000 was estimated that would further increase the TSP concentrations. The scenario analysis suggested that increasing vehicle speed, promoting public transportation and promoting electric vehicles could reduce energy demand by 28%, 28% and 18%, respectively, while implementing all the policies with improving comfort in public transportation would reduce energy demand by over 55%. Finally, a mix of these three policies with improving comfort in public transport travel could reduce all pollutant loads in the range of 50–70% in 2020.

Pongthanaisawan et al. (2007) examined the number of vehicles, the energy demand and the emissions in road transport in Thailand from 2005 to 2020, using the LEAP program. In order to reduce the energy demand and emissions, the scenarios were: (1) BAU, (2) Natural gas vehicle scenario (NGV) with compressed natural gas vehicles (CNG), (3) hybrid vehicles, and (4) fuel economy improvement (FEI) of the gasoline and diesel engines. The results of the study showed that the number of vehicles in road transport would be 27.0 million in 2005 and would increase to 42.6 million vehicles in 2020, accounting for 3.5% annual growth rate. Due to the increase of the vehicles in road transport, the energy demand would increase from 20,776 ktoe in 2005 to 34,386 ktoe in 2020, accounting for 3.4% annual growth rate. The emission in terms of CO_2 equivalent in the transport sector would increase from 80.1 million tons of CO_2 eq in 2005 to 146.9 million tons of CO_2 eq in 2020.

Pradhan et al. (2006) estimated the consequences in fuel consumption and greenhouse gas emission due to the possible intervention of the electric run trolley buses in the existing public transport system in a particular road up to the year 2025 in Kathmandu Valley. Using the LEAP model, the authors developed the Business as Usual scenario and five alternative scenarios on the basis that the passenger travel demand would be function of population and income. These scenarios were: (1) 100% replacement of vehicles catering to mass-transit in the concerned routes, (2) 50% replacement, (3) 25% replacement, (4) stopping future growth of other vehicles catering to mass-transit in the concerned routes and 25% replacement in the first year and (5) combination of scenarios. The results of the study estimated that the passenger travel demand would increase by three folds from the year 2003 to the year 2025. It was projected that a three-fold increase of the existing vehicle activity by the year 2025 in Business-as-Usual scenario would occur. The fuel consumption would be increase by 2.4 times compared to the year 2003, the total greenhouse gas (GHG) emission would be 8.5 thousand tons in year 2003, which would increase by more than 3 times in year 2025, and 174.3 thousands tCO_2e could be avoided in the combination scenario. The authors concluded that the intervention of clean energy transport in the existing public transport could have a significant positive impact on the GHG emission and the existing fuel consumption. Especially, with the intervention of trolley bus as public bus during the projected period, the total GHG emission could be reduced by 53%, if the combination scenario was implemented.

So, clean energy transport like trolley buses could reduce the vehicle activity as well as would relieve the dependency of the public transport on petroleum fuel consumption.

Shabbir and Ahmad (2010) investigated the urban transportation in Rawalpindi and Islamabad in order to analyze the status of emission of air pollutants and energy demands. The authors developed the LEAP model in order to estimate the total energy demand and the vehicular emissions for the base year 2000 and extrapolated till 2030 for the future predictions. They created the BAU scenario and the following three alternative scenarios: population reduction (POP), public transport (PUB) and natural gas vehicle (NGV). The results of the study showed that the number of total registered vehicles in the BAU scenario would be increased from 127.1 thousand vehicles to 34.4 million. In the NGV, POP and PUB scenarios, the corresponding number would be 30 million, 28.1 million and 24.7 million respectively.

Hence, the total energy consumption in the BAU was calculated to be 120.7 million liters, while for the NGV, POP and PUB scenarios the corresponding values were found to be 108.6, 98.5 and 89.8 million liters respectively. Furthermore, the value of NO_x emissions would be decreased in the alternative scenarios as compared to the BAU scenario. In BAU, the value was found to be 24.7 million tons while in the NGV, POP and PUB scenarios the corresponding values were 20.5, 20.2 and 18.4 million tons respectively. Like NO_x emissions, SO_2 emissions were also decreased in the alternative scenarios as compared to the BAU. Particularly, the amount of emissions in the BAU, NGV, POP and PUB were found to be respectively 2652.90, 2287.80, 2161 and 2139 thousand tones. PM_{10} emissions did not show any significant difference between POP and PUB, but this amount was found to be smaller than the BAU. In BAU, the emissions amount was 1337 thousand tons while in NGV, POP and PUB, this amount was 1178.30, 1089 and 1074.70 thousand tons respectively.

Winkler et al. (2006) examined a set of energy policy interventions, which could make a major contribution to sustainable development for the City of Cape Town, using the LEAP program for the period 2000-2020. Having considered the energy use patterns in Cape Town, business-as-usual trends, and the impacts of eleven possible future energy policies, the authors stated that the major energy savings could be made from modal shifts in the transport sector and with efficient lighting. By far the largest savings could be gained by a shift from private to public transport modes – savings up to 36 million litres of petrol and diesel in the first year. Switching to more efficient lighting could result in substantial savings in several sectors, amounting to 38 million kWh in 2001.

Furthermore, the authors mentioned that the improved public transport infrastructure would be a key in reducing transport energy and emissions by making a modal shift possible. A steady shift to public transport would be expected to save 1021 tons of particulates in 2020. Total reductions of SO_2 would be 1400 tSO_2 by 2020, most of which would come from industry. The scenario modeling showed that the policy (renewable energy) could have saved 49 $ktCO_2$ equivalent after the first year of implementation already. A surprising result was that transport policy could result in even larger savings in the same year, of 72 $ktCO_2$ equivalent.

Bose et al. (1997) investigated policies to reduce energy use and environmental emissions in the transport sector of Delhi. The aim of this work was to extrapolate total energy demand and the vehicular emissions, using the LEAP model and the associated 'Environmental Database (EDB)'. The study was restricted to passenger modes of transport in Delhi and did not include the freight modes. The LEAP model was run under five alternative scenarios to estimate the current consumption of gasoline and diesel oil in Delhi and forecasted these quantities for the years 1994/1995, 2000/2001, 2004/2005 and 2009/2010, respectively. The five scenarios were: a) business as usual scenario, b) improvement in the vehicular speed, c) increase the share of buses, d) introduce mass rapid transit system and e) maximum conservation scenario. Under each scenario, the model also estimated emissions of CO, HC, NO_x, SO_2, Pb and TSP.

Finally, scenario results were analyzed to study the impact of different urban transport policy initiatives that would reduce the growth of fuel demand and emissions. The fuel requirements under different scenarios indicated that gasoline and diesel demand would be increased rapidly in the future. This would be accompanied by deteriorating air quality in Delhi. For instance, improvement in the public transportation system and higher traffic speed would be a good alternative, but improved speeds might lead to a higher traffic flow, which would not be desirable. Hence, it had to be reinforced by a policy to reduce growth in populations of such vehicles.

Yan and Crookes (2009) investigated the future trends of energy demand and GHG emissions in China's road transport sector and assessed the effectiveness of possible reduction measures, using the LEAP program. Two scenarios, BAU and BC, were designed to represent the worst and best case of the development strategies for China's road transport sector between 2006 and 2030 in terms of energy demand and GHG emissions. The BAU scenario was used as a baseline reference scenario, in which the government would do nothing to influence the long-term trends of road transport energy demand. The BC scenario was considered to be the most optimized case where a series of available reduction measures including PVC (private vehicle control), FER (fuel economy regulation), PDG (promotion of diesel and gas vehicles), FT (fuel tax) and BFP (biofuel promotion) would be implemented. In the BAU scenario, total energy demand, petroleum demand and GHG emissions in China's road transport sector in 2030 would reach 444, 438.5 Mtoe and 1303.7 Mt CO_2 respectively. While in the BC scenario the figures would be 264.1, 234.8 Mtoe and 783.1Mt CO_2 with relative reduction potentials as large as 40.5%, 46.5% and 39.9% achieved, respectively.

Finally, the authors mentioned that PVC, FER and FT would be the most effective measures to reduce total energy demand, petroleum demand and GHG emissions.

Tanatvanit et al. (2003) investigated the growth in energy demand and corresponding emissions in Thailand to the year 2020 for the sectors transport, industrial and residential by using the LEAP model. Energy conservation options, including energy efficiency improvement programs, were introduced in the residential and industrial sectors while public transportation and engine technology improvements were introduced in the transport sector. The effects of energy conservation options were analyzed using a scenario-based approach. The BAU scenario was constructed based on the current trends in each sector while in the alternative scenarios, one scenario was conducted in the residential and industrial sectors and two scenarios were conducted in the transport sector. The results of analysis revealed that the improvement of public transportation could reduce future energy requirements and CO_2 emissions in 2020 by 635 thousand ton of oil equivalent (toe) and 2024 thousand ton of CO_2 equivalent, respectively.

SECTION 3

Literature review for scenario assumptions in bottom-up studies

This section makes a review of works which have adopted scenario assumptions for bottom-up studies in the sectors of energy, industry and transport. Although sets of different assumptions have been used in these studies from the three sectors, Gross Domestic Product (GDP) growth and Renewable Energy Sources (RES) are the most common assumptions which are met.

3.1 Energy Sector

For Ecuador, **Morales and Sauer (2001)** investigated the use of demand-side management (DSM) measures that might lead to reduction in fossil fuel demand and thus would mitigate greenhouse gas emissions (GHGs). Technical and economic assessments were carried out through the construction of two scenarios for the residential sector covering the period from 1995 to 2025; a base-line scenario and a mitigation scenario. These two scenarios were developed under the following considerations and assumptions:

Base-line scenario

1. Future projections were obtained for the number of inhabitants and the number of households of the urban and rural areas for the years 2010, 2020, and 2025,
2. Industrial, agricultural and fishing sectors participation in GDP would grow, participation of transport and services would stay at the same level, and participation of exports of petroleum would decrease,
3. Prices for electricity and liquid petroleum gas (LPG) would increase to reflect costs, as this had been proposed by recently enacted regulatory policies for the energy sector,

4. Increase in electricity and LPG prices would reduce demand due to price elasticity,
5. Energy intensity for all other sources of energy would remain unchanged for each end-use, and
6. No substantial changes would result from specific measures or introduction of energy conservation programs, except for substitution and penetration processes, involving, mainly, LPG and electricity, for different end-uses.

Mitigation scenario

1. Economic and demographic profile, prices for LPG and electricity, and energy demand of all sectors except residential and energy supply pattern would stay as in the base-line case,
2. Percentile of households using firewood to cook stayed as in the base-line case, for urban and rural areas, but the traditional stoves would be totally substituted by efficient stoves in the medium term, resulting in an intensity reduction between 10 % and 18 %,
3. Existing trend of strong penetration of LPG in residential sector would remain for the future to substitute gasoline (marginal use in small stoves), kerosene, firewood and even electricity, with an expected efficiency increase between 10 % and 40 %,
4. Complementary use of photovoltaic energy for cooking would be implemented in future from at least 1 % of total households,
5. Increments in using solar energy for water-heating to the level of 25 % in urban households and 14 % in rural households would be expected,
6. Increase in deployment of modern technologies for water-heating, such as heat pumps (2.5 to 5 % in the year 2025), power level control for showers (intensity decreasing between 10 and 20 %), was assumed,

7. Total substitution of efficient for conventional refrigerators would occur in the long term (energy intensity decreasing by around 40 %),
8. It was assumed substitution of efficient for conventional incandescent lamps, achieving, at the end of the period, the following levels: 50 % of electrified households with efficient incandescent lamps, 25 % with conventional incandescent lamps and 25 % with compact fluorescent lamps,
9. Penetration of efficient equipment for air-conditioning (energy intensity decreasing by 15 %) was assumed, and
10. For others end-uses (water-pumping, appliances), energy intensity was expected to decrease by between 10 % to 15 % due to replacement of equipment currently used by efficient devices, since they were already available in the local market.

For the evolution of the energy sector in Mexico for the period 1996-2025, **Islas et al. (2003)** examined three scenarios which were subjected to a cost-benefit analysis. These three scenarios had in common the structure of electrical power plants in the period 1996-2000. Particularly, the three scenarios were: (a) *the base* in which all new capacity supply was accomplished with technologies that used mainly fuel oil, such as, steam turbine technology, (b) *the official* in which all new installed capacity was accomplished using natural gas technologies and giving preference to combined cycles and gas turbines, and (c) *the transition* in which the installed capacity profile between 2000-2007 was adopted from the prospective study of the Energy Ministry, as in the official scenario. For each scenario, the energy demand was obtained by considering the following conditions:

1. Constant economic growth with a GDP average annual increase of 4%,
2. Constant average annual population growth of 1.21%, resulting in 130 million people by the year 2025,
3. Constant end-use demand structure,

4. Energy, and particularly electricity, demand growth of 4% per year, the same as the GDP,
5. Increase in installed power capacity of 5% until the year 2007,
6. After 2007, the annual growth rate of installed capacity would remain constant at 3.4%, and
7. 3% of the new electricity supply would be devoted to satisfy the peak power demand by means of internal combustion engines burning diesel and natural gas.

Besides, for each scenario the following assumptions were made by the authors:

Base scenario

1. Fuel oil consumption increased with an AAGR (average annual growing rate) of 5.8%, and
2. Using fuel oil, the installed capacity of the power sector utilities increased from 14283 to 66849 MW by the year 2025, representing 70% of the total installed capacity.

Official scenario

1. Natural gas had an AAGR of 9.9%, meaning in absolute terms an increase in natural gas consumption from 135 petajoules (PJ) in 1996 to 2110 PJ in 2025, representing 55% of the total electricity consumption, and
2. The installed capacity of combined cycle and gas turbines for power generation increased from 1957 to 56668 MW, representing 62.3% of the total installed capacity.

Transition scenario,

1. For hydroelectricity, solar photovoltaics, municipal solid waste, biomass, wind and fuel cells the AAGR of installed capacity was assumed to be respectively 5%, 26%, 42%, 42$, 39% and 42%,
2. With these hypotheses the renewable energies would grow at an average annual rate of 5.61% and would account for 54% of the installed power capacity by 2025.

Chedid and Ghajarb (2004) examined the impact of the energy sector on the Lebanese economy, and assessed the feasibility of implementing suitable energy efficiency options in the building sector for the period 1994-2040. To estimate the long-term benefits of applying these energy efficiency options, the authors compared between a baseline scenario and two realistic mitigation scenarios. In the baseline scenario, the assumption was that no significant implementation of energy efficiency policies had been achieved. On the other hand, the energy efficiency policy aimed at lifting the barriers hindering the wide scale implementation of the «*guidelines*» on thermal envelope characteristics, and consisted of providing the needed capacity building in order to activate their application. By the term «*guidelines*», the authors meant building specifications which were issued by the Lebanese Standards Organization (LIBNOR) in 1999. These specifications would be used to evaluate the thermal characteristics of building envelopes. For this study, the authors used as building components the following: wall, roof, and window. So, for the two mitigation scenarios, the common assumptions were:

1. For both residential and commercial buildings, the average life span was 75 years,
2. The average building growth rate was 2.5%,
3. The overall energy demand growth rate for heating and cooling was 3%, and
4. The energy reduction on space heating and cooling needs per building unit was 25%.

Besides, the individual assumptions of each mitigation scenario were the following:

Mitigation scenario 1

1. The “guidelines” would remain voluntary throughout the period under study, and
2. The application rate of the ‘‘guidelines’’ would vary from 0% to 70%.

Mitigation scenario 2

1. The ‘‘guidelines’’ would remain voluntary until 2015 only, but they would become a mandatory building standard from that date onward, and
2. The application rate of the ‘‘guidelines’’ would vary from 0% to 100%.

Shin et al. (2005) analyzed the impacts of landfill gas (LFG) electricity generation on the energy market, the cost of generating electricity, and GHGs emissions in Korea using LEAP and the associated “Technology and Environmental database”. Different alternative scenarios were considered:

Business-as-usual (BAU) scenario

This scenario determined the baseline case of electricity generation in Korea. The BAU scenario was composed of the existing accounts of 2000, and future projections for 15 years. The base year data-set was developed from government agencies’ statistics. Also, major socio-economic indicators such as GDP, Population etc. were presented for 2000, 2005, and 2010. The energy demand trends by fuels (Petroleum, Coal, Electricity, City gas, others) were shown from 1970 to 2010.

When the BAU scenario was completed, alternative scenarios made possible for the authors to compare the LFG electricity generation facility with existing process from environmental and economic criterion. *The basic assumptions for LFG electricity generation* were the following:

1. Methane portion of input landfill gas: 50 vol% (heating value: 4044 kcal m^{-3}),
2. Maximum capacity factor: 50–90% (basic value: 80%),
3. LFG useful capability for assessing electricity technology: 70–600Nm^3/min,
4. Merit order of LFG electricity generation facility: first (baseload),
5. Facility life time of gas engine (GE), gas turbine (GT), and steam turbine (ST): 15, 20, and 30 years, respectively,

6. Existing account (2000) and future projections (from 2001 to 2015) of existing electricity facility and energy demand in Korea were determined from the survey database of LEAP Rebublic of Korea 2000,
7. Basic characteristics of each LFG electricity generation system were referred by (a) the Ministry of Commerce, Industry and Energy (MOCIE) Report, 1999, (b) the Ministry of Environment (MOE) Report, 2002, (c) the United States Environmental Protection Agency (U.S. EPA), 1996, and (d) the United States Environmental Protection Agency (U.S. EPA), 1998.

Alternative scenario A

The 6.685MW gas engine was operated in Sudokwon landfill in 2000 and annual operation time of gas engine was 50% (BAU scenario). This scenario was composed of technological potential (Maximum capacity factor, MCF) of 6.685MW gas engine that would be increased from 50% to 90%. The rise of operation hours would result from the technological expansion, like the intensification of know-how and the advent of anticorrosive materials. Alternative scenario formation was the increase of MCF from 50% to 90% for the period of 5, 10, and 15 years. Each alternative scenario is named to gas engine (GE) 5 (increase from 50% to 90% during 5 years), GE 10 (10 years), and GE 15 (15 years).

Alternative scenario B

The potential amount of LFG utilization in Sudokwon landfill would be about 600Nm^3/ min in 2004. Alternative scenario was formed that maximum capacity of each LFG electricity generation facility would be set up in 2004. In the case of maximum capacity installation of electricity generation facilities, energy capacity would be a 0.13% portion of total electricity generation in Korea. If the generated LFG was totally utilized, each electricity generation capacity of gas engine (GE), gas turbine (GT), and steam turbine

(ST) would be about 58, 53.5, and 54.5MW, respectively. The alternative scenario was named to LFG GE 58, GT 53.5, and ST 54.5.

Davoudpour and Ahadi (2006) evaluated the twin impacts of price reform and efficiency programs on energy carriers' consumption and GHGs mitigation in the Iranian housing sector. For assessing the impact of price and applying efficient home appliances on energy demand and GHGs emission, one scenario (base scenario) with two cases (the business-as-usual and management scenarios) was developed. The definition and assumptions of the scenarios and the cases were as follows:

Base scenario

1. The demand for energy carriers was forecasted as a projection of current trends for macroeconomic and demographic data, household income, and retail price of domestic home appliances in future years,
2. The real income (expenditure) of household and the deflated home appliance price index would be constant at 2,350,000 Rial/household and 92.36, respectively, and
3. The number of households would grow by 2.82% annually.

The case of business-as-usual

1. The nominal fuel prices would increase annually with the inflation rate (deflated price was constant),
2. At the same time, consumers' pattern for energy consumption would change only as a result of the development of urban areas, and
3. No change in energy intensity of households was indicated (frozen energy efficiency).

The Case of management

1. The fuel price would increase to border price by the end of the Third Five Year Development Plan (2000–2004),
2. After 2004, the fuel price would increase with the inflation rate,

3. By the end of 2010, half of the existing home appliances would be replaced with new home appliances of 35% more efficiency (Label A of current Euro standards for home appliances), and
4. The remaining market capacity would be saturated by domestically manufactured home appliances that met national standards.

Limmeechokchai and Chaosuangaroen (2006) carried out an assessment of energy saving potential in the Thailand residential sector. The existing energy situation was created first for 2005, and a base line scenario was developed based on historical trends. Additionally, six alternative scenarios were constructed for the efficiency improvement of six main appliances: lighting equipment, electric heating device, electric motor, electric cooling device, electric load, and cooking stove. For each scenario, the following assumptions were made:

Business-as-usual scenario

1. The annual growth rate of number of household was equal to 1.39% ,
2. The growth rate of GDP was set to 5.50%,
3. The penetration levels of each end-use device were assumed to be 100%,
4. The growth rate of energy consumption for each income class (sub-sectors) had been applied following the existing trends from 2000 to 2004, namely,
5. For the low-income class (0-10000 Baht/month) the share in energy consumption would reduce from 60.97% in 2005 to 50.40% in 2011 and to 39.48% in 2016,
6. For the medium-income 1 class (10000-30000 Baht/month) the share in energy consumption would increase from 32.36% in 2005 to 41.26% in 2011 and to 50.56% in 2016,
7. For the medium-income 2 class (30000-70000 Baht/month) the share in energy consumption would increase from 3.16% in 2005 to 3.93% in 2011 and to 4.72% in 2016, and

8. For the high-income class (70000 and over Baht/month) the share in energy consumption would increase from 3.61% in 2005 to 4.41% in 2011 and to 5.25% in 2016.

Efficiency lighting equipment scenario

1. The substitution of higher efficient lighting devises would occur in three periods; period 1 from 2006 to 2011, period 2 from 2012 to 2016, and period 3 from 2017 to 2020,
2. In the case of fluorescent, high efficient lighting devices would replace the conventional light bulbs with constant rate of 10% of the total fluorescent market in period 1, 25% in period 2, and 50% in period 3,
3. In the case of incandescent, compact fluorescent would replace the incandescent light with constant rate of 5% of the total fluorescent market in period 1, 12.5% in period 2, and 25% in period 3, and
4. Since the high efficient lighting equipment had the barrier of high cost, therefore, the assumption of the penetration level of 50% of the market referred to the 50% remain of the conventional lighting equipment, which had lower cost than the efficient one.

For the remaining five scenarios, that is, the *efficient heating device* scenario, the *efficient electric motor* scenario, the *efficient cooling device* scenario, the *efficient electric load* scenario and the *efficient cooking stove* scenario, the common assumptions were the following:

1. Each device had two different efficiency improvements,
2. Efficient device 1 would replace the conventional device with constant rate 60% for both period 1 (2006-2011) and period 2 (2012-2016), and
3. Efficient device 2 would replace the conventional device with constant rates 0% in period 1 and 40% in period 2.

Additionally

For the *efficient heating device* scenario

- The efficient 1 and efficient 2 devices would give respectively 10% and 15% efficiency improvement from the conventional device,

For the *efficient electric motor* scenario,

- The efficient 1 and efficient 2 devices would give respectively 3% and 5% efficiency improvement from the conventional device,

For the *efficient cooling device* scenario,

- The efficient 1 and efficient 2 devices would give respectively 15% and 20% efficiency improvement from the conventional device,

For the *efficient electric load* scenario

- The efficient 1 and efficient 2 devices would give respectively 10% and 15% efficiency improvement from the conventional device, and

For the *efficient cooking stove* scenario

1. Only charcoal, LPG and wood stove were considered since they had the largest share of non-electricity consumption in the households, and
2. For each case, the efficient 1 and efficient 2 devices would give respectively 5% and 10% efficiency improvement from the conventional device.

Bressand et al. (2007) evaluated the impact of a variety of scenarios of GDP growth, energy elasticity and energy efficiency improvement on energy consumption in commercial buildings in China using a detailed China End-use Energy Model. *A baseline scenario (called as the Ordinary Effort scenario)* that incorporated targets stated in China's official plans and business-as-usual technology improvement was developed first, and a contrasting *green growth scenario* was created to examine the impact of stricter policies. Upon these two scenarios, *different GDP growth and elasticity scenarios* had been created to evaluate the impact of a variety of scenarios in GDP growth, energy elasticity and energy efficiency improvement on energy consumption in commercial buildings.

Ordinary Effort (OE) scenario

This scenario incorporated the collective scope of technology choices, efficiency improvements, policy targets, fuel switching, equipment ownership and other elements of the development plan that China had proposed to shape its energy growth path to 2020. For this scenario the assumption was that China's GDP would grow at a 7.9 % CAGR (Compound Annual Growth Rate) through 2010 over its 2005 base and 6.6 % CAGR from 2010 to 2020.

GDP growth and elasticity scenarios

These scenarios assumed GDP variations versus the OE scenario of ±2 percent growth annually, and elasticity between GDP and floor area growth would remain at 0.75 after 2010, instead of decreasing to 0.58.

Green growth scenario

This scenario incorporated additional energy efficiency improvements which leaded China to capture its full efficiency potential. The analysis encompassed measures such as increasing the share of efficient technologies and efficiency improvement. This required policy changes that would encourage the shift to less energy intensive products. China had developed an extensive set of building energy codes and minimum efficiency standards for appliances. However, government agencies needed to significantly increase the resources for enforcement actions in order to realize the full impact of the building cods and appliance standards.

To assess the CO_2 emissions reduction potential of China's electricity sector, **Cai et al. (2007)** employed three scenarios based on the LEAP model to simulate the different development paths in this sector. The baseline scenario (scenario 1), the current policy scenario (scenario 2), and the new policy scenario (scenario 3) sought to gradually increase the extent of industrial restructuring and technical advancement. Particularly, Scenario 1 changed the technical composition only according to policies before 2000 and the natural technical improvement. Scenario 2 differed in the technical composition because it referred to existing policies (especially several explicit targets to reach implied targets in these policies such as the percentage of nuclear power in the total electricity generation in a certain year). Technical composition in scenario 3 was based on scenario 2 and the study on the advanced climate friendly technologies. The last scenario also allowed for the larger penetration of these technologies. In all scenarios, there were the following *general assumptions*:

1. Coal remained to act as the primary energy source for electricity generation in China,
2. High-efficiency large-scale plants and those that employed clean and renewable energies would account for a greater share of the generation output under the more aggressive scenarios,
3. The exchange rate of the US dollar to the Chinese RMB was 1 USD to 8.2784 RMB,
4. The discount rate was defined to be 10%.

On the other hand, the different assumptions of each scenario were the following:

Baseline scenario

1. The main options were focused on demand-side management (improving energy efficiency of end-users; SO_2 and NO_x control; reforms in old coal-fired plants), and
2. Generation ratio by renewable energy would grow slowly.

Current policy scenario

1. The technology level was higher than in scenario 1,
2. Advanced generation technologies had been widely introduced, such as Pressurized fluidized bed combustion (PFBC) and integrated gasification-combined cycle (IGCC) systems,

3. The massive Three Gorges Dam would go into service from 2009 and the installed capacity would reach 18.2MW,
4. Nuclear installed capacity would reach 40MW (about 4% of the national installed capacity), and
5. The Renewable Energy Law published in 2005 would give renewable energy power plants effective financial and technical support.

New policy scenario

1. All plants less than 50kW had to be closed before 2003,
2. All plants less than 100kW had to be gradually phased out of the market,
3. Supercritical turbine generators would be used in projects from 2015,
4. Carbon capture and storage (CCS) would start service in 2020, and could mitigate 60 million tons of CO_2 nation-wide until 2030,
5. Other advanced coal-fired technologies would be used to a larger extent than in scenario2, and
6. Clean energy power plants such as hydro, nuclear, wind, and solar would have a bigger generation ratio.

Kadian et al. (2007) applied the LEAP system for modeling the total energy consumption and associated emissions from the household sector of Delhi. Energy consumption under different sets of policy and technology options were analyzed for a time span of 2001–2021 and emissions of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x), nitrous oxide (N_2O), total suspended particulates (TSP) and sulfur dioxide (SO_2) were estimated. Different scenarios were generated to examine the level of pollution reduction achievable by application of various options. The business as usual (BAU) scenario was developed considering the time series trends of energy use in Delhi households. The fuel substitution

(FS) scenario analyzed policies having potential to impact fuel switching and their implications towards reducing emissions. The energy conservation (EC) scenario focused on efficiency improvement technologies and policies for energy-intensity reduction. An integrated (INT) scenario was also generated to assess the cumulative impact of the two alternate scenarios on energy consumption and direct emissions from household sectors of Delhi. The policy options and assumptions for generating each scenario are the following:

Business as usual scenario

1. The historical trends would continue,
2. The percentage of rural households in Delhi would be negligible by 2011, and
3. The complete population of Delhi would be urban by 2021.

Fuel substitution scenario

1. The concept of energy ladder would be followed for fuel substitution,
2. The percentage of households using kerosene would reduce due to rising prices,
3. The share of LPG would rise,
4. Natural gas would be supplied through pipeline in Delhi, with competitive prices than LPG,
5. Due to the convenience of using natural gas, it would have a major share in cooking and water heating,
6. Rural population would use biogas for cooking,
7. Solar would have a share in cooking, water heating and lighting, and
8. Electricity would be considered as a clean and viable option for cooking.

Energy conservation scenario

1. Due to programs such as energy labeling, more efficient appliances would be available in the market,

2. The more energy intensive appliances would be replaced by the more efficient and less energy intensive,
3. Less energy-intensive refrigerators, air coolers, air conditioners and washing machines would be utilized, and
4. Cost effective efficient compact fluorescent lamps would have a significant share.

Integrated Scenario

In this scenario, all the measures taken in fuel substitution and energy conservation scenario were taken together.

Mulugetta et al. (2007) constructed power sector scenarios for Thailand to represent the range of opportunities and constraints associated with divergent set of technical and policy options. The authors included Business-As-Usual (BAU), No-New-Coal (NNC), and Green Futures (GF) scenarios over a 20-year period (2002–2022). The aim of the BAU scenario was to show the future through the prism of existing policies and strategies, and delineate the relationship of the power sector with political, economic and the environmental institutions. Furthermore, this scenario would make possible the authors to evaluate if the target was indeed achievable under the current policies or if some modifications should be necessary. The NNC scenario was inspired by a cleaner technology in order Thailand to meet its environmental obligations and to avoid expensive payoffs to contractors due to intractable community resistance. Finally, the GF scenario was a fairly aggressive promotion and implementation of renewable energy technologies in the overall energy mix. This scenario explored how the country could diversify its energy source in the light of the uncertain international energy market and for the benefit of greater energy independence. For the three scenarios, *the common assumptions* concerned the demand size and were the following:

1. The growth of electricity demand in residential, industrial, and commercial sectors would follow the Load Forecast Report 2002,

2. The growth of demand was divided into three periods which were the 9th plan during 2002-2006, the 10th plan during 2007-2011, and the 11th plan during 2012-2016,
3. The share of urban population would grow to 33% by 2022 (annual growth 2.84%),
4. For urban households, the final energy intensity (annual) would increase to 4.5% in 2006, and would decrease to 3.6% in 2011,
5. For rural households, the final energy intensity (annual) would increase to 7.2% in 2006 and to 7.6% in 2011, while it would decrease to 7% in 2016, and
6. For the Industry and Commerce sectors, the final energy intensity (annual) would decrease to 6.28% in 2007, and to 5.88% in 2012.

The different assumptions of the three scenarios concerned the supply side. These assumptions were the following:

Business-As-Usual scenario

1. System load factor (SLF) equal to 74%,
2. Decommission 75MW gas-fired in 2011,
3. Decommission 400MW oil-fired power plant in 2015,
4. New coal-fired power plants in 2007, 2008,
5. New gas-fired power plants (2003, 2008, 2009, 2010),
6. Improve efficiency of existing hydropower to gain 124.7 MW,
7. Increase capacity of Small Power Producers,
8. New mini hydro 350MW, and
9. Renewable energy share of total to rise to 5% by 2011 and 8% by 2022.

No-New-Coal scenario

1. System load factor (SLF) equal to 74%,
2. No new coal-fired power plant to build,
3. Decommission 2625MW coal-fired plant in 2010,

4. Decommission 75MW gas-fired plant in 2011,
5. Decommission 400MW oil-fired power plant in 2015,
6. Add new gas fired power plants (2003, 2008, 2009, 2010),
7. Improve efficiency of current hydropower to gain 124.7 MW,
8. Increase capacity of Small Power Producers,
9. New mini hydro 350MW,
10. Add new renewable, and
11. Renewable energy sources provide 15% of total capacity.

Green Futures scenario

1. System load factor (SLF) equal to 76%,
2. Decommission 2625MW coal-fired plant in 2010,
3. Decommission 75MW gas-fired plant in 2011,
4. Decommission 1330MW oil-fired power plant in 2015,
5. Improve efficiency of existing hydropower to gain 124.7MW,
6. Increase capacity of Small Power Producers,
7. Reduction of natural gas and coal share from 95% to 30%,
8. New mini hydro 350MW,
9. Renewable energy sources provide 35% of total capacity,
10. Implementation of biomass, Solar (PV), Wind and Hydro.

Zhang et al. (2007) estimated external costs of electricity generation in China under different scenarios of long-term energy and environmental policies. The LEAP software was used to develop a simple model of electricity demand and to estimate gross electricity generation in China up to 2030 under three energy scenarios and two abatement scenarios.

(A) Energy scenarios

Business-as-usual (BAU) scenario

1. Industry electricity demand would increase with the growth of GDP,
2. Electricity elasticity coefficient was assumed to be 0.8,
3. The household electricity would increase with the growth of population and electricity demand per person,
4. The difference between end use of electricity and gross electricity production (including the electricity used by power plants) was assumed to be 15% of the gross electricity production,
5. Efficiency of electricity generation was assumed to remain at the level of 2003,
6. The proportion of all kinds of electricity generation was assumed to remain consistent over the time horizon,
7. Electricity generation in different primary energy (Coal, Diesel, Natural Gas, Nuclear, Hydro, etc.) displayed increasing trends, and
8. The electricity generation would reach 10,668.1 billion kWh in 2030, with annual growth rate of 6.59%.

Coal replacement (COR) scenario

1. More non-fossil fuels, such as renewable and nuclear energy, would be used in power generation,
2. Fossil fuels would not have significant increase in their shares in power generation under gross energy output of BAU,
3. Gross electricity generation from coal would be 5902.3 billion kWh by 2030, 26.2% lower than that in BAU,
4. Electricity output in different primary energy (Coal, Diesel, Natural Gas, Nuclear, Hydro, etc.) displayed increasing trends, and

5. Efficiency of electricity generation would still remain at the level of 2003.

Advance technologies adopted (ATA) scenario

1. Advance technologies such as efficiency of electricity generation and end use efficiency would be adopted,
2. Several options were available to increase the efficiencies of power plants by using advance combustion techniques,
3. Efficiency of electricity generation would increase from 38% in 2003 to 50% in 2030,
4. Improvement of the end use efficiency could also lead to the reduction of electricity demand,
5. Reducing the losses of electricity during transmission and distribution (T&D) could decrease about 5% electricity generation,
6. Electricity output in different primary energy (Coal, Diesel, Natural Gas, Nuclear, Hydro, etc.) displayed increasing trends, and
7. Coal-fired electricity output would grow slower in this scenario and would be 4222.7 billion kWh in 2030, with 47.2% lower than that of BAU.

(B) Abatement scenarios

Current abatement policy (CAP) scenario

1. SO_2 emission from coal fired electricity generation would be required to be cut off at 15% of that in 2005 annually during the years of 2005 to 2010,
2. SO_2 emission from fired power plants would be required not to be higher than 10 Mt from 2011 to 2030, and
3. Coal-based power plants with new investment of de-SO_2 equipment would subsidize 0.015 RMB (Chinese currency)/kWh (equal to 0.001875US$/kWh) according to the policy of National Development and Reform Commission of China (NDRC).

Further abatement policy (FAP) scenario

1. Some coal-fired power plants would begin to implement the plan of clean electricity to reduce the emission of CO_2 from 2010,
2. 30% of CO_2 would be abated up to 2030 in coal-fired power plants by the technology of CO_2 capture,
3. Many fired power plants would decide to control the emission of NO_x from 2010, and
4. 50% of NO_x from coal-fired power plants with the technologies of NO_x control would be cut off from 2010 to 2030.

Lee et al. (2008) estimated the future mitigation potential and costs of CO_2 reduction technology options to the electricity generation facility in Korea. The monoethanolamine (MEA) absorption, membrane separation, pressure swing adsorption, and O_2/CO_2 input system were selected as the representative CO_2 reduction technology options. In order to analyze the mitigation potential and cost of these options, the authors used the LEAP framework for setting future scenarios and assessing the technology options implication. The baseline case of energy planning scenario in Korea was determined in a business-as-usual (BAU) scenario. A BAU scenario was composed of the existing account (2003) and future projections for 20 years. Additionally, four alternative scenarios were developed which were based on the installation plan of new power plants and CO_2 capture facilities. The *general information for scenario analysis* was the following:

1. Maximum capacity factor for coal and oil utilization was 95.1%,
2. Maximum capacity factor for combined cycle utilization was 93.5%,
3. The time range of estimated system was from 2000 till 2020,
4. The discount rate was 5%,
5. The facility life time was 30 years,

6. Current account-based 2003 year and future projections (to 2020) of existing electricity facilities and energy demand in Korea were determined from the survey database of LEAP, Republic of Korea (ROK) 2003.

Business-as-usual scenario

For the period 2002-2020, the average growth rate was:

1. 4.5% for GDP,
2. 2.8% for primary energy (in million ton of oil equivalent),
3. 2.4% for per capita energy use (in tons of oil equivalent per person), and
4. 2.5% for the total final energy (in million ton of oil equivalent)

Alternative scenario I – Coal steam utilization

For CO_2 capture, the capacity (400 MW) of the new electricity generation facility based on coal steam would be installed after 2006.

Alternative scenario II – Oil steam utilization

For CO_2 capture, the capacity (400 MW) of the new electricity generation facility based on oil steam would be installed after 2006.

Alternative scenario III – Combined cycle utilization

For CO_2 capture, the capacity (400 MW) of the new electricity generation facility based on combined cycle would be installed after 2006.

Alternative scenario IV – Integration of all scenario installation

For CO_2 capture, the capacity (400 MW) of the new electricity generation facility based on coal steam, oil utilization and combined cycle would be installed after 2006.

Finally, for each scenario the projections of the share of electricity generation from different processes are given in the following table 3.1:

Table 3.1: The projections of the share of electricity generation

Processes for alternative scenario 1	2006	2009	2012	2015	2018
Coal steam	37.1%	34.2%	29.7%	24.2%	24.2%
Coal steam with CO_2 capture	1.5%	8.0%	11.2%	13.0%	12.9%

Combined cycle	12.0%	7.9%	8.3%	10.7%	10.8%
Hydro	2.1%	2.1%	2.1%	2.1%	2.1%
Internal combustion	0.4%	0.4%	0.2%	0.2%	0.2%
LNG steam	0.6%	0.6%	0.6%	0.6%	0.6%
Nuclear	40.3%	42.1%	44.3%	46.6%	46.6%
Oil steam	6.4%	4.7%	3.5%	2.5%	2.5%
Processes for alternative scenario 2	**2006**	**2009**	**2012**	**2015**	**2018**
Coal steam	38.6%	42.2%	40.9%	37.2	37.2
Combined cycle	11.9%	7.9%	8.3	10.7	10.8
Hydro	2.1%	2.1%	2.1	2.1	2.1
Internal combustion	0.4%	0.4%	0.2	0.2	0.2
LNG steam	0.6%	0.6%	0.6	0.6	0.6
Nuclear	40.1%	42.0%	44.3	46.6	46.6
Oil steam	6.3%	4.6%	3.4	2.4	2.4
Oil steam with CO_2 capture	0.03%	0.1%	0.2	0.2	0.2
Processes for alternative scenario 3	**2006**	**2009**	**2012**	**2015**	**2018**
Coal steam	38.6	42.2	40.9	37.2	37.2
Combined cycle	11.7	7.2	7.0	8.8	8.8
Combined cycle with CO_2 capture	0.2	0.7	1.3	1.9	2.0
Hydro	2.1	2.1	2.1	2.1	2.1
Internal combustion	0.4	0.4	0.2	0.2	0.2
LNG steam	0.6	0.6	0.6	0.6	0.6
Nuclear	40.1	42.0	44.3	46.6	46.6
Oil steam	6.4	4.7	3.5	2.5	2.5
Processes for alternative scenario 4	**2006**	**2009**	**2012**	**2015**	**2018**
Coal steam	37.1	34.2	29.7	24.2	24.2
Coal steam with CO_2 capture	1.5	8.0	11.2	13.0	12.9
Combined cycle	11.7	7.2	7.0	8.8	8.8
Combined cycle with CO_2 capture	0.2	0.7	1.3	1.9	2.0
Hydro	2.1	2.1	2.1	2.1	2.1
Internal combustion	0.4	0.4	0.2	0.2	0.2
LNG steam	0.6	0.6	0.6	0.6	0.6
Nuclear	40.3	42.1	44.3	46.6	46.6
Oil steam	6.3	4.6	3.4	2.4	2.4
Oil steam with CO_2 capture	0.03	0.1	0.2	0.2	0.2

Papagiannis et al. (2008) presented the results of an analysis on the economic and environmental impacts of the application of an intelligent demand side management system, called the Energy Consumption Management System (ECMS), in the European countries. Several operational strategies combining variable market penetration of the ECMS and expected energy savings were examined. At first, the authors created the *reference scenario* for which the following were necessary:

(a) Prediction for the development of the simulated system till the end year of the simulation

In this prediction it was assumed that no energy efficiency improvement action would take place. The scope of this simulation was the calculation of the baseline values of all system parameters in the analysis time period.

(b) Prediction of the electric energy demand growth rate for each country and for the EU

This prediction was based on the historical data concerning electricity demand growth between 1988 and 2004 and on national communications reported in UNFCCC. Results were given in 5-year intervals; 2000-2005, 2005-2010, 2010-2015, 2015-2020, 2020-2025.

(c) Power generation planning for the analysis period

These data included the number, type, and installed capacity of new power stations planned to operate till the end year of the simulation as well as any operating power station planned to seize in the same period.

In the next step, the authors built the proper energy efficiency improvement scenarios. The following considerations were used to reproduce the expected ECMS market penetration:

1. The ECMS system was expected to enter the market first in the year 2007,
2. The penetration of the ECMS system was assumed to grow exponentially till the end of year 2010 when an upper limit was reached,
3. Then penetration would remain stable at this upper limit till the end of year 2025.

Following the upper limits for the ECMS, penetration was considered for the different sectors and the various scenarios, according to the expected market penetration:

(a) Low-penetration scenario: 4% for the industry, 10% for the residential sector, 15% for services and 20% for street lighting.

(b) Medium-penetration scenario: 8% for the industry, 15% for the residential sector, 20% for services and 35% for street lighting.

(c) High-penetration scenario: 12% for the industry, 25% for the residential sector, 30% for services and 50% for street lighting.

For each of the above penetration rates per sector, average electric energy savings of 5%, 10% and 20% were estimated. The Agriculture and Transport sectors were omitted from the analysis, since no ECMS penetration was expected in these sectors.

Zhou and Lin (2008) evaluated the impact of a variety of scenarios of GDP growth, energy elasticity, and energy-efficiency improvement on energy consumption in commercial buildings in China using a detailed China End-Use energy model. A baseline scenario (named as the ordinary effort scenario) incorporating targets stated in China's official plans and business-as-usual technology improvement was developed first, and a contrasting Green Growth scenario was created to examine the impact of stricter policies. The assumptions of these two scenarios were the following:

Ordinary effort scenario

1. China's GDP would grow at a 7.9% Compound Annual Growth Rate through 2010 over its 2005 base,
2. China's GDP would grow at a 6.6% Compound Annual Growth from 2010 to 2020,
3. The elasticity of commercial floor area to GDP was set to 0.75 for 2010 to match official 2010 floor space targets, and 0.58 for years after 2010 (implying that the commercial floor area would grow from 8.0 billion m^2 in 2000 to 14.7 billion m^2 in 2010, and 21.2 billion m^2 in 2020),
4. Penetration rate of building energy end-uses would reach 55% for most building types by 2020 based on qualitative objectives stated in research by China's Energy Research Institute,
5. Energy intensity would grow rapidly, for example, with brighter lighting of retail space or thermostats set at lower temperatures in the summer,
6. The use of office equipment would also grow significantly, resulting in higher energy use per floor area in office buildings, and

7. Energy efficiency was modeled as the combination of the efficiency and market shares of different types of technologies.

Green Growth (GG) scenario

1. This scenario incorporated additional energy-efficiency improvements which would lead China to capture greater energy savings potential,
2. The growth of floor space was assumed to be the same as in the official effort scenario,
3. The trends in delivered useful energy (energy intensity) were assumed to be identical as in the official effort scenario,
4. For each technology, the GG scenario described the impact, for example, of a more stringent equipment standards program that accelerates the improvement in efficiency,
5. The technology mix would change either through stricter building codes or through incentive programs, and
6. The GG scenario looked the impact of more rapid adoption of more efficient technology choices such as increasing the penetration of geothermal heat pumps.

For these two scenarios, different GDP growth and elasticity scenarios had been created to evaluate the impact of a variety of scenarios in GDP growth, energy elasticity and energy-efficiency improvement on energy consumption in commercial buildings. GDP scenarios assumed variations from the Ordinary Effort Scenario of ±2% annual growth rate. Also the elasticity between GDP and floor area growth remained at 0.75 after 2010, instead of decreasing to 0.58.

Using the LEAP model from 2006 to 2025, **Wijaya and Limmeechokchai (2009)** examined utilization of geothermal energy scenarios for future electricity supply expansion in Java-Madura-Bali (Jamali) system which was the largest electricity consumer in Indonesia. The assumptions for the ***business-as-usual (BAU) scenario*** were the following:

1. Taking 2006 as the base year, the population growth rate was set to 1% per year and the expected electrification ratio was set to 93% in 2026,
2. For the household sector, the growth rate/year of the electricity demand was 8.9% for the period 2006-2010, 8.2% for 2011-2015, 7.1% for 2016-2020, and 6.2% for 2021-2025,
3. For the commercial sector, the growth rate/year of the electricity demand was 9.6% for the period 2006-2010, 8.5% for 2011-2015, 7.8% for 2016-2020, and 7.2% for 2021-2025,
4. For the public sector, the growth rate/year of the electricity demand was 10.7% for the period 2006-2010, 11.1% for 2011-2015, 10.7% for 2016-2020, and 10.7% for 2021-2025,
5. For the industry sector, the growth rate/year of the electricity demand was 4% for the period 2006-2010, 3.5% for 2011-2015, 3.6% for 2016-2020, and 3.8% for 2021-2025,
6. Due to lack of data, the total installed capacity was set to 19531 MW,
7. Merit order 1 was assigned to Steam, Geothermal, and Combined Cycle power plants, merit order 2 was assigned to Hydro and Gas Turbine power plants, and merit order 3 was assigned to Diesel power plants (Merit order 1 indicated power plant for the base load, merit order 2 indicated power plant for the middle load, and merit order 3 indicated power plant for the peak load),
8. Expected losses in transmission and distribution were 15% for the period 2006-2010, 14% for 2011-2015, 13% for 2016-2020, and 12% for 2021-2025,
9. The supply planning was based on required reserve margin, for which the projection was 35% until 2019 and 30% from 2020 onwards, with the discount rate to be 10%,

10. The next committed power plant after 2010/2011 was only nuclear power plant, which would feed into Jamali system in 2016, 2017, 2023 and 2024 by each additional capacity of 1000 MW,
11. Since there was no more data for committed power plant, the other additional power plant (from steam, combine cycle and gas turbine power plants) would be calculated as the input in endogenous capacity variable, and
12. The power plant operation would follow the government's intention in order to promote coal resources use optimally.

Additionally to the BAU scenario, three scenarios of geothermal energy utilization were in consideration: 50 MW of geothermal power plant was added in the first geothermal (1G) scenario, 100 MW of geothermal power plant was added in the second geothermal (2G) scenario, and for the last geothermal (3G) scenario, 124 MW was added in the endogenous capacity. Finally, to maintain planning reserve margin, the other power plant types were included as the additional capacity beside of geothermal power plant in each scenario, namely, Combine cycle, Gas turbine, and Steam power plants.

Foran et al. (2010) explored options for efficiency improvements in Thailand's residential sector by constructing a baseline and an efficient scenario for each one of the following five devices: (a) Refrigerators, (b) Air-conditioners, (c) Fans, (d) Rice Cookers, and (e) compact fluorescent light bulbs. The baseline scenarios were a forward projection of previously achieved trends in energy efficiency, taking into account any announced policy decisions on future efficiency. The efficiency scenarios were defined as systematically greater improvements in energy efficiency than baseline. The authors attempted to determine trends in energy efficiency by referring to data from the Electricity Generating Authority of Thailand's (EGAT) appliance labeling programs. If a trend was evident, then the baseline and efficiency scenarios would be explicitly based on those trends, with other major assumptions clearly specified. If no clear trend was evident, then future scenarios would be based on the assumption of 0.5–1.0% improvements in Unit Energy Consumption (UEC). To aid scenario building, the range of energy efficiency levels among end-user devices in the EGAT labeling program was also examined. The most recent labeling data supplied by EGAT was 2005. The time horizon for the scenarios was from 2006 till 2026. For each device, the assumptions for the baseline scenario and the efficient scenario were the following:

(a) Refrigerators

Baseline scenario

1. The weighted average of UEC (unit energy consumption) of a new refrigerator would increase over time, reflecting the observed trend toward larger capacity,
2. The new unit of UEC would increase by 1% per year from 2006 to 2020 (less than half of 2.55% observed for the period 1995–2005),
3. From 1995 to 2005, the entry of new models at lower UEC caused the total stock of UEC to decline,
4. However, from 2007 to 2020, once the weighted average of UEC of a new unit exceeded the weighted average of UEC of the total stock, the latter would begin to rise.

Efficient scenario

1. A regime of periodically tightened minimum and voluntary standards would result in the weighted average UEC of new units to decline 6.5% every 5 years between 2006 and 2026, with no increase during intervening or subsequent years, and
2. The figure of 6.5% would be equal to the rate of change in the new unit of UEC observed during 2000–2001.

(b) Air-conditioners

Baseline scenario

1. Between 2006 and 2026, the energy efficiency ratio (EER) of new compliant (labeled) units was fixed at 3.26 (the number 5 year 2006 standard),
2. The EER of noncompliant (unlabeled, unregulated) units was fixed at 2.43, and
3. The current estimated one-to-one ratio between new compliant and noncompliant sales would continue to 2020.

Efficient scenario

1. For new compliant units, the weighted average EER would increase as the minimum energy performance measures (MEPS) and the number 5 standard was periodically tightened over time,
2. If this efficient scenario was carried out consistently to 2020, increases MEPS would increase by 25% between 2005 and 2020,
3. For new noncompliant units, an average EER of 2.43 would hold, and
4. Within 6 years of program implementation, all appliances entering the market were MEPS compliant.

(c) Fans

Baseline scenario

1. It was assumed a −0.5% per year change in new device UEC to 2026, consistent with trends observed between 2001 and 2005.

Efficient scenario

1. After 6 years of program implementation, it was possible to shift the weighted average of UEC to the highest observed efficiency levels on the Thai market in year 2005,
2. The necessary rate of UEC improvement was 2.26% per year for 6 years,

3. This rate of improvement would hold for the entire period 2006–2020 (i.e., 36% decline in UEC over 20 years), and
4. Implementing this efficient scenario would result in 8% savings (195 GWh/year) after 10 years and 17% savings (555 GWh/year) after 20 years.

(d) Rice cookers

Baseline scenario

1. It was assumed a −0.5% per year change in UEC to 2026

Efficient scenario

1. This scenario assumed that a −1.0% per year in UEC could be achieved, and
2. Implementing this efficient scenario would result in 2% (92 GWh/year) energy savings after 10 years and 8% (347 GWh/year) energy savings after 20 years

(e) Compact fluorescent lighting (CFL)

Baseline scenario

1. With rising incomes, the CFL share of light bulbs would increase from 45% to 60% between 2006 and 2020, and
2. For unit energy consumption (UEC), it was assumed a −0.5% per year change between 2006 and 2026.

Efficient scenario

1. With more aggressive marketing (e.g., promotion of energy savings using internet along lines similar to the US Energy Star program), the CFL share in 2020 would reach 75%,
2. It was possible in 6 years to shift the UEC of CFL bulbs in the 13–20-W range to the second highest observed efficiency level on the Thai market in year 2005 (79 lm/W),
3. The necessary rate of UEC improvement was 1.9% per year for 6 years,
4. Thereafter, the UEC would decline 1% per year between 2013 and 2026, and

5. Implementing this efficient scenario would result in 4% (10 GWh/year) energy savings after 10 years and 20% (88 GWh/year) energy savings after 20 years.

Mustonen (2010) investigated household energy demand patterns and the development of electricity demand in a rural village in Lao People's Democratic Republic. Based on the situation preceding electrification of the village, the development of village electrification was studied by simulating the village energy system, accounting for all village energy uses but transportation. To study the potential development of electricity demand in the village, three scenarios were constructed using the LEAP model: ''*residential demand (RES)*'', ''*income generation (INC)*'' and ''*public services (PBL)*''. The RES scenario was based on household electrification, depicting a typical situation in newly electrified rural communities in developing countries. The INC scenario modeled various electrically powered income generating activities that would create daytime demand in the village power system, helping to improve system performance and financial viability as well as to augment villagers' incomes. The PBL scenario was based on the assumption that public services were emphasized and financially supported in accordance with the modern understanding of productive uses of energy. For the three scenarios, the time span was from 2006 till 2030, and their *common assumptions* were the following:

1. The population baseline was 92 households and 6 persons per household,
2. Annual population growth of 0.3% had been assigned for the village to represent a situation where the birth rate and migration into the village narrowly exceeded the number of deaths and migration into urban centers,
3. Population per household was constant during the time span, while the number of households was increasing,
4. Residential energy consumption was driven by the number of households,

5. The thermal efficiency of open fire was 5%,
6. As household energy efficiency improvement was modeled in terms of thermal efficiency of firewood combustion, the improved technology was a wood stove with 15% thermal efficiency (Other cooking fuels or amount of firewood used for other residential needs had not been considered in the three scenarios),
7. The rated power of all appliances combined was 74W per household in 2007 and would increase over the years,
8. During 2007, the first year of supply, 59 households had been connected giving household electrification rate of 64%,
9. All households used electricity for lighting and gradually would acquire other appliances such as fans, televisions, and radios,
10. Electricity generation was modeled according to the generation units of the new hybrid power system,
11. As a private sector developer owned and operated in the village the generation units during the time span, energy sources or technologies other than those already existing in the system were not considered in the scenarios,
12. The generation capacity consisting of micro-hydro power, diesel generator and solar PV panels was the same for all scenarios, and
13. Availability of all energy sources was unconstrained.

Apart from the aforementioned common assumptions, the authors also made for each scenario the following different assumptions:

Residential Demand scenario

1. Electricity demand in the village would grow slowly simulating how electricity demand typically would take two to three years to mature as people wired their houses, purchased appliances and switched from other fuels to electricity,

2. There were no electrified public services, and
3. The only electrified income generating activities were two general stores that would adopt electric lighting in 2009 and gradually would acquire refrigerators.

Income Generation scenario

1. A broad range of parallel supporting development activities was assumed in order to induce initiative and capacity to start up manufacturing and service activities,
2. Households with rising incomes were consuming more electricity compared to the situation of the Residential Demand scenario,
3. Machinery for agricultural production included rice mills and water pumps for the rice fields,
4. Other manufacturing and production activities included wood processing and ice making,
5. For service sector activities, this scenario assumed a restaurant, tailor and barbershops, in addition to two general stores and repair shops for motorcycles,
6. The businesses in the service sector required electricity mostly for lighting only, and
7. There were no electrified public services.

Public Services scenario

1. The development of public sector services was introduced,
2. Local organizations would establish a village electricity fund that would use the collected funds to develop public services in the village, as well as to maintain the distribution network,
3. The new public services would include electric lighting for the village office building in 2009 and the village school in 2010,
4. Street lighting would be introduced in 2010 and would expand incrementally,

5. A health center would set up in the village in 2015, equipped with electric lighting and a vaccine refrigerator,
6. Low-income households that had not been electrified after the first 10 years would receive subsidized electrification beginning from 2018, and
7. The fund also would subsidize energy efficient stoves, encouraging all households to acquire one.

Phdungsilp (2010) presented a study on the options for energy and carbon development for the city of Bangkok. The LEAP model was used to simulate a range of policy interventions and to predict how these would change energy and carbon development from 2000 to 2025. The planning period was assumed to start in 2005, and 2000 was used as the baseline year. This study focused on three key implications: energy savings, local air pollutants, and avoided CO_2 emissions.

Business-as-usual (BAU) scenario

The BAU scenario represented a base case without policy interventions, as it was a projection of what might occur in the absence of specific energy policies and strategies. This scenario was constructed based on existing trends of the parameters in specific sectors, and it was based on existing policy trends. Particularly, the following assumptions were made:

1. In the commercial sector, energy demand would grow in accordance with the number of buildings,
2. The industrial sector would grow in accordance with Gross Provincial Product of the manufacturing sector,
3. The government sector would be constant during the study period,
4. The residential sector would grow in accordance with the number of households in each area,

5. The present efficiency of any appliances and technologies, and the pattern of energy utilization for different appliances and technologies would remain unchanged in the future, and
6. The transport sector would grow in accordance with the estimated travel demand.

Individual energy policies that were created for each sector under consideration were then combined to produce alternative scenarios aiming to illustrate the effect of policy interventions on energy utilization and carbon emissions. The following energy policies (EP) were stated by the author:

EP1 – Residential Sector: Promoting high efficiency appliances

Conventional refrigerators, air-conditionings, and fans are replaced by high efficiency ones by 2025.

EP2 – Residential Sector: Passive design and daylighting application

New households in outer Bangkok Metropolitan area will be built on passive design and improve lighting by daylighting application, consequently reduced cooling load (10%) and energy consumption for lighting (10%), starting 2005.

EP3 – Commercial Building Sector: Efficient HVAC system

Improve efficiency of HVAC 10% by 2005 in every building type.

EP4 – Commercial Building Sector: Utilization of daylighting in lighting system

Utilization of daylighting can improve the lighting systems. Assume 5% savings in lighting by 2005 and increases to 10% in 2010, and 15% in 2020.

EP5 – Commercial Building Sector: Behavioral change in HVAC and lighting systems

Saving of 10% in HVAC systems by 2025, and 10% savings in lighting systems by 2025, driven by changes in user behavior.

EP6 – Industry Sector: Energy efficiency

Increasing industrial energy efficiency targeted at 10% by 2010. The improvements are from lighting, compressed air, motors as well as improved boiler and steam system efficiency.

EP7 – Industry Sector: Switching to natural gas

The Thai government has the policy to promote the use of natural gas (NG), which is a domestic resource, as the country's major source of energy. Thermal energy supplied by non-renewable resources, liquefied petroleum gas, and electricity in industries switches fuels to natural gas by 2010.

EP8 – Transport Sector: Introducing NGV to gasoline and diesel vehicles

Introduce NGV to gasoline and diesel vehicles including passenger car, microbus and passenger pickup, van and pickup, fixed routed taxi, fixed route bus, bus for hire, private bus, non-fixed route truck, private truck, and other. Penetration rates are about 5% by 2005, rising to 10% in 2010 and 20% in 2025.

EP9 – Transport Sector: Switching to gasohol in gasoline vehicles

Thai government has a policy to switch all gasoline vehicles to gasohol (gasoline+ethanol) starting in 2007. This measure will be applied to passenger car, microbus and passenger pickup, van and pickup, motortricycle, urban taxi, fixed routed taxi, motortricycle taxi, and motorcycle.

EP10 – Transport Sector: Introducing biodiesel in diesel vehicles

Biodiesel grows to a market share of 20% by 2025. This measure will be applied to all diesel vehicles.

EP11 – Transport Sector: Modal shift from private passenger to mass transit systems

Increase the share of mass transit of 40% by 2015, rising to 60% by 2025, considering for passenger car, microbus and pickup, van and pickup, and urban taxi.

EP12 – Supply Side: Electricity produced from biogas

Assume 100MW of plant with capacity factor of 0.7 by 2025.

EP 13 – Supply Side: PV installed in household and building

Assume 500MW of installed PV in households and buildings by 2025.

EP14 – Supply Side: Municipal solid waste

Assume 120MW of MSW plant will be installed by 2025.

EP 15 – Supply Side: Solar thermal electricity

Assume 400MW of solar thermal electricity plant by 2025.

EP 16 – Supply Side Renewable electricity

Include all scenarios from supple side.

The supply-side policies were examined to meet a target of 10% electricity generation from renewable sources in the existing Bangkok energy system by 2025. It was assumed that to meet the target, the electricity would be generated from biogas, PV installed in household and building, municipal solid waste, and solar thermal electricity.

Wangjiraniran and Euaarporn (2010) explored the impact of utilizing gas, coal, and nuclear energy for long-term power generation on generation cost, emission, and resource availability in Thailand. A baseline scenario was created on the basis of the existing power development plan (PDP). Further, three alternative scenarios of coal, nuclear and gas options were projected for the period beyond the PDP, i.e. 2022-2030. For each scenario the following assumptions were made:

Base scenario

1. Economic growth and overall energy elasticity were as follows,

Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Growth of GDP	2	3	4.5	5.3	5.5	5.5	5.8	5.8	5.7	5.6	5.5	5.5	5.5
Elasticity	1.11	1.14	1.03	1.12	1.12	1.10	1.09	1.06	1.05	1.04	1.02	1.01	0.98

2. The driver of elasticity demand would remain unchanged after the year 2021,

3. The increase of base-load capacity was mainly from natural gas combined cycle, coal-fired, and nuclear power plant, expected to be commissioned in 2020,
4. Biomass and other renewable energy were also included in term of the intermediated and peak load under the mechanism of SPP and VSPP schemes, where only firm contracts had been taken into the account,
5. After 2021, all fuel options for base load capacity would be dispatched by its merit order and specific commercialized capacity to restrain 15% of reserve margin, which was similar to the designated level in PDP,
6. Renewable energy capacity was assumed to be constant and power imported capacity was kept at the same level of 10% of total supply, and
7. Natural gas would still be the major part of power generation, with lower market share compared to the year 2008 due to the expansion of coal and nuclear power.

Coal scenario

1. The coal option became favourable to reduce in long-term the portion of natural gas utilization in power generation,
2. After 2021, only coal-fired power plants would be installed for the incremental capacity of base load requirement,
3. The installed capacity and imported capacity during the PDP2007 period remained identical to the base scenario, and
4. Coal would dominate Thailand power industry at 67% in the year 2030.

Nuclear scenario

1. After 2021, the incremental based load requirement would be fulfilled with thermal nuclear power plants,
2. Other supply options remained unchanged from the base scenario, and

3. Nuclear energy would dominate Thailand power industry at 58% in 2030, but this would be definitely based on the condition that the nuclear option should have been approved for starting commissioning within 2020 and ready for large expansion in the long-run.

Gas scenario

1. Coal and nuclear options would encounter barriers for expansion,
2. Renewable energy and other options could not be introduced to the market as expected,
3. The conventional combined cycle gas turbine would cover the entire incremental base load requirement after 2021, and
4. Natural gas would have much more influence on the power market compared to the base scenario.

Dagher and Ruble (2011) evaluated possible future paths for Lebanon's electric sector. In Lebanon, electricity generation, transmission, and distribution were monopolized by a vertically integrated public utility, Electricite du Liban (EDL). During the Lebanese civil war (1975–1990), the electricity sector was suffering from both infrastructure damage and mismanagement problems. Subsequently, the Council for Development and Reconstruction (CDR) launched the Power Sector Master Plan between 1992 and 2002 that involved the rehabilitation of the transmission and distribution networks, as well as, the expansion of the generating capacity. Those times, EDL was operating seven thermal power plants with a total installed capacity of 2038 MW, and six hydro-power plants with a capacity of around 221 MW. There were also two privately owned hydro-power plants with a capacity of around 50 MW that were selling their electricity production to EDL.

However, due to lack of capacity, inadequately maintained facilities and networks, and poor management, EDL had been increasingly unable to meet the growth in electricity demand. This shortage of supply had led to the development and rapid expansion of an off-grid backup sector as an alternate supply that was operating in a legal gray zone. This existing status led the authors to evaluate the future paths of the Lebanon electric sector by developing three scenarios, a business-as-usual scenario (or a baseline, BS), a renewable energy scenario (RES), and a natural gas scenario (NGS) for both the medium-term (2020) and long-term (2050) planning horizons. In all scenarios the authors assumed that:

1. A national priority was to satisfy 100% of electricity demand,
2. As consumers were paying much higher prices for the backup–provided power, market forces would naturally drive out the backup capacity, and
3. The share of the backup sector production would fall from 21.6% in 2006 to 0% in 2020.

The remaining assumptions for each scenario follow:

Business-as-usual scenario

1. EDL would expand its capacity between 2007 and 2050, in such a way to satisfy the total electricity demand,
2. The shares of fuel oil, diesel oil (excluding the backup sector), and hydro would be adjusted to make up for the diminishing share of the backup sector, and
3. From 2020 onwards, generation from fuel oil would constitute 40.3% of all electricity generation, diesel oil 52.2%, and hydro 7.5%.

Renewable energy scenario

1. In this scenario, it was assumed that EDL would completely satisfy the growth in electricity demand up to 2050 by the introduction and expansion of wind energy systems along with an expansion of the existing technologies,
2. From 2006 till 2020, wind-based electricity would expand from 0% in 2006 to 12% in 2020 and 15% in 2050, and

3. In 2020 and 2050 the respective shares of each of the existing fuels would be respectively 35% and 26% for fuel oil, 48% and 56% for diesel oil, and 5% and 3% for hydro.

Natural gas scenario

1. In this scenario, it was assumed that EDL would completely satisfy the growth in electricity demand up to 2050 by the introduction and expansion of natural gas using combined cycle (CC) generators along with an expansion of the existing technologies,
2. During the period 2006-2020, natural gas-based electricity would expand from 0% in 2006 to 22% in 2020 and 24% in 2050,
3. For both 2020 and 2050, the share of fuel oil would be the same and equal to 32%,
4. The share of diesel oil would also be the same for both 2020 and 2050, and equal to 41%, while
5. In 2020 and 2050 the share of hydro would be 5% and 3% respectively.

Kim et al. (2011) summarized the recent trends in the Republic of Korea (ROK) energy sector. The ROK had been experiencing drastic changes in its energy system, mainly induced by industrial, supply security, and environmental concerns. Energy policies in the ROK had evolved over the years to address challenges through measures such as privatization of energy-sector activities, emphases on enhancing energy security through development of energy efficiency, nuclear power and renewable energy, and a related focus on reducing greenhouse gas emissions. More specifically, major features of the ROK's energy policy were the following:

a. The process of privatization in the energy sector included (a) the division of the state electricity monopoly, (b) the development of the Korea Power Exchange to coordinate a wholesale market for electricity, as well as, the further development of the ROK's electricity transmission system, and (c) revised tax structures for some fuels (including biofuels) and autos to provide incentives for the use of renewable fuels and more efficient vehicles,

b. Participation in Northeast Asia energy cooperation research, including pipeline development in east Siberia, sharing and upgrading oil refining facilities, research and development related to Northeast Asian natural gas supply and in cross-border pipeline projects with Russia, China, and/or the Democratic Peoples' Republic of Korea (DPRK), cross-border electricity transmission, and coal mine development in Russia and Siberia,

c. In the industrial sector, Korea would increase its support for R&D to improve the energy efficiency of industrial equipment and facility upgrades,

d. In the transport sector, Korea would improve the fuel efficiency of automobiles by establishing a low-carbon, highly energy-efficient public transportation system and implementing a plan that would allow Korea to emerge as one of the top four producers of green cars in the world,

e. In the residential and commercial sectors, Korea's energy-efficiency labeling program would gradually be expanded to cover all buildings, as well as, Korea would promote the development and construction of zero-energy, carbon-neutral buildings,

f. By 2030, fossil fuels were projected to account for only 61% of total ROK energy consumption, down from the existing 83%, while the use of renewable energy would increase to 11% from 2.4% in 2007, and

g. Under the National Energy Committee resolutions, renewable energy sources and nuclear power would account respectively for 11% and 27.8% of the energy mix by 2030 (This represented a sizable increase from the existing levels of 2.4% for renewable energy and 14.9% for nuclear power).

Till 2011, three different future energy paths for the ROK had been developed. The «reference» or «Business-as-Usual (BAU) path» which assumed generally that existing policies and currently evolving economy/energy sector trends would continue. Two additional variants that assumed BAU demand for electricity (and other fuels), but modeled different trends for nuclear power generation capacity (the «Minimum Nuclear» and «Maximum Nuclear» paths) had also been developed.

Minimum nuclear (MIN) path

1. This path assumed no additional reactors, beyond those currently listed by the World Nuclear Association as under construction or planned and having defined dates for the start of construction, would be ultimately built in the ROK,
2. Existing reactors would be decommissioned after 40 years of life for PWRs, and 30 years of life for CANDU units, but would not be replaced,
3. As a result the total nuclear generation capacity in the ROK would fall from a peak of about 29 GW in 2019/2020 to 20 GW by 2030, and
4. To compensate for the decreased nuclear capacity relative to the BAU case, the MIN path included an increase in coal-fired and liquefied natural gas (LNG) combined-cycle plants in a ratio of 70%/30%.

Maximum nuclear (MAX) path

1. This case assumed the same schedule for decommissioning of existing reactors as in the MIN (and BAU cases), but assumed that a new 1400 MW PWR unit would be placed in service each year from 2016 through 2029 (14 units total), much more than replacing the 4 smaller units decommissioned during that time,
2. With the exception of Kori Unit 1 (the first unit built in the ROK), the retirement schedule for all LWR unit was assumed to be extended to 50 years,

3. The total nuclear generation capacity under the Maximum Nuclear path by 2030 would be 42.8 GW.
4. The additional nuclear capacity above the BAU case that was included in the MAX case was assumed to displace coal-fired and LNG-combined cycle plants, again in the ratio 70%/30%.

Takase and Suzuki (2011) described the current status of and recent trends in the Japanese energy sector, including energy demand and supply by fuel and by sector. Particularly, the authors discussed the current energy policy situation in Japan, focusing on policies related to climate change targets, renewable energy development and deployment, liberalization of energy markets, and the evolution of the Japanese nuclear power sector. This work also presented the structure of the Japan LEAP dataset, described several alternative energy scenarios for Japan (with an emphasis on alternative scenarios for nuclear power development and GHG emission abatement), and touched upon key current issues of energy policy facing Japan. The scenarios which had been developed were the following: The *business-as-usual* (BAU) assuming generally that existing policies would continue, the ''*Minimum Nuclear*'' and ''*Maximum Nuclear*'' which assumed BAU demand but were developed based on a review of projections of nuclear capacity by several groups in Japan and elsewhere, and a ''*National Alternative*'' which included a combination of energy efficiency and low-carbon energy measures (mainly renewable and nuclear) aggressively applied. Further, for the latter scenario, two variants were developed, one with the nuclear capacity of the Minimum Nuclear scenario, and another with the nuclear capacity of the Maximum Nuclear scenario. All scenarios included projections through 2030, with 2007 being the final historical data year. The assumptions for each scenario follow:

Business-as-usual (BAU) scenario

1. This scenario was developed to match as closely as possible the ‘‘reference’’ or ‘‘BAU’’ cases outlined by the Advisory Committee on Energy and Natural Resources (ACER) under the Ministry of Economy, Trade and Industry (METI) and the Institute of Energy Economics of Japan (IEEJ),
2. Energy demand generally followed the IEEJ long-term outlook, which provided more detailed end-use break downs than the outlook by ACER and METI, but the ACER/METI outlook was used as a guide for trends in electricity generation capacity,
3. The projections of ACER and METI for nuclear capacity were slightly lower than those of IEEJ (61.50GW versus 62.86GW by 2030), and finally
4. It was assumed that a total of 10 additional units would be completed by 2020, yielding a total capacity of about 61 GW by then, with no new additions to 2030.

Minimum nuclear scenario

1. Only three reactors under construction that time (Tomari-3, Shimane-3, and Ohma plants) would be completed before 2030,
2. No other reactors would be built before 2030, resulting in a year-2030 capacity of about 21 GW, and
3. The reactor lifetime was 40 years operations.

Maximum nuclear scenario

1. Four units, with a total capacity of about 5 GW, would be added beyond the BAU case by 2020, and
2. These units would yield a capacity scenario similar to the plans submitted to METI by electric utilities.

National Alternative scenario

The following efficiency measures would be implemented by 2020:

1. 100% of newly-installed hot water supply systems in the residential sector would be of high-efficiency types using heat pump or heat recovery technologies,
2. 100% of the housing stock would meet at least 1992 insulation standards,
3. 87% of new cars would be of the HV (hybrid vehicle) or EV (electric vehicle) types, resulting in overall efficiency of the stock of passenger vehicles being 1.5 times better than that of 2005, and
4. Domestic PV (photovoltaic) installations would be total 79 GW, and wind power capacity would be 11 GW.

The following energy efficiency measures would be implemented by 2020:

5. For Residential sector: LCD television replacing CRT television, LCD computer monitors, high performance refrigerators, electronic device standby energy reduction, fuel cell cogeneration,
6. For Commercial sector: improved commercial transformers, nonfilament street lights, LED traffic lights, convert incandescent lamps to LED, convert fluorescent lamps to LED, replace emergency lights with LEDs, LCD computer monitors, reduction of electronic devices standby energy, improved vending machines, energy saving elevators, improved insulation in rental offices, energy management systems for buildings, cogeneration engine or turbine, and
7. For Industry sector: inverter controlled motor drives, improved industrial transformers, motors high efficiency, high-efficiency fluorescent lighting, LED and other high-efficiency lighting, house renovation rather than replacement (construction industry).

The following renewables would be implemented for achieving a low-carbon society

8. Small hydro (1.74 GW by 2020, 3.02 GW by 2030),

9. Geothermal (1.04 GW by 2020, 1.62 GW by 2030),
10. Biomass and waste power (5.19 GW by 2020, 5.19 GW by 2030),
11. Solar heat (51 PJ by 2020, 87 PJ by 2030), and
12. Wind power (13 GW by 2030).

Finally

13. Photovoltaic capacity in 2030 was set at 143 GW referring economic potential.

Wang et al. (2011) provided insights into the latest development of energy production, energy consumption and energy strategic planning and policies in China. Particularly, the authors adopted the LEAP model to forecast China's future energy consumption by sector, as well as to describe potential future energy supply arrangements. The basic parameters of analysis for the model (including model's «base year» and certain key future assumptions) were derived from public data, reports and national statistical yearbooks for China, augmented by assumptions of the China LEAP working group. The model was driven by end-use sector final energy consumption in all economic and residential sectors: household, industry, transport, commerce, and agriculture. So, three scenarios were developed to show different policy options, focusing on the future deployment of nuclear power in China: The *business-as usual scenario* for which no adoption of special energy or climate change policies was made, and for these key elements there was an extrapolation of recent economic development trends, and the «*maximum nuclear power*» and «*minimum nuclear power*» cases which considered national energy security and climate change and low-carbon economic development factors to produce different emission scenarios by adjusting the future capacity of nuclear and other electricity sources.

Business-As-Usual (BAU) scenario

1. This scenario reflected a 20- year economic development path that would yield average annual GDP growth rates of 8.38% between 2010 and 2020 and 7.11% between 2020 and 2030,
2. China's population forecast (adopting national population plans and projections) showed the peak population arriving between 2030 and 2040 at 1.47 billion people, with continued and pronounced movement of population from rural to urban areas,
3. In the steel, cement, and pulp and paper sectors, physical output was projected to rise through 2020, but then fall slightly for steel, remain unchanged for cement, and rise only slightly for pulp and paper through 2030,
4. In these industries the energy intensities per unit physical product was projected to fall by 1.0–1.8% annually, varying by industry and time period,
5. China would improve and increase its international trade, while at the same time would emphasize domestic energy savings and emissions reduction policies, would continue the process of energy technology development, and would increase technology investments,
6. Through 2030, heavy industry would continue to occupy an important position in the economy, with tertiary industries (such as services) starting to play more dominant roles only after 2030,
7. To project transportation energy demand, it was assumed that the requirements for passenger transport (measured in passenger-km) would rise as a function of changes in per-capita income with an elasticity of 0.8,
8. The requirements for freight transport (ton-km) would rise with increasing GDP, with an elasticity of 0.8,

9. For passenger transport, additional key assumptions included a trend toward air travel and especially highway travel, and a reduction in rail transport (falling from 34% of passenger-km in 2005 to 20% in 2030), with a similar but more modest shift in the freight transport sector,
10. Energy intensities in most transport sub-sectors (rail and most road passenger and freight transport) were assumed to fall by 20% between 2000 and 2030, and
11. On the energy supply side, it was assumed a rapid development of renewable energy and nuclear energy resulting in a capacity of nuclear power at 70 GW in 2020, which would rise to 100 GW in 2030.

Maximum Nuclear Power scenario

1. The maximum nuclear scenario considered more aggressive development of nuclear power development than in the BAU case, in part to reduce greenhouse gas emissions,
2. The assumed nuclear capacity was 80 GW for 2020 and 134 GW for 2030, and
3. The added nuclear capacity largely would displace thermal generation.

Minimum Nuclear Power scenario

1. This scenario took a more moderate development of nuclear power than the BAU or maximum nuclear cases,
2. Nuclear capacity would reach 60 GW in 2020, and would rise to 80 GW by 2030,
3. Future capacities of wind power, solar power, geothermal power, and CCGT (combined-cycle gas turbines) were assumed to be higher than in the maximum nuclear scenario, reflecting the use of more renewable energy in order to meet climate targets.

Yophy et al. (2011) provided an overview of energy supply and demand in Taiwan, and a summary of the historical evolution and current status of its energy policies, as background to a description of the preparation and application of the LEAP model of Taiwan's energy sector. The Taiwan LEAP model was used to compare future energy demand

and supply patterns, as well as, greenhouse gas emissions, for alternative scenarios of energy policy and energy sector evolution. The description and assumptions for each scenario follow:

Business-as-usual scenario

1. This scenario was based on the structure of Taiwan's energy sector as described in ''Energy Balance Sheet of Taiwan'',
2. Taiwan's population of 23 million in 2008 was expected to fall to 20.3 million by 2056,
3. The growth rate of household size (number of persons per household), based on historical data from 1998 to 2008 had an average of -1.33% annually,
4. In Taiwan Power Company's long-term load forecast which had been completed before the 2008 financial crisis, economic growth rates were 3.77%/year until 2016 and 3.28%/year until 2021,
5. The intensity of energy use in Taiwan's energy sectors and subsectors would remain at 2008 levels through 2030,
6. The GDP elasticity of energy demand was and would remain 1.0, meaning that a 1% rise in GDP yields a 1% increase in energy demand,
7. The operating lifetime of the first three nuclear power plants would be extended for 20 additional years starting from 2018,
8. The first unit of the fourth nuclear power plant would come on line at the end of 2011,
9. Taiwan's nuclear power capacity under the BAU case was projected to increase to 18.0% in 2012, then gradually drop to14.5% in 2019 since no additional nuclear units would be added,
10. The annual petroleum output was taken to be 386.1 million barrels,

11. The processing capacity of the domestic terminals for liquefied natural gas would reach 12 million metric tons per year by 2010, 16 million metric tons by 2020, and 20 million metric tons by 2025, and
12. The impact of the financial tsunami on Taiwan's economy would be temporary.

GOV (government's energy conservation and carbon emission reduction policy) scenario

1. The government's target was to reduce the energy intensity in Taiwan's economy by enhancing energy efficiency,
2. To model this policy, the intensity of fuel use was reduced for almost all fuels in all demand sectors and subsectors by 2% annually through 2025 (after which intensities would not change), and
3. Under the GOV scenario, demand side energy totals would be 805.2 trillion kcal by 2030, which was 327.8 trillion kcal less than in the BAU case.

FIN (financial tsunami) scenario

1. The financial tsunami would have long-term negative effects on Taiwan's economy,
2. Overall sectoral growth rates were reduced starting in 2016 by 9.4% relative to the BAU case (which maintained sectoral growth rates at constant levels), with a decrease of 21.3% in growth rates by 2021.

RET (retirement of nuclear) scenario

1. This scenario assumed that the first, second, and third nuclear plants would be retired, and not replaced, at the end of their 40-year lifetimes,
2. The two units from the fourth nuclear plant would be never operated,
3. As, there were no changes between the BAU and RET scenarios in terms of future energy demand, the key differences between the BAU and RET cases had to do with the generation of electricity and related fuel-cycle impacts,

4. The energy conversion output would increase by 2 trillion kcal in the RET case by 2030, as compared to the BAU case, with the difference related to a variation in gas requirements in electricity generation between the scenarios, as more coal-fired power (from imported coal) would be used to replace the nuclear plants retired and not built.

ALL (all scenario assumptions) scenario

1. This scenario assumed, as in the GOV case, that the government met its energy conservation target, namely, the reduction of energy use by at least 2% annually through 2025,
2. The financial tsunami would cause major effects on Taiwan's economic growth from 2016-on, reducing the GDP growth rate in most economic sectors,
3. The ALL scenario incorporated the assumption of the nuclear retirement case, in which Taiwan's existing nuclear plants would be gradually phased out, and
4. The energy demand would reach 755.3 trillion kcal in 2030.

For the Greek energy system, **Roinioti et al. (2012)** built five energy scenarios for the future – with a focus on the electricity production system – and explored how these scenarios were reflected in economic, environmental terms and in terms of energy efficiency. The reference scenario described the most likely evolution of the power sector and reflected the business-as-usual state of affairs including the programmed integration/withdrawal measures of thermal units and the aimed resource energy sources (RES) expansion for 2020. Each one of the remaining four scenarios was a combination of a future and a strategy. A «future» was an uncertainty affecting the energy system (economic growth, fuel costs, etc.) and a «strategy» was a set of technological options. The technological options were based on the scenarios of the Ministry of Environment, Energy and Climate Change of 2010. The four scenarios were (a) the green scenario characterized by low emissions, high growth, and advanced RES technologies, (b) the orange scenario with high emissions, high growth, and traditional energy & RES, (c) the red scenario characterized by high emissions, low growth and traditional energy, and (d) the blue scenario with low emissions, low growth, and advanced RES & traditional strategy. The modeling period was from 2009 to 2030, using 2009 as the base year. The five scenarios were based on the following assumptions:

Reference scenario

1. The GDP growth rate would peak at 3% in 2017, the 3% growth rate would continue until 2025, and after 2025 this rate would drop to 2.5%,
2. The energy demand was linked to the energy elasticity of the above GDP growth rate,
3. The capacity was expanded between 2009 and 2030, in such a way as to satisfy the total electricity demand,
4. The capacity would increase from 12.4 GW in 2009 to 31.8 GW in 2030,
5. Lignite capacity would be reduced to more than half, while the combined cycle natural gas units were projected to reach 11.9 GW of capacity in 2030,
6. The wind parks capacity would be increased from 0.9 GW in 2009 to 8.5 GW in 2030, while the photovoltaics capacity was projected to increase to 2.2 GW in 2030,
7. Biofuels consumption in road transport was assumed to reach 0.41 million tons of oil equivalent (mtoe) in 2020 and 0.46 mtoe in 2030,
8. The fossil-fuel prices projection of the International Energy Agency (IEA) (2009) reference scenario was used, and
9. The CO_2 price projected by Deutsche Bank was applied until 2020, while the central CO_2 price used by the UK government was applied for the period 2020–2030.

Green scenario

1. The GDP growth rate would rise to 1.1% in 2012 and would peak at 4.3% in 2015,
2. From the peak point, the GDP growth rate would gradually decline to 3.6% in 2021 and 3.5% in 2026,

3. Wind parks capacity was projected to reach 10.3 GW in 2030 and small hydro capacity was projected to increase to 4.4 GW in 2030,
4. Lignite use in the electricity production would be reduced significantly, while natural gas use would increase, with the installed capacity of the combined cycle natural gas units reaching 9.3 GW in 2030,
5. Large scale centralized solutions were implemented,
6. Advances in technology would result to the introduction of solar thermal and geothermal power plants (0.5 GW and 0.4 GW, respectively, in 2030),
7. Biofuels consumption was projected to increase to 0.69 mtoe in 2020 and 1.35 mtoe in 2030,
8. Electric cars would be also introduced in the market, with their electricity consumption reaching 0.01 mtoe in 2030,
9. As economic activity increased, the energy demand would rise as well, leading to higher fossil-fuel prices,
10. Therefore, the fossil- fuel prices projection of the International Energy Agency (IEA) (2009) Higher Prices Scenario was linked to the Green scenario,
11. The drive for higher emissions due to higher GDP growth was offset by the large penetration of advanced RES technologies in the electricity mix, and
12. A high CO_2 price scenario was assumed due to higher GDP growth resulting in higher energy demand.

Orange scenario

1. The GDP growth rate would rise to 1.1% in 2012 and would peak at 4.3% in 2015,
2. From the peak point, the GDP growth rate would gradually decline to 3.6% in 2021 and 3.5% in 2026,

3. There were limited technology breakthroughs, which would result to the expansion of existing RES technologies (wind, hydro), mostly in local level,
4. The installed capacity of wind energy would increase to 10 GW in 2030,
5. Coal units were introduced to meet with the very high energy demand, reaching 2.4 GW of installed capacity in 2030,
6. Natural gas was dominant in the energy mix: the combined cycle natural gas capacity was projected to increase to 11.9 GW in 2030,
7. Lignite would still constitute an important fuel for electricity production,
8. Only 20% of the lignite power plants would be withdrew,
9. Biofuels consumption was projected to reach 0.62 mtoe in 2020 and 0.91 mtoe in 2030,
10. Electric cars would be introduced to the market,
11. As economic activity increased, there would unquestionably be a higher demand for energy and a corresponding increase in emissions,
12. The fossil-fuel prices projection of the International Energy Agency (IEA) (2009) higher Prices Scenario and a high CO_2 price scenario (U.K. Department of Energy and Climate Change (DECC),2011; Deutsche Bank,2011) were used, and
13. Expected growth of the economy was the primary driver of CO_2 emissions.

Red scenario

1. The GDP growth rate would peak at 2.9% in 2016, and after 2016 this rate would gradually decline to 1.5% by 2030,
2. Similar to the Orange scenario, there would be limited technology breakthroughs,
3. Gas and lignite would be substantial carriers in the energy system,

4. Combined cycle natural gas units capacity was projected to increase to 10.6 GW in 2030, Coal units were again assumed to be introduced in the electricity production system due to the low cost of coal,
5. Coal units installed capacity would reach 1.8 GW in 2030,
6. RES development would be kept on a minimum level, since RES investment risks were high,
7. National policy would be decoupled from the European,
8. Biofuels consumption would be limited to 0.41 mtoe in 2020 and 0.46 mtoe in 2030,
9. Electric cars were assumed not to achieve any significant market share,
10. As GDP growth was slowing down, the energy demand would also rise in a slower pace,
11. Fossil-fuel prices were assumed to be 30% lower in 2030, than in the Reference scenario,
12. The fossil-fuel prices projection of the International Energy Agency (IEA) (2009) lower prices scenario was incorporated, and
13. A low CO_2 price scenario (U.K. Department of Energy and Climate Change (DECC),2011; Deutsche Bank,2011) was used due to the assumed lower GDP growth of the red scenario.

Blue scenario

1. The GDP growth rate would peak at 2.9% in 2016, and after 2016 this rate would gradually decline to 1.5% by 2030,
2. Advances in technology would not be fully exploited due to limited capital availability, Instead, clean energy, competitive to gas and lignite would be developed,

3. The wind energy installed capacity was projected to increase to 8.5 GW in 2030, while the capacity of small hydro stations and photovoltaics would increase to 2.2 GW and 1.2 GW, respectively,
4. Lignite use in electricity production would be reduced, as a result of the gas dominance in the energy system (2.3 GW and 9.3 GW, respectively),
5. Similar to the Red Scenario, biofuels consumption would be limited to 0.41 mtoe in 2020 and 0.46 mtoe in 2030 and electric cars were assumed not to achieve any significant market share.
6. The fossil-fuel prices projection of the International Energy Agency (IEA) (2009) lower prices scenario and a low CO_2 price scenario (U.K. Department of Energy and Climate Change (DECC),2011; Deutsche Bank,2011) were applied.

Tanoto and Wijaya (2012) explored the possibility of long-term electricity expansion planning in the Java-Madura-Bali (JaMaLi) area by including nuclear power plant in order to meet the future demand and environmental protection concern as well as to increase the supply security up to 2027. During the study period, the potential of energy resources available for JaMaLi area along with two electricity supply scenarios based on nuclear and non-nuclear sources were assessed. In both scenarios, *for modeling demand* the following assumptions were made:

1. JaMaLi's electricity sales in 2007 according to data from Ministry of Energy and Mineral Resources were used in the analysis,
2. The sectoral demand was 34 TWh for residential sector, 41 TWh for industrial sector, 15 TWh for commercial sector and 5 TWh for public sector,

3. From 2008 to 2027, the annual electricity demand growth was expected to increase as much as 12.6%, 3.4% 11.4%, and 11.4% for residential, industrial, commercial and public sectors, respectively,
4. In the same period, the economic development was projected to be about 6.1% per year, and
5. The population growth was assumed to be 1% per year and the electrification ratio was expected to be 100% by 2020.

Scenario 1

1. In this scenario, the supply assumption considered several aspects in order to meet vast electricity demand as the power generation was planned by following the demand requirement,
2. The planning reserve margin to secure the electricity supply should be meeting 30% by 2027, The transmission and distribution losses in 2007 would be 13.6%, and this would be reduced to 12% by 2027,
3. The dispatch of power plant in the JaMaLi system would be ordered as follows: coal-steam, geothermal and combined cycle power plants in the base load, hydropower and gas turbine power plants in the middle load and diesel-engine power plants in the peak load, and
4. The efficiencies of power plant would be 80% for hydropower and geothermal, 22% for gas turbine, 35% for combined cycle, 37% for diesel engine, and 32% for coal steam.

Scenario 2

1. In this scenario, the development of nuclear plant was back to the National Energy Management Blueprint 2005-2025, which mentioned that first electricity from nuclear power plant had been expected to be produced in 2006,

2. The second nuclear power plant would follow in 2017 and this would complete the first phase of nuclear power plant development,
3. The second phase would have a third nuclear power plant contributing to the JaMaLi system by 2023 followed by a fourth in 2024, with an additional capacity of 1000 MW for each year, and
4. Nuclear power plants would contribute about 3% of total installed capacity, and would reduce the fossil power plants such as coal and natural gas by 2 GW and 1.9 GW respectively.

Wangjiraniran et al. (2013) explored the possible scenarios under the constraint of nuclear and coal-fired power development. In addition, the consequence on the overall cost, greenhouse gas and diversification index of Thailand power generation system was also investigated. The reference scenario was created on the basis of the power development plan (PDP2010). Three alternative scenarios with the repeal of nuclear power plant (NPP), coal-fired power and their combination were comparatively simulated.

Reference scenario (REF)

1. Demand forecast and supply options were based on the latest official load forecast and power development plan (PDP2010),
2. It was assumed that the growth rate of gross domestic production would be approximately 4.2% annually,
3. Capacity expansion and supply option were referred to the recent power development plan (PDP2010), of which the increase of base-load capacity would be mainly from natural gas combined cycle, coal-fired, and nuclear power plant, expected to commissioning in 2020,
4. The target of 6000 MW of renewable energy capacity in 2030 had been set to build up the market with their full potential under the current prospective,

5. Biomass would take the majority among renewable energy due to their competitive cost,
6. The limited potential of agricultural residual would be the major constraint, and
7. Solar and wind energy were treated as intermittent resources and aimed to reduce partial load of local distribution.

No Nuclear scenario with minimized cost (NN-LC)

1. This scenario represented negative perspective of public acceptance on nuclear power plant (NPP),
2. Barriers of the NPP commissioning would be built up from time to time, such as difficulty of commissioning site development, delay of nuclear development program and etc.,
3. To slow down the electricity tariff due to the repeal of NPP, coal-fired power would be selected replacing the missing 5000 MW of NPP installed capacities, and
4. Renewable energy deployment could be implemented on target similar to the REF scenario.

No Nuclear scenario with gas replacement (NN-Gas)

1. This scenario also represented negative perspective of public acceptance on NPP,
2. In contrast to the NN-LC scenario, climate change and environmental impact would become the more concern instead of cost reduction,
3. Renewable energy deployment could be implemented on target with their full potential similar to the REF scenario,
4. The multiple units of 700 MW natural gas combine cycle would be selected to replace the missing NPP capacity in order to minimize the emitted greenhouse gases level, while
5. Coal-fired powers would be still kept going on target of the plan to reduce the dependency of natural gas.

No Nuclear and No Coal Scenario (NN-NC)

1. This scenario represented the negative perception on both NPP and coal-fired power generation,
2. The difficulty of NPP development, coal-fire power would also become unacceptable option due to its environment impact,
3. Clean coal technology could not be competitive with the current conventional technology, and
4. Natural gas combined cycle would be the only option allowed to serve the rising of electricity demand, and recover the missing capacity of NPP and new coal-fired power plant.

3.2 Industry Sector

Langley (1986) presented an analysis of the existing pattern of energy use in the United Kingdom iron and steel industry. Account was taken of structural changes in the industry, together with the likely uptake of energy efficiency measures, to examine the prospects for improved energy efficiency in this industry up to the year 2000. In the context of two scenarios, two sets of measures were examined: A set of technically proven conservation measures and a set of research and development (R&D) conservation measures. The first scenario was *a high output scenario* for which it was assumed that the output would rise to approximately 18 million tons. The second scenario was *a low output scenario* for which the output would remain approximately 12 million tons. Each set of measures included the following:

The set of technically proven conservation measures

1. For coke ovens, coke dry-quenching could be implemented,
2. For sinter plant, partial (>500°C) or full (>250°C) heat recovery was suggested,

3. For blast furnace, the proposed technologies were evaporating cooling, recovery of pressure energy at top furnace and reduced gas losses,
4. For basic oxygen steel-making (BOS) furnace, a sensible heat recovery and top gas combustion were advised,
5. For electric arc furnace, the suggestion was exhaust gas recovery, and
6. For finishing plant, the substitution of continuous casting for ingot casting or heat recovery from soaking pit waste gases and pre-heat furnaces was suggested.

The set of research and development conservation measures

1. For coke oven and sinter plant, a stack gas sensible heat recovery,
2. For blast furnace, a slag sensible heat recovery,
3. For BOS furnace, a reduction of iron loss by vaporization and a slag sensible heat recovery, and
4. For electric furnace, a slag sensible heat and cooling water recovery.

Ackerman and de Almeida (1990) studied the impact of fuel-wood shortages on the industry of the Brazilian state of Minas Gerais. Particularly, the technology of charcoal-based iron- and steelmaking had been still employed on a large scale in this Brazilian state. However, the growing demand for charcoal, driven by Brazilian industrial development, exceeded the sustainable yields of local forests, creating a fuel-wood crisis. So, alternative wood supply and demand policy options were analyzed through two possible scenarios: a business-as-usual scenario and an alternative scenario. For each scenario, the authors made the following assumptions:

Business-as-usual

1. The steel industry would still use the obsolete technology of charcoal-based iron and steelmaking,
2. Charcoal would be used as the primary wood for fuel use, and

3. Charcoal consumption level would threaten the shortages of wood as it was far above the sustainable levels.

Alternative scenario

1. A change through less charcoal intensive technologies was suggested,
2. Actions such as reforestation were promoted to increase the wood supply,
3. The doubling of the area of eucalyptus projects over the next ten years was proposed,
4. The introduction of pre-heating throughout the pig iron industry and the doubling of the use of more efficient superficie kilns were advised,
5. Some residential adoption of more efficient wood stoves was necessary, and
6. The improvement of the efficiency of the older plants up to the level of the new ones.

Liu et al. (1995) studied the cement industry in China to determine the prospects for renovation and for building new facilities during the 1990s, and, in particular, the prospects for improved energy efficiency. The potential was good for renovating most vertical-kiln plants to improve their energy intensity 10-30% while substantially increasing their capacity and reducing pollution, all at low cost. State-of-the-art precalciner kilns offered small energy-efficiency advantages, but important environmental and product-quality advantages over improved vertical kilns. The authors presented three scenarios that differed as to the technology of new plants, emphasizing: (i) high-cost, state-of-the-art precalciner kilns, (ii) moderate-cost advanced vertical kilns, and (iii) low-cost vertical kilns without advanced technology. The three scenarios were: a business-as-usual scenario, a moderate scenario, and an expensive scenario. In the three scenarios, the common assumptions were:

1. 10 million tons of cement production would be retired before 2000, and
2. From 1990 up to 2000 the net increase of annual cement production capacity would reach 250 million tons.

Additionally, the different assumptions for each scenario were the following:

Business-as-usual scenario

1. Investment patterns would follow the patterns of the 1980s,
2. A significant percentage of the needed capacity would be covered by vertical kilns,
3. The construction of modern precalciner kilns would not be significant, and
4. Any specific option of production processes to meet the targeted output was not recommended.

Moderate scenario

1. The needed capacity would be provided mostly by advanced mechanized vertical kilns,
2. The construction of modern precalciner kilns would take a moderate role, and
3. The capacity ratio of vertical to precalciner kilns in new capacity was assumed to be 3:2.

Expensive scenario

1. The vast amount of the needed capacity would be provided by advanced precalciner kilns,
2. Advanced vertical kilns would be the complement, and
3. The capacity ratio of vertical to precalciner kilns in new capacity was 1:3.

For the iron and steel industry worldwide, **De Beer et al. (2000)** examined the long-term projections assuming four scenarios; a frozen scenario which was the worst case scenario, a moderate change scenario which was the business-as-usual scenario, an accelerated change scenario, and a wonderful world scenario. For each scenario, the authors made the following assumptions:

The frozen scenario

1. For each region, industry efficiency level and emission factors were fixed at 1985-1995 levels, and
2. Any industry trend improving energy efficiency and reducing emissions was ignored

The moderate change scenario

- The existing energy efficiency measures which were underway would be taken up by the whole European industry.

The accelerated change scenario

1. The developed countries would increase the implementation of energy efficiency measures,
2. China, Russia and Eastern Europe would incorporate new and emerging production techniques for all new capacity, and
3. A respectable percentage of older plants which were less efficient would close.

The wonderful world scenario

1. Developing countries would go through a rapid transition in order to meet the Western best practise efficiency standards via accelerated introduction of new and emerging technologies and closing the old plants,
2. The introduction of CO_2 capture on blast furnace across the globe was assumed, and
3. A larger world market for scrap steel would be established.

Ruth and Amato (2002) investigated implications of changes in the cost of carbon for output, energy use and carbon emission profiles of the iron and steel industry in United States and compared the results for different climate change and technology policies. The authors assumed a baseline scenario and an alternative climate change policy scenario. For each scenario, the following assumptions were made:

The baseline scenario

1. The annual GDP growth rate would be 1.9%, and
2. The total output of the iron and steel industry in the US would be about at the same level over the next two decades.

The alternative climate change policy scenario

1. To investigate the impacts that market-based and technology-led climate change policies would have on energy use profiles and carbon emissions of the industry, it was assumed that the policies would have been implemented in the year 2000, and
2. Costs of carbon of \$25, \$50 and \$75 per ton of carbon were selected to coincide with the costs of carbon commonly referred to in the climate change policy debate.

Hidalgo et al. (2005) constructed four scenarios to examine the global iron and steel industry. The first scenario was a baseline scenario where the historical trends would continue and the carbon value would be zero. The other three scenarios were emission trading scenarios, for which the authors were introduced emission trading markets on the steel industry in EU-15 countries, in EU-27 countries and in Annex-B countries respectively. In addition, carbon value for the three alternative scenarios varied from 0 to 250 €/tCO_2.

Demailly and Quirion (2006) analyzed how production and profits in the European cement industry might depend upon allocation approaches. Two contrasting allocation methods of free allowances were considered. Under «grandfathering», the number of allowances a firm would get was independent of its current behavior. Under «output-based allocation», it was proportional to its current production level. Whereas almost all the quantitative assessments of the EU Emissions Trading System had assumed grandfathering, the real allocation methods used by Member States stood somewhere between these two polar cases (notably because of the updating every five years and of the special provision for new plants and plant closings). Particularly, the authors studied the impacts of these two polar allocation methods by linking a detailed trade model of homogeneous products with high transportation costs (GEO) with a bottom-up model of the EU-27 cement industry for the period 2008-2012. To capture the future trends, three scenarios were constructed; A baseline scenario and two alternative scenarios. The baseline scenario was a business-as-usual scenario which assumed that no climate policy would be implemented, while the alternative ones were a Grandfathering (GF) scenario and an Output-based allocation (OB) scenario. The authors adopted the following general assumptions which were common across all the three scenarios:

1. In the period 2005-2007, the CO_2 price was modelled at an average of 20€/tCO_2 while in the period 2008-2012 it was modelled from 10 to 50€/tCO_2,
2. The power generators were assumed to have the ability to pass on to electricity customers 100% of their extended cost rise, and
3. Non-EU27 countries would not implement any climate policy at all.

Further, the assumptions for the two alternative scenarios were the following:

GF scenario

1. A European GHG Emissions Trading Scheme would be employed with allowances grandfathered, and
2. In 2004, the firms were being grandfathered 90% of their total emissions.

The OB scenario

1. The allocation of allowances for a firm would be proportional to its current production, and
2. This output-based allocation of allowances was assumed to represent for every firm 90% of its 2004 emissions per ton of cement.

In the case of Korean chemical industry, **Song et al. (2007)** developed two scenarios; a business-as-usual scenario and an alternative one. For each scenario, the assumptions made by the authors were the following:

Business-as-usual scenario

1. Historical trends would continue,
2. Input CO_2 concentration to chemical absorption tower would account for 10-15% of total emissions gases, and
3. Maximum capacity factor would be 83%.

Alternative scenario

1. CO_2 removal was applied to 5%, 10% and 15% of the total emissions in the years 2005, 2010 and 2015 respectively, and
2. CO_2 removal efficiency is 65%, 80% and 95% for the same years.

In order to assess the CO_2 abatement potential of China's steel industry, **Wang et al. (2007)** developed a model using LEAP software to generate three different CO_2 emission scenarios for the industry from 2000 to 2030. The three scenarios were the Baseline Scenario (Scenario 1), the Current Policy Scenario (Scenario 2) and the New Policy Scenario (Scenario 3). Scenario 1 only took into account the industry policies adopted before 2000, and Scenario 2 took into account policies adopted between 2000 and 2005. Scenario 3 was also called the Mitigation Scenario, which meant that more ambitious energy conservation and emission reduction objectives and relevant policies would be adopted in this scenario. In their analysis, the authors made the following general assumptions:

1. In 2010 the fuel price index (price of 2000 was 1) for coal was 1.1, for fuel oil 1.2, for natural gas 3 and for electricity 1.2,
2. In 2020 the fuel price index for coal would be 1.2, for fuel oil 1.3, for natural gas 3.5 and for electricity 1.3, and
3. In 2030 the fuel price index for coal would be 1.3, for fuel oil 1.5, for natural gas 3.7 and for electricity 1.4.

The different assumptions for each scenario follow:

Baseline scenario

1. A whole energy efficiency improvement of 1% in 2010, 1.5% in 2020 and 2% in 2030 as well as, the implementation of energy conservation plans from the 6th to 10th five-year plan periods were assumed,
2. The incentive policies in terms of finance, credit and taxation toward energy conservation projects were promoted,
3. Some backward technologies and equipment (e.g. mold casting, open hearth furnaces, small blast furnaces and small electric furnaces) were identified along with the need to eliminate them,
4. A strong demand for steel products delays industry restructuring and technological upgrading was assumed,
5. Small and medium plants would be still producing a large proportion of the total output, and
6. Specific energy saving measures would be adopted and energy intensity would continue to decline with slow rate.

Current policy scenario

1. A whole efficiency improvement of 2% in 2010, 2.5% in 2020 and 3% in 2030 were adopted,
2. New policies with more ambitious objectives were introduced and implemented,
3. The new energy conservation targets included new technology development guidelines and new requirements for Chinese steel makers such as the improvement in the scale of production, in the efficiency, in the technical expertise, in energy consumption and in environmental protection performance,
4. The industrial concentration would increase and the market would be dominated by larger modern steel corporations,

5. The production of these corporations would be continuously expanding and the technical equipment would be gradually improving resulting in small equipment which would be quickly eliminated,
6. More energy conservation technologies would be applied, and
7. There would be significant increases in dry coke quenching and other exhaust gas and heat recovery equipment.

New policy scenario

1. A whole energy efficiency improvement of 3% in 2010, 3.5% in 2020 and 4% in 2030 were adopted,
2. The new targets and objectives were more ambitious in terms of energy conservation and emission reduction,
3. Industrial concentration was even stronger and the proportion of super large equipment was higher than before,
4. Exhaust gas and heat recovery devices were almost all-prevading,
5. Structural adjustment for production process was stringer than before, and
6. Through increased waste steel recycling, the proportion of electric arc furnaces and other modern technologies such as smelt reduction was greater.

Cai et al. (2008) studied emissions reduction potential and mitigation opportunities in the major emission sectors in China. The LEAP model along with three scenarios was employed in this study. The sectors were: (a) iron and steel, (b) cement, (c) pulp and paper, (d) electricity, and (e) transport. The first scenario assumed implementation of only those policies and projects announced prior to 2000 – the «*Pre-2000 Policy*» scenario. The second scenario assumed implementation of all policies announced before 2006 – or the «Recent Policy» scenario. The third scenario assumed implementation of select packages of GHG mitigation options – herein referred to as the «Advanced Options» scenario. The scenario analysis timespan covered the years 2000–2020 with 2000 as the baseline year. The following general assumptions were applied to all the three scenarios:

1. Chinese GDP in 2020 would be four times larger than it was in 2000 with an average annual growth rate of 7.5% from 2000 to 2010 and 6.5% from 2010 to 2020,
2. After 2020, the average annual growth rate would be 5.5% until 2030,
3. In 2010 the fuel price index for coal would be 1.1, for fuel oil 1.2, for natural gas 3, and for electricity 1.2,
4. In 2020 the fuel price index for coal would be 1.2, for fuel oil 1.3, for natural gas 3.5 and for electricity 1.3.

The following different assumptions for each scenario were made:

Pre-2000 policy scenario

1. A whole efficiency improvement 1% per year in 2010 and 1.5% per year in 2020 were assumed,
2. A concrete energy conservation plan in the iron and steel industry for the 6th to 10th five-year plan was used,
3. The establishment and the implementation of standards, labelling and certification of energy efficiency since 1980s were adopted,
4. The elimination of out-dated technologies and equipment was adopted resulting in the promotion of new energy conservation technologies and equipment since the 1980s,
5. Incentive policies in terms of finance, credit and taxation towards energy conservation projects since the 1980s were promoted,
6. the elimination of small illegal cement plants since 1999 and the upgrading of the technology and equipment for pulp and paper industry was assumed, and

7. "Policy Outlines of Energy Conservation Technologies" would have had started the implementation of technical retrofit in 1984.

Recent policy scenario

1. A whole efficiency improvement 2% per year in 2010 and 2.5% in 2020 were assumed,
2. China's iron and steel industry as a key sector in China's Medium and Long-term Energy Conservation Plan in 2004 was highlighted,
3. China's iron and steel development policy for restructuring the production and the technology in the steel industry in 2005 were adopted,
4. The improvement of production capacity and product quality in the 10th five-year plan since 2000 was assumed,
5. A management reformation and more provincial control over the industry in 2000 was adopted,
6. Energy efficiency enhancement such as extra investment and technology upgrades and market system renovation in order to attract foreign investment were assumed, and
7. More environmental protection supervision from the government and the rearrange of pulp and paper industry structure were required.

Advanced options scenario

1. A whole efficiency improvement of 3% per year in 2010 and 3.5% per year in 2020 was assumed, and
2. A number of new technologies and systems were introduced such as the establishment of energy management center, advanced coke oven, advanced blast furnace technology, dry coke quenching, advanced sinter machine, advance direct steel rolling machine, smelt reduction technology, advanced converter, advanced electric arc furnace, preventative maintenance, process management and control, kiln shell heat loss reduction, high-efficiency motors and drives, active additives, composite cement,

combustion system improvement, high-efficiency roller mills, high-efficiency powder classifiers, efficient transport systems in cement industry, the adjustment of iron/steel ratio, the use of waste derived fuels and the conversion to multi-stage pre-heater kiln.

Szabo et al. (2009) introduced a bottom-up global model of the pulp and paper sector with a focus on energy consumption and carbon emissions. It was an annual recursive simulation behavioral model with a 2030 time horizon incorporating several technological details of the industry for 47 world regions. The long time horizon and the modular structure allowed the model users to assess the effects of different environmental, energy and climate policies in a scenario comparison setup. In addition to the business as usual developments of the sector, a climate commitment scenario was also analyzed, in which the impacts of changing forest management practices were also included. The following assumptions were made for each scenario:

Business-as-usual scenario

1. The historical trend for world paper demand would continue with an average yearly growth rate at 2.1%,
2. For the paper production the trend would continue to grow uninterruptedly,
3. Global trade would grow from 1.5% to 4% per year.
4. Due to international trade, resource owners and specifically Latin Americans and Russians would increase their shares in raw materials and by 2030 they would account for the 75% of raw wood export,
5. Asia would be the major importer and the vast amount of its consumption would be covered by import,
6. The pattern for energy use would not have a uniform pattern across the world,
7. Carbon emissions would continue to rise with an average 2% per year and Asia would increase its carbon emissions dramatically by 25%, and

8. The carbon values were assumed at 0-30€/tC for Europe and zero for the rest of the world.

Climate commitment scenario

1. A committed future in carbon reduction could be achieved by a strategic plan which would include changing of forestry management practises, introduction of sustainable forest management and imposition of constraint policies such as carbon taxes and trading permits,
2. The carbon value for Europe and for the rest of the world was assumed at 0-140€/tC, and
3. The transitional resource supply constraints were assumed to be in Asia 20-40% by 2020, in Europe 6% by 2012, in North America 12% by 2012 and in South America 20-40% by 2020.

Zhang et al. (2009) constructed a technology selection model for industrial pollutants reduction by incorporating mass flow analysis of the production system, bottom-up modeling methodology, and linear programming for optimizing annualized discounted cost. A case-study analysis of chemical oxygen demand (COD) emission control was carried out on the Chinese pulp industry, the nation's leading source of industrial COD discharge. The model was used to generate and analyze the technology prospects and COD emission situations under three scenarios for 2010, 2020 and 2030. The three scenarios were: (a) the baseline scenario which reflected the most pessimistic future for COD control, (b) the without policy reduction scenario, and (c) the reduction policy scenario in which the impact of COD reduction policy on technology advancement could be examined. Scenario settings took into account the central government's policy objective of a 10% reduction in COD from 2005 levels by 2010. The assumptions for each scenario were the following:

Baseline scenario

1. The proportion of all technologies at 2005 would not change in the future, and
2. No changes in technology structure would be made, and even obsolete technologies and capacities would remain in use.

Without reduction policy scenario

1. Competitive market mechanisms would exist and technologies would be incorporated into the pulp sector depending on their cost advantages (costs of some advanced technologies were set to decrease in the future),
2. Technologies with financial attractiveness would enjoy higher application rates in the future, and
3. Some technologies would also contribute to reducing pollution emissions through increasing efficiency and environmental performance.

Reduction policy scenario

1. COD total amount control was taken into consideration, and
2. Clean technologies with low pollution loads might develop faster under this scenario.

Park et al. (2010) assessed potential future CO_2 reduction in the Korean petroleum refining industry by investigating five new technologies for energy savings and CO_2 mitigation: crude oil distillation units (CDU), vacuum distillation units (VDU), light gas-oil hydro-desulfurization units (LGO HDS), and the vacuum residue hydro-desulfurization (VR HDS) process. Particularly, the authors applied a business-as-usual (BAU) scenario for existing refining processes, and alternative scenarios introducing energy saving technologies to decrease CO_2 emissions. In the BAU and alternative scenarios, the LEAP model was used to determine the forecasts of energy consumption, CO_2 emissions, and environmental impact which focused specifically on the Korean refining industry in the national and industrial sectors. The assessment period was from 2008 up to 2030.

Business-as-usual scenario

1. GDP would increase by 42% between 2005 and 2010, by 48% between 2020 and 2020, and by 41% between 2020 and 2030,
2. The population would reach the sizes of 48.3 million in 2005, 48.9 million in 2010, 49.3 million in 2020 and 48.6 million in 2030,
3. The industrial sector would account for most of the energy demand at 117.5 million ton of oil equivalent (MTOE) in 2010, 146.5 MTOE in 2020, and 162.3 MTOE in 2030, and would be the main contributor to GHGs emissions, and
4. The current trends in demand of petroleum products would hold during the assessment period (2008-2030).

Alternative scenario I

This scenario was a crude oil distillation unit with pre-flash in the CDU process. This technology could reduce the load of the CDU by reducing the crude oil per unit. It operated in about 34.8% of all CDUs in 2001. Therefore, this scenario assumed that CDUs with pre-flash technology would be replaced by CDUs without pre-flash by 2030.

Alternative scenario II

This scenario was the inclusion of a vacuum distillation unit with steam stripping in the VDU process. This technology added steam into the furnace with atmospheric residue (AR) to decrease the partial pressure of the hydrocarbon. It was installed in about 73.2% of the VDUs in 2001. Therefore, this scenario assumed that VDUs with steam stripping technology would be replaced by VDUs without steam stripping by 2030.

Alternative scenario III

This scenario was the inclusion of oxidation desulfurization in the LGO HDS process. To improve the environment, 99% or more of the sulfur in refinery gas should be recovered. Oxidation desulfurization could perform ultra-deep desulfurization. This new technology would complete its development by 2014. Therefore, this scenario assumed that the LGO HDS would be replaced with oxidation desulfurization starting in 2015.

Alternative scenario IV

This scenario saved energy by changing to an internal type vacuum column. This technology could reduce energy consumption by using a vacuum ejector because of its low pressure brought about by structured packing and good separation. Development of this technology would be complete by 2009. This scenario assumed that the internal type vacuum column would replace the VRHDS starting in 2010.

Alternative scenario V

This scenario was the use of overhead vapor waste heat recovery in the vacuum residue. The heat energy of the reflux water in the VDU was not reused. Technology for recovering heat energy from the system would be developed after 2009. This scenario assumed that overhead vapor waste heat recovery technology would replace the VR HDS starting in 2010.

Zhu et al. (2010) investigated energy consumption and CO_2 emissions in the processes of chemical production in China through calculating the amounts of CO_2 emissions and estimating the reduction potential in the near future. The research was based on a two-level perspective which treated the entire industry as Level one and six key sub-sectors as Level two, including coal-based ammonia, calcium carbide, caustic soda, coal-based methanol, sodium carbonate, and yellow phosphorus. These two levels were used in order to address the complexity caused by the fact that there were more than 40 thousand chemical products in this industry and the performance levels of the technologies employed were extremely uneven. Three scenarios with different technological improvements were defined to analyze the potential of CO_2 mitigation for the manufacturing of these chemicals in the near future in China. The time scope was set to 2015 which was the end of China's twelfth five-year period. The following assumptions were made for each scenario:

Baseline scenario

1. Levels and structures of the technologies employed in these sub-sectors were assumed to remain similar to those used in 2007,
2. Energy performances and CO_2 emissions for per unit product would not change, and
3. The outputs of the six chemicals would continue to grow at an annual rate of 2%.

Low technical improvement rate scenario

1. Technical performance would improve to a small extent,
2. Domestically advanced technologies in 2007 (representing the least energy requirements and CO_2 emissions in China that time) would be widely applied for producing those chemicals in 2015,
3. The average levels of energy consumption and CO_2 emissions in 2015 were set as equal to those of domestically advanced levels in China in 2007,
4. The associated emission factors would remain the same as in 2007 giving more emphasis to the existing potential lying in current domestically available advanced technologies within China's chemical industry rather than the energy sector,
5. The six sub-sectors were not treated in the same way because the conditions varied among them,
6. For ammonia, calcium carbide, methanol and yellow phosphorus, the main difference lied in the production scales, that is, small-scale plants would consume more energy, hence resulting in more CO_2 emissions, and heavily polluting the local environment as well,
7. These small-scale units should be prohibited for new capacities by the government and advanced large-scale techniques should penetrate the market in the future,

8. For caustic soda, there were no such restrictions imposed on the supply market that time,
9. Though the diaphragm cell process was inferior to the ion membrane process in terms of technical performance to some extent, the former was not so heavily environmentally polluting,
10. The domestic data for the ideal levels for the two processes were obtained respectively and a moderate rate of 60% was set for the market penetration of ion membrane (this rate was 35% in 2007),
11. For sodium carbonate, the two processes had their advantages and shortcomings in different aspects, though the ammonia-soda process required more energy for operation than the combined-soda process, and
12. In 2015 the technology structure of sodium soda manufacturing would remain the same as that in 2007.

High technical improvement rate scenario

1. The average levels of the technology performances in 2015 would be commensurate with best practices worldwide in 2007, implying a further improvement based on the Low technical improvement rate scenario,
2. Indirect CO_2 emission factors of electricity and steam uses were also lowered to 0.842 tons CO2/MWh and 0.411 tons CO2/ton steam because of the growing utilization of cleaner and efficient power and steam generation technologies,
3. The proportion of ion membrane for caustic soda producing would jump to 85%, and
4. The structure of sodium soda production would remain unchanged.

Atabi et al. (2011) investigated the impact of various policies on the reduction of CO_2 emissions from Iranian cement industry using the LEAP model. A Business-as-Usual (BAU) scenario for the existing Iranian cement industry was applied. Moreover, the current and future demands for the cement industry were defined for 2005-2020. The current and future productivity of the cement industry was predicted in the BAU scenario. Then, a mitigation scenario was developed for which different policies to mitigate the energy demand were considered as input data for the LEAP model. Then, the model was compared with the BAU scenario by predicting the demands of energy carriers and the calculated mitigation in emissions. The policies surveyed were fuel switching and more energy efficient technologies. Particularly, the following assumptions were made for each scenario:

Business-as-usual scenario

1. The existing status of the Iranian cement industry would be maintained in the future, and
2. Greenhouse gas emission in Iran's cement industry would be predicted by the main variables of BAU, such as the growth rate of cement production from 2005 to 2020, the type and rate of fuel consumption, the rate of technological changes and energy intensity.

Mitigation scenario,

1. All cement production units older than 20 years would be replaced with new and efficient technologies,
2. Energy efficient improvement plans would be implemented on units that were 10 to 20 years old,
3. Natural gas and biomass share would be 5% more than that in the BAU scenario in 2020, and
4. Energy carrier demand would increase 139% in the period 2005-2020.

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Phdungsilp and Wuttipornpun (2011) developed energy and carbon modelling of Thai industrial sector and some policy options. Particularly, the authors assessed the existing status and future development related to energy consumption and CO_2 emissions over the twenty-five years from 2005-2030. The LEAP system was used to simulate what might happen to energy demand and carbon emissions in the future in a business-as-usual (BAU) case and with alternate scenarios. These scenarios were primarily governed by four factors: economic growth, proportion of energy types, efficiency of energy devices, and energy intensity The BAU aimed to show the future through the prism of current policies and strategies. The alternate policy scenarios were inherited from BAU scenario. They were, thus, reflected sensitivities on the original scenario. More specifically, the alternate policy scenarios considered the cumulative impact of five industrial energy policies, including improvement of industrial energy efficiency, switching to natural gas, combined heat and power (CHP) in designate factories, efficient electricity end-use devices, and process integration. These scenarios could be also considered as mitigation scenarios, which meant that more ambitious energy conservation and emission reduction objectives and relevant policies would be adopted. The assumptions for the BAU scenario were the following:

Business-as-usual scenario

1. Past trends would continue in the future,
2. No change compared to the industrial structure in 2005 would occur,
3. This implies that the current patterns in the industrial structure would be maintained and the industrial sub-sectors would be the same,
4. No new policies for energy savings and emission mitigation would be implemented,
5. Energy demand was predicted as a function of time, and
6. The GDP growth rate was assumed to be 4.5% for the period 2005-2010 and 5.5% for the period 2011-2030.

On the other hand, the policy options and assumptions for the generation of the Alternate policy scenarios were the following:

Policy option 1: Improvement of industrial energy efficiency

1. A target of 10% and 20% increasing energy efficiency by 2015 and 2030 was assumed, and
2. These improvements would be from compressed air, boiler and steam systems, and lighting systems.

Policy option 2: Switching to natural gas

1. Thermal energy supplied by non-renewable resources such as diesel and fuel-oil would be switched to natural gas by 2015.

Policy option 3: Combined heat and power in designate factories

1. Combined heat and power (CHP) systems would be used to produce electricity in selected industries,
2. The waste heat would be used to replace heat from fuel-oil fired boilers,
3. CHP systems would replace fuel-oil by 2015, and
4. Electricity consumption would decrease 10% in each industry.

Policy option 4: Efficient electricity end-use devices

1. Only electricity would be considered – availability of efficient and less energy intensive pumps, compressors and motors for industrial processes,
2. This policy could be considered as a part of Energy Labeling Program, and
3. It was assumed that electricity efficiency would increase 20% by 2010.

Policy option 5: Process integration

1. Process integration would be applied to food and beverages, chemical and paper industries, and

2. It was assumed 20% reduction in useful energy intensity by 2015.

Policy option 6: Integrated policy

1. All of the above mentioned policies were considered together, and
2. This policy option would give the cumulative effect of the different options, giving Thai industry the lowest possible emission reductions.

Ke et al. (2012) analyzed current energy and CO_2 emission trends in China's cement industry as the basis for modeling different levels of cement production and rates of efficiency improvement and carbon reduction from 2011 to 2030. Particularly, the authors estimated two types of potential energy savings and CO_2 emission reductions:

a) Best practice savings potential using scenario-analysis based on the assumption of a one-time improvement of China's cement industry to the current world best practice energy intensity and one-time implementation of currently available aggressive energy efficiency and carbon reduction measures, and
b) Continuous improvement potential based on continuous energy efficiency improvement and carbon reduction.

The LEAP system was used for the scenario-based modelling. To analyse the impact of different energy efficiency and carbon reduction measures and policies, four scenarios were constructed: the frozen scenario, the best practice scenario, the reference scenario, and the efficiency scenario. The frozen scenario was constructed based on 2009 production and energy data of China's cement industry and reflected a future path at the current energy efficiency and emission level of China's cement industry without further efficiency improvement. The best practice scenario evaluated the theoretical upper bound savings potential of China's cement industry by assuming that the cement production instantly reached the existing world best practice energy intensity and implemented currently available aggressive energy efficiency and carbon reduction measures by 2011 and stayed at that level from then on.

In contrast to the one-time achievement in the best practice scenario, the reference and efficiency scenarios were constructed as continuous improvement scenarios, taking into account current production trends and assuming different implementation levels of efficiency measures, technologies, and fuel switching policy choices. Compared to the reference scenario, the efficiency scenario reflected faster efficiency improvement due to more aggressive policy choices. Regarding the four scenarios altogether, the following should be pointed out:

1. The frozen scenario was taken as the basis to estimate the continuous improvement potential and best practice savings potential,
2. The potential energy savings and CO_2 emission reductions were estimated according to the differences of energy consumption and emissions between a given scenario (e.g., reference or efficiency or best practice) and the frozen scenario,
3. Only energy-related CO_2 emission reductions were taken into account in the analysis,
4. Average emission factor was 73.3 t CO_2 per terajoule (TJ) for alternative fuels, indicating that the use of alternative fuels could reduce about 23% CO_2 emissions overall compared to burning bituminous coal for which it was assumed that the emission factor was 94.6 t CO2 per TJ,
5. For the period 2010-2011, electricity share would be 10.5%, Diesel share 0.4%, and Biomass share 0.2%, and
6. National average grid emission factor (kg CO2/kWh) would be 0.755 for 2010, 0.742 for 2011, 0.655 for 2015, 0.584 for 2020, and 0.451 for 2030.

Additionally, for each scenario the separate assumptions including the final energy intensity, the cement output shares by technology, the energy shares, and the penetration of waste heat recovery (WHR) power generation are given below:

Frozen scenario

From 2010 to 2030:

1. Final energy intensity (Gj/t cement) of the technologies «Rotary Kilns» and «Shaft Kilns» would be equal to 3.01 and 3.52 respectively,
2. For «Rotary Kilns» and «Shaft Kilns», mass shares of cement output would be equal to 79.1% and 20.9% respectively,
3. Coal energy share and alternative fuels share would be 86.7% and 2.2% respectively, and
4. Penetration of WHR power generation would be 0%.

Best-practice scenario

1. «Shaft Kilns» would be phased out in 2010, and «Rotary Kilns» would remain the only available technology,
2. After 2010, «Rotary Kilns» technology would have final energy intensity equal to 2.07 and mass share of cement output 100%,
3. From 2011, alternative fuels would replace coal as the main fuels for cement production,

After 2010:

4. Coal energy share would decline to 40%, and alternative fuels share would increase to 48.8%,
5. The penetration of WHR power generation would be 100%, and
6. An average of 36 kWh of electricity could be produced per t clinker through WHR power generation.

Reference scenario

1. «Shaft Kilns» technology would be phased out in 2015, and «Rotary Kilns» would remain the only available technology,
2. Between 2010 and 2015, final energy intensity of «Shaft Kilns» would be 3.52, while for «Rotary Kilns» final energy intensity would decline from 3.01 in 2010 to 2.97 in 2015,
3. For «Shaft Kilns» mass share of cement output would decline from 20.9% in 2010 to 10.5% in 2015, while the corresponding share of «Rotary Kilns» would increase from 79.1% in 2010 to 89.5% in 2015,

After 2015:

4. Final energy intensity of «Rotary Kilns» would decline to 2.93 in 2020 and to 2.49 in 2030, while its mass share of cement output would be 100% from 2020 onward,
5. Alternative fuels would replace gradually coal as the main fuels for cement production,
6. Coal energy share would decline from 80% in 2015 to 60% in 2030, while alternative fuels share would increase from 8.9% in 2015 to 28.8% in 2030, and
7. The penetration of WHR power generation would increase from 75% in 2015 to 90% in 2030.

Efficiency scenario

1. «Shaft Kilns» technology would be phased out in 2011, and «Rotary Kilns» would remain the only available technology,
2. In 2010 and 2011, final energy intensity of «Shaft Kilns» would be 3.52, while for «Rotary Kilns» final energy intensity would decline from 3.01 in 2010 to 3.00 in 2015,
3. For «Shaft Kilns» mass share of cement output would decline from 20.9% in 2010 to 16.7% in 2011, while the corresponding share of «Rotary Kilns» would increase from 79.1% in 2010 to 83.3% in 2011,

After 2011:

4. Final energy intensity of «Rotary Kilns» would decline to 2.93 in 2015, to 2.49 in 2020 and to 2.07 in 2030, while its mass share of cement output would be 100% from 2015 onward,
5. Alternative fuels would replace gradually coal as the main fuels for cement production,
6. Coal energy share would decline from 84.4% in 2011 to 40% in 2030, while alternative fuels share would increase from 4.5% in 2011 to 48.8% in 2030, and
7. The penetration of WHR power generation would increase from 64% in 2011 to 100% in 2030.

Zhang et al. (2012) developed a technology-based model to assess alternative water pollution reduction policies in the pulp and paper industry of China up to 2020. Under different policy scenarios, emission amounts of wastewater, chemical oxygen demand (COD), ammonia nitrogen (NH_4-N) and absorbable organic halides (AOX) were calculated. Scenario design covered all important policy measures that would make differences to water pollution emissions of China's pulp and paper industry. Apart from a baseline scenario, the following four individual policy scenarios were constructed according to different pollution reduction policies:

a) ***Scenario A:*** Raw material substitution through forest-paper integration and promoting domestic waste paper recycling,
b) ***Scenario B:*** Shutting down backward small-sized pulp and paper mills, making minimum size requirement for newly built plants,
c) ***Scenario C:*** Promoting cleaner production technologies in both new and existing plants, and
d) ***Scenario D:*** Strengthening effluent discharge limitations and promoting tertiary treatment of wastewater.

The effect of each individual policy scenario at the absence of other measures was simulated by the model. Finally, an integrated scenario (scenario E) with all policy measures was defined to explore the best environmental performance that could be achieved. So, scenario E represented the most optimistic technological advancement expectation and best environmental performances.

The different scenarios shared the following common assumptions:

1. The average annual increase rate of total output of paper product was set to be 4.6% during 2011–2015 and 4.2% during 2016–2020,
2. Total pulp demand would be 106.7 million tons in 2015 and 131.2 million tons in 2020,
3. Newsprint output would be 4.3 million tons in 2010, 5.4 million tons in 2015 and 6.6 million tons in 2020,
4. Household paper output would be 6.2 million tons in 2010, 7.7 million tons in 2015 and 9.5 million tons in 2020,
5. Printing and writing paper would be 22.6 million tons in 2010, 28.3 million tons in 2015 and 34.8 million tons in 2020,
6. Wrapping paper would be 6.0 million tons in 2010, 7.5 million tons in 2015 and 9.2 million tons in 2020,
7. Paper board would be 31.3 million tons in 2010, 39.2 million tons in 2015 and 48.1 million tons in 2020,
8. Corrugated paper would be 18.7 million tons in 2010, 23.4 million tons in 2015 and 28.8 million tons in 2020,
9. Other paper would be 3.6 million tons in 2010, 4.5 million tons in 2015 and 5.5 million tons in 2020, and

10. Total paper output would be 92.7 million tons in 2010, 116.0 million tons in 2015 and 142.6 million tons in 2020.

Additionally, the different assumptions for each scenario were the following:

Baseline scenario

1. No policy intervention situation in which structures and pollution emission intensities of all production processes would remain unchanged, and
2. Pollution emissions would be only determined by total output expansion.

Scenario A

1. The outputs of domestic wood pulp and bamboo pulp had been expected to reach 7.5 million tons and 1.6 million tons in 2010 respectively,
2. Total capacities of wood pulp and bamboo pulp would reach 13.65 million tons and 3.95 million tons respectively after all scheduled projects have been constructed,
3. The imported wood pulp share was set to be 13.6% for 2010, 14% for 2015, and 12% for 2020,
4. The share of domestically produced non-wood pulp was set to be 14% for 2010, 10.6% for 2015, and 9% for 2020,
5. The share of domestically produced wood pulp was set to be 8.4% for 2010, 10.3% for 2015, and 12% for 2020,
6. The share of domestically produced reclaimed pulp was set to be 62.7% for 2010, 64.0% for 2015, and 66% for 2020, and
7. The share of domestically produced other pulp was set to be 1.3% for 2010, 1.1% for 2015, and 1% for 2020.

Scenario B

1. Chemical wood pulp lines below 51 kt/yr, non-wood pulp lines below 34 kt/yr and recycled fiber-based pulp lines below 10 kt/yr would be shut down,
2. Newly built facilities and expansion of existed mills would also meet minimum scale requirements,
3. These measures would accelerate capacity replacement and increase the average size of pulp and paper mills in China.

Scenario C

1. Application of cleaner technologies would be promoted including Dry and wet feedstock preparation and horizontal continuous cooking, Dry timber debarking, Extended delignification cooking, Low energy batch cooking, Multi-stage countercurrent pulp washing, Closed screening, Oxygen delignification before bleaching, Elemental chlorine free bleaching (ECF), Total chlorine free bleaching (TCF), Advanced alkali recovery, Medium consistency refining, Flotation deinking for recycled pulp, Enzymatic deinking for recycled pulp, and High efficiency white water reuse and fiber recovery,
2. Future penetration rates were set mainly according to the expectations in some technology guidelines for cleaner production and energy saving as well as to experts' opinions and the authors' judgment,
3. For each clean technology the following penetration rates were set in 2010, 2015, and 2020 respectively:
    - 40%, 70% and 85% for Dry and wet feedstock preparation and horizontal continuous cooking,
    - 55%, 75% and 90% for Dry timber debarking,
    - 10%, 25% and 45% for Extended delignification cooking,
    - 15%, 25% and 35% for Low energy batch cooking,

- 45%, 70% and 90% for Multi-stage countercurrent pulp washing,
- 30%, 60% and 90% for Closed screening,
- 50%, 80% and 90% for Oxygen delignification before bleaching,
- 15%, 45% and 65% for Elemental chlorine free bleaching (ECF),
- 2%, 5% and 10% for Total chlorine free bleaching (TCF),
- 30%, 60% and 85% for Advanced alkali recovery,
- 20%, 40% and 65% for Medium consistency refining,
- 40%, 75% and 90% for Flotation deinking for recycled pulp,
- 2%, 8% and 20% for Enzymatic deinking for recycled pulp,
- 20%, 40% and 70% for High efficiency white water reuse and fiber recovery,

4. End-of-pipe effluent treatment would play an essential role in emission control.

Scenario D

1. This scenario reflected the changes in wastewater treatment technologies driven by stricter discharge limitations, and
2. The overall application rate of tertiary treatment technologies was set to be 20% in 2015 and 35% in 2020.

3.3 Transport Sector

Bose and Srinivasachary (1997) investigated policies to reduce energy use and environmental emissions in the transport sector of Delhi. The aim of this work was to extrapolate total energy demand and the vehicular emissions, using LEAP and the associated 'Environmental Database (EDB)'. The study was restricted to passenger modes of transport in Delhi and did not include the freight modes. Travel demand was first estimated by analyzing data on vehicle population, average distance travelled, and occupancy level. Next, data on travel demand, proportion of travel demand catered by road and rail, modal split, occupancy and fuel efficiency were compiled within the LEAP framework for estimating the energy demand in Delhi. Additionally, emission factors were compiled under EDB module of the LEAP structure for estimating the resultant pollution loading. The LEAP model was run under five alternative scenarios for estimating the current consumption of gasoline and diesel oil in Delhi and forecasting the same quantities for the years 1994/1995, 2000/2001, 2004/2005 and 2009/2010, respectively. For each scenario, the authors made the following assumptions:

The Business as usual (BAU) scenario

1. The existing trends of vehicular growth in Delhi would continue, and
2. Fuel efficiency norms, modal split pattern and occupancy levels would remain unchanged till 2009/2010 from 1990/1991 observations.

Improvement in the vehicular speed scenario

1. Through appropriate traffic management measures, travel speed on Delhi roads would increase from an average existing speed of 20 km/h to 40 km/h (energy efficient speed) by 1994/1995 for all types of vehicles.

Increased buses share scenario

1. Modal split during 2000/2001 would be brought to the same level as was the case in Delhi during 1981/1982,
2. Through appropriate transport policy interventions, there would be an increase in the share of buses during 2000/2010 to the level which was in 1981/1982,
3. A large portion of the passenger travel demand in Delhi would be met by bus services thereby it would bring overall efficiency of passenger movement, and
4. The extent of total petroleum demand would therefore reduce in this scenario along with reductions in emission levels, when compared with BAU scenario.

Introduction of mass rapid transit system (MRTS) scenario

1. The MRTS would be introduced by 2004/2005 and would continue to grow further in phases,
2. By 2004/2005, a portion of passenger road transport would be substituted by railway and would save petroleum demand over future years, and
3. Reduce emission levels would be observed, as compared with BAU scenario.

Maximum conservation scenario

1. To have envisaged the adoption of measures for improving the speed of vehicular traffic by 1994/1995 (in the short run),
2. To have increased the share of public bus by 2000/2001 (in medium run), and
3. To have introduced MRTS by 2004/2005 (in the long run).

For India, **Bose (1998)** presented a transport simulation model (using the LEAP system) under three alternative transport policy scenarios. Particularly, for analyzing energy use and emissions in meeting travel requirements of residents, the author implemented the model in four Indian metropolises for the period 1990-2011; Delhi, Calcutta, Mumbai and Bangalore. For the ***business-as-usual scenario***, the author made the following assumptions:

1. The existing trends of growth in the registration of vehicles in each city would continue,
2. The existing fuel efficiency norms, occupancy levels and vehicle utilization pattern for different modes would remain unchanged into the future.

The general aim of the ***second transport policy scenario was to strengthen public transport to reduce urban congestion***. The assumptions for this scenario were:

1. Buses would meet 80% of the travel demand in Delhi, Calcutta and Bangalore, while the share of buses in Mumbai would not change,
2. The cumulative share of cars and jeeps would be reduced by half in Delhi, Mumbai and Bangalore and by a quarter in Calcutta, and
3. A ratio 2:1 between two-wheeled vehicles and intermediate public transport modes was adopted.

The third transport policy scenario aimed to promote cleaner and alternative fuels, as well as, to improve engine technologies. Its assumptions were the following:

1. The share of four-stroke engines in Delhi, Calcutta and Mumbai would increase from 11%-12% to 50%, while for Bangalore this share would increase from 20% to 25%, with a view to phase out two-stroke technologies,
2. 15% of autorickshaws would run on propane and 10% would run on electricity (battery operated vehicles),
3. The share of cars fitted with three-way catalytic convertors using unleaded gasoline, battery operated electric cars, and cars that use compressed natural gas (CNG) would increase while the share of old model gasoline and diesel cars would decrease,
4. The share of CNG-powered taxis would increase whereas, the share of diesel-powered taxis would decrease, and all taxis using gasoline would be fitted with three-way catalytic convertors,
5. The share of CNG powered and battery operated buses would increase,

6. No CNG-based vehicles would be introduced in the next decade in Calcutta and Bangalore,
7. Three-way catalytic convertors (and therefore unleaded gasoline) would not be introduced in Bangalore, and
8. Sulphur content in gasoline and diesel would reduce to 0.05% and 0.25%, respectively.

El-Fadel and Bou-Zeid (1999) investigated mitigation measures to reduce GHG emissions from the road transportation sector in Lebanon. Several simulations were conducted to evaluate GHG emissions under different mitigation scenarios ranging from a do-nothing scenario to the introduction of various technological improvements and policy setting. More specifically:

Scenario1: Base conditions for the year 1997 (base-year emissions levels)

The purpose of this scenario was to check Motor Vehicle Emission Inventory (MVEI) model calibration versus IPCC results and produce base-year emission levels. For the base year 1997, a relatively good agreement was obtained between the IPCC estimation method and MVEI (4145 Gg of CO_2/year for the IPCC method versus 3940 Gg of CO_2/year using MVEI). For the same year, 97% of the radiative forcing results from the combined CO_2, NOx and CO emissions.

Scenario 2

The purpose of this business-as-usual scenario was to Project the GHG emissions in 2020 if no aggressive mitigation measures would be adopted. This scenario mainly served as a benchmark against which emission reduction realized in scenarios 3 and 4 were assessed. The assumptions for this scenario were the following:

1. Growth in fleet number is 2.5±3% per year,
2. Growth in activity per passenger car is 1.5% per year,

3. Controlled inspection and maintenance (I/M) program would be equivalent to 1984 program in California,
4. N_2O emission factor of scenario 1 was multiplied by 5 due to increased use of catalytic converters

Projections for the year 2020 under scenario 2 indicated that total emissions, expressed as CO_2 equivalent, would nearly double in comparison to 1997. This was mainly due to the increase in travel demand and limited emission reduction measures. Under this scenario, the CO_2 contribution would increase from 66.5% to 77.6% of the total GHG emissions.

Scenario 3

The purpose of this scenario was to assess the maximum possible reductions in emission from technological improvement. Its assumptions were the following:

1. I/M and clean fuel program equivalent to 1996 enhanced program in California,
2. Average fleet age reduced by 5 years from scenario 2,
3. All gasoline vehicles were equipped with catalytic converters, and
4. N_2O emission factor of scenario 1 was multiplied by 10.

In scenario 3, a reduction of 31% below business-as-usual (scenario 2) was proven to be feasible. In this scenario, CO_2 contributed 85% of the total GHG emissions and N_2O emerged as the third largest contributor to the global warming. The sensitivity analysis indicated that the combined effect of average age reduction by five years, inspection/maintenance and fuels improvement programs yielded minor reductions in emissions. The major factor that contributed to the reduction was the change in fleet technology increasing the percentage of gasoline vehicles equipped with catalytic converter from 50% to 100%.

Scenario 4

The purpose of this scenario was to study the effect of travel improvement and management plans on GHG emissions, as well as, to assess the feasibility of a reduction to 1997levels in 2020. Its assumptions were the following:

1. "Best technology" conditions as in scenario 3,
2. Average speed in time periods with congestion increased by 8 km/h,
3. Reduction in passenger car activity compensated by better urban planning, and
4. Increase in public transport activity.

Scenario 4 was built on the improvement achieved in scenario 3 to maintain 1997 emission levels relatively constant. While the increase in average speed by up to 8 km/h during congestion periods had little effect on reducing emissions, activity reduction of private passenger cars by shifting to public transport and improved urban planning (which reduces trip length) might have a greater potential, as stated. Hence, the total activity of buses was increased by 1 km for each reduction of 25 km in total car activity. It was found that the activity per car should be reduced to 7800 km/car/year.

To investigate the link between transport and energy demand in Mexico for the period 1980-2030, **Bauer et al. (2003)** developed a business-as-usual scenario and three alternative growth scenarios. Regarding the ***business-as-usual scenario***:

1. It was assumed that the number of automobiles would follow the historical trend of a 4.3% average annual increase,
2. The expected number of automobiles in 2013 would be 13 million
3. By 2030, the number of automobiles would reach 37 million,
4. From available historical data of the period 1992-1997, total gasoline demand was derived by considering that private automobiles (representing on average for the period 1970-1998 69% of the total number of vehicles) were consuming 77.3% of the total amount of gasoline.

On the other hand, it was assumed that the rates of population growth would remain the same for each one of the three alternative growth scenarios. For each one of these scenarios, the programmed fuel chain model used growth rates for the GDP and the population as drivers to derive the evolution of the income per capita. In particular, projections of population growth were obtained from the National Council for Population (CONAPO). Then, using the Gompertz curve, the number of automobiles was expressed firstly as a function of the income per capita, and correspondingly, as a function of the year in which such income levels were attained.

Growth Scenario A

1. Population was expected to grow from 97.2 million in 1999 to 128.9 million in 2030,
2. The annual average growth for GDP would be 3.7%,
3. The expected number of automobiles in 2010 would be 19 million,
4. The expected number of automobiles in 2030 would be 58 million, and
5. By 2030, the number of private automobiles was projected to rise to 83% of total vehicles with a corresponding increase in the share of gasoline of 93%.

Growth Scenario B

1. Population was expected to grow from 97.2 million in 1999 to 128.9 million in 2030,
2. The annual average growth for GDP would be 5.2%,
3. The expected number of automobiles in 2010 would be 25 million,
4. The expected number of automobiles in 2030 would be 76 million, and
5. By 2030, the number of private automobiles was projected to rise to 86% of total vehicles with a corresponding increase in the share of gasoline of 96%.

Growth Scenario C

1. Population was expected to grow from 97.2 million in 1999 to 128.9 million in 2030,
2. The annual average growth for GDP would be 6.2%,

3. The expected number of automobiles in 2010 would be 30 million,
4. The expected number of automobiles in 2030 would be 78 million, and
5. By 2030, the number of private automobiles was projected to rise to 87% of total vehicles with a corresponding increase in the share of gasoline of 97%.

Dhakal (2003) estimated and analyzed the historical and future trends of energy demand and environmental emissions from passenger transportation of the Kathmandu Valley, Nepal covering CO_2, CO, HC, NO_x, SO_2, total suspended particles (TSP) and lead (Pb). The author used the LEAP framework to construct future scenarios up to year 2020 and to analyze their implications. These scenarios mainly dealt with (a) traffic improvement measures, (b) promotion of public transportation and (c) electric vehicles. Particularly, the following scenarios were built:

(a) Business-as-usual (BAU) scenario

In this BAU scenario, total passenger travel demand up to 2020 was obtained from regression analysis with time and population of Kathmandu Valley for 1988–2000. This non-intervention scenario incorporated the recently announced government plan of closing down of trolley bus service and ban on the registration of new two-stroke two wheelers. Due to shorter life, it was assumed that four-stroke two wheelers would replace all two-stroke two wheelers by the year 2010. Modal split, vehicle occupancy, fuel economy, and emission factors were assumed the same as those of the base year.

(b) Increasing average vehicle speed scenario

In this scenario, it was assumed that low average vehicle speed would increase through appropriate traffic management so that average vehicle speed would reach 40 km/h by the year 2005 and onwards. This would improve emissions volumes due to improvements in fuel economy.

(c) Increasing share of public transportation scenario

In this scenario, it was assumed that the share of public travel demand would increase in the future due to government policy of discouraging two wheelers and private cars, and encouraging public transportation. The share of travel demand of bus and minibus was assumed to increase linearly from the existing 42% (25% and 17%, respectively, for bus and minibus) to 70% (45% and 25%, respectively) by 2020. This would be compensated by reductions in the travel demands, in passenger km, of two wheelers and private cars, equally.

(d) Promotion of electric vehicles scenario

In this scenario, the share of transport modes by vehicle types were assumed to be the same as the BAU scenario but all three-wheeler passenger travel from 2005 was assumed to be electric such as the currently operating 'Safa Tempo', including the currently operating liquid petroleum gas (LPG) three wheelers, as stated. Apart from that, 20% of the bus passenger travel demand was assumed to be met by trolley bus (run by overhead electricity supply similar to the Chinese cities) by 2015 and all government gasoline car travel demands were assumed to be replaced by electric car by 2015.

(e) Comfortable travel scenario

This scenario assumed that occupancy rates (average number of passengers per vehicle) in all the public transportation modes would decline to provide a reasonably comfortable situation to attract commuters to public transportation. The changes in the occupancy rates were: bus from 50 to 35, minibus from 35 to 25, LPG microbus from 12 to 10, and LPG and electric three wheelers to 8.

(f) Maximum potential scenario

In this scenario, it was assumed that all options of scenarios (b) up to (e) would be implemented as a comprehensive policy package for improving energy demand and pollutant emissions.

Kumar et al. (2003) assessed greenhouse gas mitigation potentials of different biomass energy technologies in Vietnam for the period 1995-2020. The selected biomass energy technologies considered for mitigation of greenhouse gases included:

a. BIGCC (Biomass Integrated Gasification Combined Cycle) based on wood and bagasse,
b. Direct combustion plants based on wood,
c. Co-firing power plants,
d. Stirling engines, and
e. Cooking stoves.

Using the LEAP model, the following scenarios were considered:

Scenario 1: The base case with no mitigation options

This scenario was an extension of the existing trend of the energy consumption in Vietnam.

Scenario 2: Replacement of coal stoves by biomass stoves

The mitigation option considered was the replacement of coal-fired cooking stoves by the biomass-fired cooking stoves. This replacement was considered in both rural and urban households. The penetration rate of the stoves had been assumed higher in the urban sub-sector as compared to that in the rural sub-sector because of the easy access and also the flexible attitude and the purchasing power of the urban households as compared to that of the rural households.

Scenario 3: Substitution of kerosene and liquid petroleum gas (LPG) stoves by biogas Stoves

In this scenario, the mitigation option considered was the replacement of kerosene and LPG stoves by the biogas-based cookstoves. This replacement was considered only in the rural households.

Scenario 4: The substitution of gasoline by ethanol in transport sector

This scenario considered the substitution of gasoline by ethanol. This would require the development of ethanol feedstock, conversion and fuel distribution infrastructure. It had been assumed that the substitution of gasoline by ethanol would reach 2% by the year 2010.

Scenario 5: The replacement of coal by wood as fuel in industrial boilers

In Vietnam, most of the industrial boilers used coal as fuel. The combustion of coal emitted greenhouse gases. Replacing coal by wood as fuel could control this. At that period, 5% of the boilers used biomass as fuel. In this scenario, it had been assumed that the same boilers would be used for both coal and wood.

Scenario 6: Electricity generation with biomass energy technologies

The growth rate of different technologies has been assumed based on extensive literature review. The growth rates of BIGCC, direct combustion steam turbine plants and Stirling engine after year 2005 had been assumed to be 20%, 20% and 30% respectively. It was also assumed that the installed capacity of the biomass-based plants on the above technologies in the year 2005 would be 30, 30 and 0.1 MW respectively. The growth rate of Stirling engines was assumed higher based on the fact that these were decentralized units of very low capacity and could be mass-produced.

Scenario 7: The integrated scenario

This scenario included all the options in the aforementioned 6 scenarios.

Additionally, *the following general assumptions* were made regarding cooking stoves costs:

1. The capital cost of kerosene, LPG and biogas stoves were \$42, \$60 and \$16 respectively,
2. Lifetime was assumed to be 3, 5 and 7 years respectively,
3. The biomass stoves was assumed to be \$0.9075,

4. The cost of coal stoves was assumed to be the same as that of biomass stoves,
5. The biomass stoves referred to both the stoves using firewood and agricultural residues as fuel,
6. The lifetime of the biomass stoves and coal stoves was assumed to be 3 years,
7. The efficiencies of the biomass and coal stoves were assumed to be same as kerosene stoves,
8. The fuels whose transportation, transmission of distribution had been considered, were electricity, natural gas, kerosene, diesel, residual/fuel oil, LPG bottled gas, crude oil, bagasse, anthracite coal, rice husk, firewood and ethanol,
9. The loss of the biomass fuels in transportation was assumed to be higher than that of fossil fuels, assumed at 5%,
10. The cost of transportation included the annualized capital cost and the operation and maintenance cost of the system of transportation, and
11. The transportation cost for diesel, gasoline, kerosene and residual oil were considered through the pipeline.

Tanatvanit et al. (2003) investigated the growth in energy demand and corresponding emissions in Thailand to the year 2020 for the transport, industrial and residential sectors by using a model based on the end-use approach. Among the three sectors, the transport sector was the largest energy consuming sector in Thailand. Regarding the transport sector, three scenarios were developed: (a) the business-as-usual scenario based on the existing trends, (b) the public transportation improvement scenario which considered the public transportation system, especially the Mass Rapid Transit (MRT) system and the extensions of the Bangkok Mass Transit System (BTS), and (c) the fuel economy improvement scenario which considered the improved engine technologies that would reduce fuel requirement. More specifically:

Business-as-usual scenario

In this scenario it was assumed that the existing trends of parameters would increase continuously. For certain types of vehicle, the authors presented for the Bangkok metropolitan area and for the provincial area (a) the estimated travel demand (10^6 passenger-kilometer) in 2000, 2010, and 2020, and (b) the average fuel economy (l/km) using gasoline, diesel and liquefied petroleum gas. The vehicle types were Passenger car, Microbus and pickup, Van and pickup, Motortricycle, Urban taxi, Fixed route taxi, Motortricycle taxi, Fixed route bus, Bus for hire, Private bus, Non-fixed route truck, Private truck, Tractor, and Small rural bus.

Public transportation improvement scenario

According to the master plan of Mass Rapid Transit Authority (MRTA), the first phase of the MRT project would be operated in 2003 with an average distance of 14 km. The total distance of the whole project was approximately 80.4 km, which would be completed in 2017. In addition, the extension project of BTS had been already approved. The total distance of the extended project was approximately 20 km. The following four assumptions were taken into account in this scenario based on the plan of the MRTA:

1. The working time started at 5:00 am and ended at 12:00 pm,
2. The commissioning schedule of the Mass Rapid Transit project would be operated on time of the plan,
3. The number of passengers was based on the MRTA's study, and
4. The extended project of the Bangkok Mass Transit System Public Company Limited would be operational in 2007.

Fuel economy improvement scenario

In recent years, the efficiency of the automotive technologies in terms of fuel requirement per vehicle kilometer had been improved, especially the efficiency of passenger cars and passenger pickups. Two assumptions were taken into consideration in this scenario:

1. The proportion of the efficient passenger cars increased annually by 1% of the additional passenger cars in each year, and
2. The fuel economy of conventional and efficient automotive technologies was based on the study of King Mongkut's Institute of Technology and included gasoline, diesel and liquefied petroleum gas.

Zachariadis and Kouvaritakis (2003) presented a long-term «*business-as-usual*» outlook of energy use and CO_2 emissions from transport in the 10 states of Central and Eastern Europe (CEE) that had acquired the status of «*accession countries*» to the European Union. This was done with the aid of macroeconomic and demographic forecasts taken from international organizations. These forecasts were adjusted in order to account for recent developments and moderate projections of fuel prices that considered both the path of convergence of CEE economies towards EU standards and the potential future development of crude oil prices. To develop their model the authors made the following assumptions for GDP, population and fuel prices.

Assumptions for the GDP growth rates

1. For the period 2000–2010 the (usually high) GDP growth rates of 2001–2002 were assumed to persist, at least until the middle of this decade, fall slightly in the next decade 2010–2020 and finally reach more modest growth levels in the period 2020–2030,

2. Real annual GDP growth rates were set to be respectively for the periods 2000-2010, 2010-2020, and 2020-2030:
    - 5.2%, 4.7%, and 3.6% for Bulgaria,
    - 4.1%, 3.7%, and 3.5% for Czech Rep.,
    - 4.7%, 3.5%, and 3.0% for Estonia,
    - 4.6%, 4.0%, and 3.0% for Hungary,
    - 4.5%, 4.0%, and 3.8% for Latvia,
    - 4.1%, 5.0%, and 4.0% for Lithuania,
    - 4.8%, 5.0%, and 3.5% for Poland,
    - 2.9%, 4.3%, and 4.0% for Romania,
    - 3.7%, 3.5%, and 3.3% for Slovak Rep., and
    - 4.3%, 3.0%, and 2.5% for Slovenia.

Assumptions for the population size

1. The authors used the demographic projections of the United Nations, and
2. According to these projections, a significant decrease in population was expected in most CEE countries, with most notable examples those of Estonia (1.1 million in 2030 compared to 1.6 million in 1990) and Latvia (2.7 million in 1990–1.9 million in 2030).

Assumptions for the fuel prices (FP)

1. For most countries, fuel price reforms would have been achieved largely by 2010, while for others this reform would have been completed somewhat later in order to avoid shocks within a short period of time,
2. After 2010–2015, it was assumed that transportation fuel prices would mainly be affected by the trend of the international price of oil,

3. The real price of crude oil would decrease from its 2000 levels of 28 US$ per barrel to about 20 US$ in 2005, would remain at about that level until 2010 and would then increase to 26 US$ in 2020 and 28 US$ in 2030,
4. In the case of passenger cars, the agreements of the European Commission with the automobile manufacturer associations of Europe, Japan and Korea were assumed to take effect in CEE countries too,
5. For the period after 2012, which was the time horizon of these agreements, only marginal efficiency improvements would be considered for new vehicles,
6. Regarding fuel economy of new cars, different hypotheses would be followed for each country, depending on existing national regulations and keeping in mind the overall trend of convergence with EU standards,
7. Regarding fuel efficiency of trucks, although there was no explicit regulation or voluntary commitment as in the case of cars, it was assumed that efficiency improvements of the order of 10–15% for new vehicles would have been achieved within the decade 2000–2010, with a much smaller improvement afterwards,
8. Efficiency improvements up to 2020 were also assumed for both diesel and electric trains as well as for aircraft, in line with findings of the relevant literature,
9. The aforementioned assumptions concerned «autonomous» enhancement in energy efficiency of transport modes, in addition to potential further improvements calculated endogenously as a long-term result of rising fuel prices,
10. Concerning the use of biofuels in transportation (i.e. organic substances that originate from biomass and are either blended with gasoline or diesel or are used as pure substitutes of conventional fuels), it was assumed that all countries would follow EU rules sooner or later,

11. Biofuel shares (expressed as a fraction of total transportation gasoline and diesel) would be 1%, 2% and 5% in years 2010, 2020 and 2030, respectively, and
12. The impact of blending gasoline and diesel with biofuels on final consumer prices would be negligible, since higher fuel production costs would probably be offset by tax exemptions scheduled to be implemented on these fuel blends.

For the densely populated Mexico City Metropolitan Area (MCMA), **Manzini (2006)** described three future scenarios up to the year 2030 for the potential reduction of CO_2 emissions and associated costs when (a) biogenic ethanol blends and oxygenates were substituted for gasoline, and (b) hybrid, flex fuel and fuel cell technologies were introduced in passenger automobiles, including pickups and sport-utility vehicles (SUVs). A business-as-usual scenario, named also as the reference scenario, and two alternative scenarios were created in which a possible evolution of the MCMA automobile stock would be showed up to the year 2030. For the three scenarios the following assumptions were made:

Reference scenario

1. All automobiles including SUVs and pickups would run with gasoline internal combustion engines,
2. There would be no change in gasoline composition,
3. CO_2 emission factor was 68.6 kg/GJ,
4. Sales would grow at an average 2.7% annually, a rate which had been deduced from the growth of the vehicle stock for the last 10 years, extrapolated to 2030.

First alternative scenario (ALT1)

1. A new technology, parallel hybrid (HYB) gasoline ICE-electric motors, would be available on the market by 2006, and

2. In 2006, gasoline sold in the MCMA contained ETBE15 (ethyl tertiary butyl ether), produced with 48% of anhydrous bioethanol.

Second alternative scenario (ALT2)

1. Additionally to the hybrid automobiles of the ALT1 scenario and the ETBE15 for gasoline, two more alternative technologies were introduced,
2. Flex fuel (FLEX) automobiles, fuelled by blending 85% ethanol 15% gasoline (E85) in the year 2008, and
3. Ethanol fuel cell (FUEL CELL) automobiles, fuelled by E100, by 2013.

Pradhan et al. (2006) estimated up to the year 2025 the consequences in fuel consumption and greenhouse gas emission due to the possible intervention of the electric run trolley buses in the existing public transport system in a particular road up in Kathmandu Valley. This work projects the scenarios on the basis that the passenger travel demand is function of population and income. Basically, the authors used LEAP to develop the following scenarios:

Business as Usual scenario

Its purpose was to set the baseline projection of the current energy demand, cost and emission when no alternatives would be implemented.

The 100% replacement scenario

The purpose of this scenario was to find out the implications of 100% replacement in cost, emission and energy demand. The scenario would give an idea if the government policy intervened in future to replace entire existing vehicles with the trolley buses. In this scenario it was assumed that the existing public vehicles would be replaced entirely by trolley buses from 2005 onward. Similar policy would have been there for diesel three wheelers in the past: stopping diesel three wheelers from running inside the capital.

The 50% replacement scenario

Its purpose was to know the consequences if the decision was made only for 50% replacement. The assumption was that only 50% of the existing travel demand would be met by the trolley buses.

Stopping growth with 25% replacement scenario

The purpose of this scenario was to investigate if the new permits in the route could be stopped and trolley buses would be allowed to meet the travel demand with 25% replacement. Future growth of the existing public vehicles would be stopped and 25% of the travel demand would be achieved by trolley buses.

Combined scenario

Its purpose was to assess the possible combination of the above scenarios which would seem more realistic. In this scenario the assumption was that a fixed number of trolley buses would be introduced to have had the combined effect of above replacement scenarios, that is, 60 number of buses on year 2005, additional 30 number of buses on year 2010 and additional 30 number on ear 2016 would be introduced.

To investigate the use of bioenergy for the transportation sector in Mexico for the period 2005-2030, **Islas et al. (2007)** constructed a base scenario together with four alternative scenarios. For the base scenario it was assumed that fossil fuels were the dominant source of energy, while for the four alternative scenarios the assumption was that fossil fuels were substituted by biomass fuels produced either by ethanol or by biodiesel. For each one of the scenarios, the assumptions were the following:

Base scenario

1. Fuels derived from oil and natural gas were the most-used options, and
2. Gasoline and diesel were the most used fuel.

High penetration scenario of ethanol production

1. In the first stage of the emerging phase (from 2005 up to 2015), ethanol production would expand at an average annual growth rate of 45%,
2. In the second stage of the emerging phase (from 2016 up to2025), the average annual growth rate of the ethanol production would be reduced to 30%, and
3. In the maturity phase (from 2026 up to 2030) the average annual growth rate of the ethanol production would be further reduced to 20.5%.

Moderate penetration scenario of ethanol production

1. From 2005 up to 2015, ethanol production would expand at an average annual growth rate of 40%,
2. From 2016 up to2025, the average annual growth rate of the ethanol production would be reduced to 30%, and
3. From 2026 up to 2030, the average annual growth rate of the ethanol production would be further reduced to 13%.

High penetration scenario of biodiesel production

1. In the first stage of the emerging phase (from 2005 up to 2015), biodiesel production would expand rapidly at an average annual growth rate of 45%,
2. In the second stage of the emerging phase (from 2016 up to2023), the average annual growth rate of the biodiesel production would be reduced to 33%, and
3. In the maturity phase (from 2024 up to 2030) the average annual growth rate of the ethanol production would be further reduced to 21%.

Moderate penetration scenario of biodiesel production

1. There was a restricted rate on the expansion of the agricultural land dedicated to tropical and temperate oil producing plants for biodiesel production, because there were not enough fiscal incentives and governmental subsidies to foster biodiesel.
2. From 2005 up to 2015, biodiesel production would expand at an average annual growth rate of 40%,
3. From 2016 up to2023, the average annual growth rate of the biodiesel production would be reduced to 25%, and
4. From 2024 up to 2030, the average annual growth rate of the ethanol production would be further reduced to 15%.

Pongthanaisawan et al. (2007) examined the number of vehicles, the energy demands and the emissions in road transport in Thailand from 2005 to 2020, using LEAP program. In order to reduce the energy demands and emissions, the scenarios for long-range energy alternative planning in road transport were the following:

Business-as-usual scenario

In this scenario the number of vehicles was forecasted based on GDP. The based year was 2005. The travel demand could be calculated from the number of vehicles, the average distance travel and the average fuel economy of each vehicle type. The present efficiency of vehicle and the pattern of energy utilization of vehicle were unchanged from 2005 to 2020. The ongoing projects were not implemented and the environmental emissions were evaluated by using the technology environmental database (TED) in the LEAP model.

Natural gas vehicle scenario

This scenario considered the substitution of bi-fuel engine for SI engine such as sedan car, urban taxi, and the substitution the compressed natural gas (CNG) dedicated engine for CI engine such as fixed route buses, van and pickup in the Bangkok Metropolitan area.

Further, the penetration rate of natural gas vehicle from 2005 to 2020 would follow the 2005 plan of the PTT Public Co, Ltd.

Hybrid car scenario

In this scenario, it was assumed that hybrid cars would be substituted for the new conventional sedan with a market penetration rate of 15% of new sedan saturated in 2015. The period of the scenario was from 2005 to 2020. The fuel economy of hybrid vehicle was 4.6954 liter gasoline/vehicle-100 kilometer.

Fuel economy improvement scenario

In this scenario, the authors assumed that Thai government would implement the minimum fuel economy standard programme to reduce energy demands and emissions. With this programme, the fuel economy of sedan and pickup should exceed the minimum fuel economy standard, namely, 6.9lt/100 km for sedan and 5.86lt/100 for pickup).

Fontaras and Samaras (2010) investigated the future characteristics of the European passenger car. Especially, the authors mentioned that a new average CO_2 emissions limit for passenger cars was introduced in EU in 2009 imposing gradual average CO_2 emissions reduction to 130 g/km until 2015. They studied possible changes in vehicle characteristics for meeting this limit taking into account the average European passenger car of 2007–2008. For this purpose, first the most important factors affecting vehicle fuel consumption over the reference cycle (NEDC) were identified. At a second step, the CO_2 benefit from the optimization of these factors was quantified, through simulations of 6 different passenger cars commonly found in the European fleet. For the simulations, Advisor 2002 was employed and validated against published type approval data. A pool of vehicles representative of those typically found in the European passenger car fleet was selected. Particularly, six vehicles were chosen and modeled with different mass (kg), capacity (cc), max power (kW), frontal area (m^2), aerodynamic drag coefficient, and rolling resistance factor. Three of the six vehicles were gasoline vehicles coded as «gasoline small», «gasoline medium» and «gasoline large», while the other three were diesel vehicles coded similarly as «diesel small», «diesel medium» and «diesel large». Data were collected in order to model vehicle operation including: vehicle weight, coast down times or aerodynamic characteristics, tire rolling resistance values, gear–final drive ratios, wheel characteristics (dimensions—weight) and specific fuel consumption engine operation maps. In certain cases, when actual data for particular vehicle components were not available, the authors made qualified assumptions based on previous experience and values representative of the European passenger car fleet were used. Such assumptions were made especially for gearbox efficiency which was not possible to determine, idle fuel consumption and in few cases for aerodynamic drag coefficient.

To assess the possibility of using ethanol as diesel substitute, **Saisiritat et al. (2010)** created for the period 2008-2022 an energy demand model for the Thailand transportation sector. The results of ethanol demand were shown through the development of the following two scenarios:

a. The ***business-as-usual scenario***, which reflected DLT (Department of Land Transport) planning to use the NGV (natural gas for vehicle) bus in the new fixed route bus, and
b. The ***alternative scenario***, which introduced ethanol bus (termed ED95 technology for 95% ethanol and 5% additive blend) instead of the NGV bus in Bangkok.

Shabbir and Ahmad (2010) investigated the urban transportation in Rawalpindi and Islamabad to analyze the status of emission of air pollutants and energy demands. A simple model of passenger transport was developed using LEAP. The LEAP model was used to estimate total energy demand and the vehicular emissions for the base year 2000 and extrapolated till 2030 for the future predictions. Transport database in Rawalpindi and Islamabad, together with fuel consumption values for the vehicle types and emission factors of NOx, SO_2 and PM_{10} corresponding to the actual vehicle types formed the basis of the transport demand, energy consumption and total emission calculations. Apart from *base scenario,* their model was run under three alternative scenarios to study the impact of different urban transport policy initiatives that would reduce energy demand and emissions in transport sector of Rawalpindi and Islamabad. For each scenario the assumptions were the following.

Business-as-usual (BAU)l scenario

1. This scenario was based on a continuation of the existing trends, and
2. By extrapolating these trends, values were projected to 2030 without any change.

Population reduction scenario

1. Population stress in the GIRA (Greater Islamabad and Rawalpindi Area) would be reduced,
2. Average annual population growth rate of 3.39% in Rawalpindi and 5.75% in Islamabad in BAU would be reduced by 1%, and
3. Vehicle growth rate, travel demand and other factors would decrease proportionately.

Public transport scenario

1. If a change was brought at minimum rate in both cities, there would still be a significant effect,
2. The growth rate of private vehicles would be decreased by 1%, and
3. The growth rate of public transport especially buses would be increased by 1%.

Natural gas vehicle scenario

1. The natural gas could be used in both gasoline and diesel engine with minor modification,
2. The substitution for gasoline and diesel engine in urban taxi, cars, jeeps and station wagons in the region of Rawalpindi and Islamabad would be applied, and
3. The substitution rate of NGV for above mentioned vehicles was assumed to be 1%.

To project fuel (gasoline and diesel) consumption from vehicles in China until 2030, **Zhang et al. (2010)** designed three alternative energy consumption decrease scenarios; the business-as-usual scenario, the advanced fuel economy scenario, and the alternative energy replacement scenario. These scenarios were based on energy policies and alternative vehicle types of China until 2030. *The fuel economy (fuel consumption per km travel distance)* of different vehicle types was subject to variation of government regulations; hence the fuel consumption of passenger cars (PCs), light trucks (Lts), heavy trucks (Hts), and buses and motor cycles (MCs) were calculated with respect to (i) the number of vehicles, (ii) distance traveled, and (iii) fuel economy. On the other hand, the consumption rate of alternative energy sources (i.e. ethanol, methanol, biomass-diesel and compressed natural gas) was not evaluated. The number of vehicles was evaluated using the economic elastic coefficient method, relating to per capita gross domestic product (GDP) from 1997 to 2007. The common assumption which was made for the three scenarios was that until 2030 vehicle stocks would remain unchanged. Furthermore, the individual assumptions for each scenario are the following:

Business-as-usual (BAU) scenario

1. Vehicle technology would be maintained at the existing level,
2. In 2004, fuel economy of new passenger cars would be 10%, with a 15% decrease in 2006 and 2008, respectively, compared to that of 2004, and

3. The fuel economy of other vehicle categories would remain unchanged.

Advanced fuel economy scenario

1. Due to improvements in vehicle technology, fuel economy of new Lts, Hts and Buses would decrease by 10%, 10%, 10%, 5%, and 5% during 2007–2008, 2008–2013, 2013–2018, 2018–2023, and 2023–2028, respectively,
2. Based on the BAU scenario, the fuel economy of new PCs would further decrease by 10% during 2008–2020 and 2020–2025,
3. As there would be no research and/or policies on the fuel economy of MCs, the fuel economy of new MCs would remain the same to those levels of the BAU scenario. Alternative fuel replacement was not considered in this scenario,
4. If fuel efficiency changes were not going to be implemented as planned, more fuel would be required as in the BAU scenario.

Alternative energy replacement scenario

1. Until 2030, the percentage of diesel PCs would continue to approach that in Europe, where 40% of PCs used diesel fuel in 2006,
2. The proportion of other types of diesel vehicles would remain unchanged,
3. Ethanol-gasoline use would become the national standards by 2010, with the regulated proportion of ethanol being 10%, 15%, 20% and 25% by 2015, 2020, 2025, and 2030, respectively,
4. Biomass-diesel would account for 5%, 10%, and 20% of vehicle diesel in 2010, 2020, and 2030, respectively,
5. The production of ethanol might ultimately account for 20% of vehicle gasoline usage by 2020,
6. The production of bio-diesel would account for 15% of the vehicle diesel usage by 2020,

7. Bio-fuel usage was not considered to have a great impact on the security of food supply, and
8. Buses with compressed natural gas would account for 5%, 10%, 15%, 20%, and 25% of buses in Chinese cities in 2010, 2015, 2020, 2025, and 2030.

He et al. (2011) established a methodology to analyze carbon emissions from the urban transportation sector at the Chinese city level. By using as an example Jinan, the capital of China's Shandong Province, they developed an analytical model to simulate energy consumption and carbon emissions based on the number of trips, the transportation mode split, and the trip distance. In this work, the authors also described the simulation of three transportation system development scenarios. For each scenario, the following assumptions were made:

Business-as-usual scenario

1. There was no policy intervention and the current trend of motorization would continue,
2. Car trips (including private cars, business cars, and taxis) would account for 35% of total trips, which was roughly the existing situation in Beijing, but still much lower than that in U.S. cities, and
3. NMTs (non-motorized transportation) would continue to shrink, but public transit would continue a steady growth.

Low Policy Intervention Scenario

1. The existing proposed urban transit development policies would be well implemented,
2. The public transit share in key cities should reach 45% by 2030,
3. The existing BRT (bus rapid transit) development policy in Jinan would continue to build a high-quality service network,

4. The rail construction would follow the already-adopted plan and would offer 7% of trips,
5. The costs for BRT and metro construction would be about RMB 30 M/km and 400 M/km, respectively,
6. The total capital requirements would be 20 billion RMB, and
7. The car growth rate would be reduced, whereas the NMTs would continue to shrink.

High Policy Intervention Scenario

1. If significant efforts were made to reform the urban development pattern to promote the transit-oriented development, together with a great urban NMT system and public space design, Jinan could reach sustainable urban transportation development results with efforts and policies which would establish the following:
   - High-density (overall, Floor Area Ratio greater than 6.0) development around metro stations and BRT corridors with highly mixed land use within walking and biking distance,
   - City renovation to support a safe and convenient walking and biking system,
   - A fine road network and smaller parcels of land use in newly developing areas,
   - A robust public spaces network to “invite” personal life in the city rather than in cars,
   - An excellent accessibility to the public transit system,
   - A highly mixed land use development in areas of new development,
   - Robust car restriction policies, parking policies, congestion charging, and traffic calming designs.
2. Based on the experiences in Hong Kong and Singapore, Jinan could control car usage to less than 20% of total trips, thereby maintaining the share of public transit and NMTs at more than 80% of total trips.

3. Public transit could cover 50% of total trips by 2030;
4. The car trip share would peak in 2020 and then drop to 15% by 2030.

The results of this study illustrated that if no policy intervention was implemented for the transportation mode split (the business-as-usual (BAU) case), then emissions from Chinese urban transportation systems would quadruple by 2030. However, a dense, mixed land-use pattern, as well as transportation policies that encourage public transportation, would result in the elimination of 1.93 million tons of carbon emissions—approximately 50% of the BAU scenario emissions.

Considering jointly energy and materials flow, **Palencia et al. (2012)** examined the impacts of using (a) hybrid vehicles, (b) plug-in hybrid vehicles and (c) fuel cell vehicles together with vehicle light-weighting using high-strength steel, as measures to reduce carbon emissions from light-duty vehicle fleet. To study the evolution of light-duty vehicle fleet until 2050, the following six scenarios were developed:

1. The base
2. The plug-in hybrid electric vehicle (PHEV),
3. The fuel cell vehicles (FCV),
4. The base together with a high strength steel (HSS),
5. The FCV together with HSS,
6. The PHEV together with the HSS.

These scenarios represented different choices regarding powertrains, fuels and materials for vehicle manufacturing. Particularly:

- The base scenario represented the continuation of current policies for the promotion of biofuels and natural gas use,

- Scenarios 2 and 3 intended to reduce CO_2 emissions replacing gasoline fueled internal combustion engine vehicles with alternative powertrains
- Scenarios 4, 5, and 6 considered that a penetration of vehicles by 5% weight reduction would be achieved using high strength steel.

Pongthanaisawan and Sorapipatana (2013) examined the pattern and growth in energy demand as well as related GHG emissions from Thailand's transport sector. Furthermore, the authors analyzed potential pathways of energy demand and GHG emissions reduction from this sector of the measures which had been set by the Thai Government. A set of econometric models were developed to estimate the historical trend of energy demand and GHG emissions in the transport sector during 1989–2007 and to forecast future trends to 2030. Two mitigation option scenarios of fuel switching and energy efficiency options were designed to analyze pathways of energy consumption and GHG emissions reduction potential in Thailand's transport sector compared with the baseline business-as-usual (BAU) scenario. Particularly, for each one of the three scenarios the following assumptions were made:

Business-as-usual (BAU) scenario

1. Nothing would influence the long-term trends of transport energy demand and none of the mitigation options was implemented during 2008–2030,
2. Annual population growth rate was 0.6%,
3. Average annual GDP growth rate was 4.5%, and
4. Annual crude oil price increase was 5.0%.

Fuel switching option scenario

1. GHG emissions were mitigated by replacing conventional gasoline and diesel with bioethanol and biodiesel respectively,

2. The substitution of bioethanol for gasoline, and biodiesel for diesel would begin in 2008 for meeting the targets of the government,
3. Bioethanol was targeted to substitute for conventional gasoline in increasing amounts of 3.0, 6.2 and 9.0 million liters per day by 2011, 2016, and 2012 respectively, and
4. Biodiesel was targeted to replace conventional diesel for 3.0, 3.64, and 4.5 million liters per day by 2011, 2016, and 2022, respectively.

Energy efficiency option

1. Consumers would increasingly opt for hybrid cars in place of conventional cars equipped with engine greater than 2000 c.c., and eco-cars in place of those having engine size less than 1600 c.c.,
2. High energy efficiency cars would penetrate to conventional cars slowly in the early period since 2008 and rapidly increasing during the middle period until the share of them would approach to one hundred percent of all new cars in 2030,
3. Average vehicle travels would be 16502 km per year,
4. Average fuel economy of conventional mid-size and small-size passengers cars would be 8.98 and 7.14 lt of gasoline per 100 km respectively, and
5. Average fuel economy of hybrid cars and eco-cars are 7.10 and 5.0 lt of gasoline per 100 km respectively.

SECTION 4

An analysis of long-term scenarios for the transition to renewable energy in Greece

4.1. Introduction

An important issue for public health, economy and the environment is air quality that is negatively related to climate change. Although various policies have been implemented in national and sectoral level, air pollution continues to pose a threat to human health and affects the economy and the environment. However, Europe under the framework of integrated policies has achieved to reduce emissions of various air pollutants and substances such as sulphur dioxide (SO_2), carbon monoxide (CO), benzene (C_6H_6) and lead (Pb) (European Environment Agency, 2013).

In 2007, targets were set in order to develop an energy efficient and low carbon Europe. These targets, known as the "20-20-20" targets, include:

- A 20% reduction in EU greenhouse gas emissions from 1990 levels;
- An increase in the share of EU energy consumption produced from renewable resources to 20%;
- A 20% improvement in the EU's energy efficiency.

Moreover, in 22 January 2014, an integrated policy framework for the period up to 2030 was presented towards a renewable energy economy as the share of renewable energy sources is set to increase by at least 27% till 2030.

The Greek government in an effort to adopt a green economy has included ambitious policies and measures for increasing the use of renewable energy. Specifically, Law

3851/2010 sets the framework for the deployment of renewable energy. The government tries to ensure that the 2020 European targets are met. The development of renewable energy sources in the electricity sector is of crucial importance to achieve the National and European objectives. The overall target of 20% participation of Renewable Energy Sources (hereafter **RES**) in gross final energy consumption is composed of 40% participation of RES in electricity production, 20% in heating and cooling and 10% in transport.

Additionally, it is necessary to make investments in the electricity sector and exploit the potential of wind and solar energy. An important development is to connect Greek islands with abundant wind and solar power potential to the mainland transmission network and to expand hydropower and natural gas capacity (IEA/OECD, 2011).

At national level the energy sector is very important for economic development. From an environmental perspective, the energy sector in Greece can be characterized by the inefficient use of energy, the small reduction of greenhouse gas emissions as well as the slow replacement of conventional fuels (like lignite).[26] Nevertheless, many actions have been initiated in order to comply with EU policies on the management of energy by looking for improvements over the national legal framework considering the production and consumption of energy.[27] Furthermore, Renewable Energy in Greece is at a relatively high level of capacity utilization, particularly in the most prevalent forms, following the global and European trend and creating a national strategy (European Environment Agency, 2012; p. 178).

The remainder of this paper is structured as follows. In Section 2, we explore the basics concerning the penetration of renewable energy sources in the Greek energy system and specifically in the electricity generation sector, providing information for the existing

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[26] For the effect of electricity consumption from renewable sources on countries' economic growth levels see Halkos and Tzeremes (21014a).

[27] For the effect of countries compliance with the Kyoto protocol agreement (KPA) policies see Halkos and Tzeremes (2014b) and Halkos (2014).

legislative framework. Section 3 presents the Long range Energy Alternatives Planning system (LEAP), the proposed scenarios and the basic key assumptions. Section 4 comments on and analyzes the results of the simulation output, emphasizing the technical, environmental and economic implications. Finally, the last section summarizes our main findings.

4.2 Background

Renewable energy sources constitute a cost-effective solution for the energy sector, the society and the environment offering in terms of energy supply much more friendly solutions compared to conventional fossil fuels. Energy independence, geographical dispersion and diversity of the primary forms of energy are some of the reasons that are evaluated and included in government planning of many countries worldwide. In economic terms, the use of RES while depending on the economic prosperity of the country, has further a long-term perspective even during a financial crisis. Although, greenhouse gas mitigation strategies are generally considered costly, the renewable energy and more efficient conversion technologies may have positive socioeconomic effects, create employment and lead to increase in exports (Mathiesen et al., 2011).

The Greek Ministry of Environment, Energy and Climate Change confirms the negative effects of climate change, the solution of which is one of the key priorities. At regional level, actions required to address climate change must involve a change of the current growth model towards a sustainable, green economy and low or zero carbon emissions through the use of modern technology. The low carbon model should be based on horizontal coordination of mitigation policies that will be implemented in the sectors of energy, industry, transport and agriculture. The Greek Action Plan for Greenhouse Gases Abatement[28] includes the decarbonisation of the Greek energy system by introducing low carbon sources or RES

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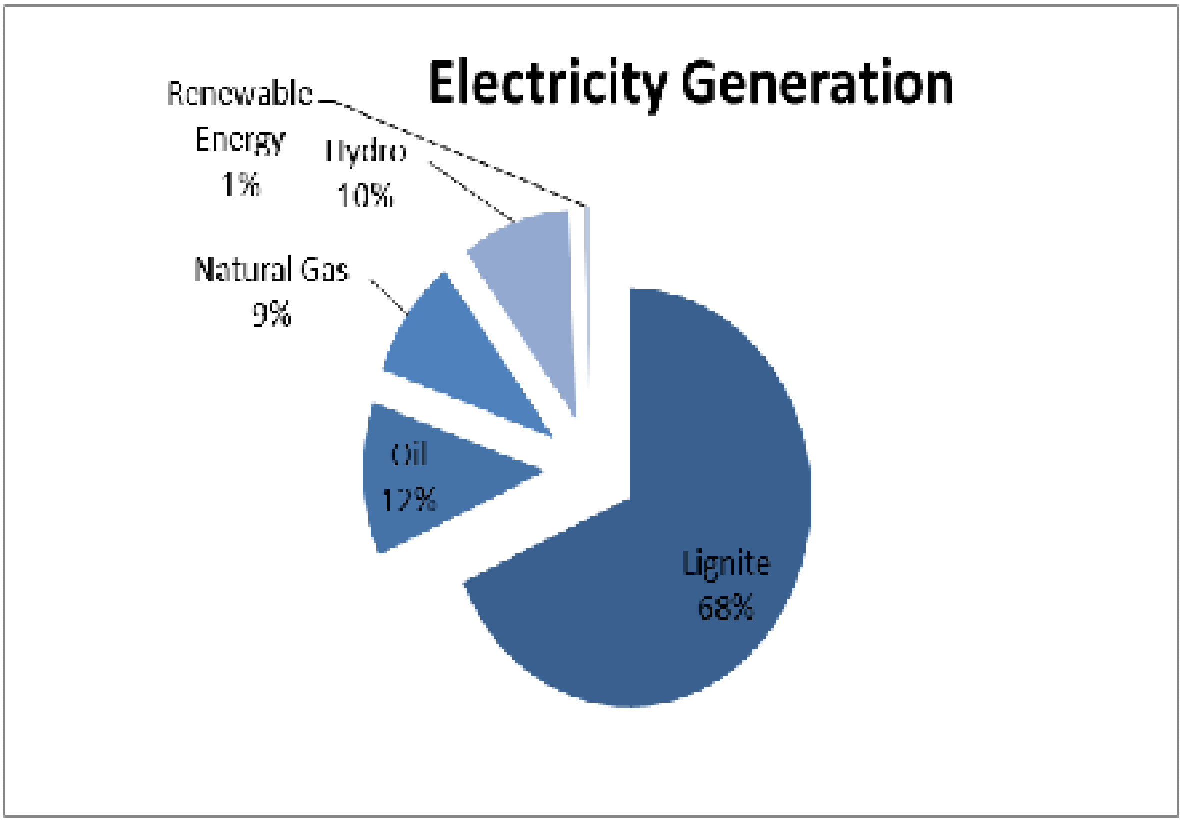
[28] For details on the hypotheses and principles on calculating abatement costs see Halkos (1992, 1993, 2010, 2014).

(IEA/OECD, 2011). The Greek renewable energy policy follows EU requirements such as the binding target to increase the share of renewable energy in gross final energy consumption by 2020. The government plans to reach the 2020 renewable energy targets through a combination of measures on energy efficiency and renewable energy[29].

Figure 4.1: Electricity Generation in Greece for 2012



4.2.1. Legislative framework

According to Law 3851/2010, on the acceleration in the development of RES to deal with climate change and other provisions relating to the jurisdiction of the Ministry of Environment, Energy and Climate Change, the Greek government proceeded to increase the national goal for participation of RES in final energy consumption to 20%, which specializes in 40% participation of RES in electricity, 20% in heating and cooling needs and 10% in transport (Ministry of Environment, Energy and Climate Change, 2012a).

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[29] Policies and measures are described in detail in Ministry of Environment, Energy and Climate Change (2010).

Considering the economic part of Law 3851/2010, new electricity pricing for the main categories has been submitted and is analyzed in Table 4.1. The aforementioned Law is an important part of the National Action Plan for Renewable Energy, which taking into account the standards of the European Energy Policy, is prepared to be able to «*play the role of a potential tool for monitoring national energy goals*» (Ministry of Environment, Energy and Climate Change, 2012a; Law, 3851/2010).

Table 4.1: Electricity power pricing of key Renewable Energy Sources (Greece)

Generating electricity from:	**Energy Price (€ / MWh)**	
	Interconnected system	**Non-interconnected islands**
Wind energy exploited in onshore power installations greater than 50 KW.	87,85	99,45
Wind energy utilized to power installations less than or equal to 50 KW.	250	250
Photovoltaics to 10 KW in the residential sector and small businesses.	550	550
Hydraulic energy utilized by small hydropower stations with installed capacity up to 15 MW.	87,85	87,85
Solar energy utilized by solar thermal power plants.	264,85	264,85
Solar energy utilized by solar thermal power plants with storage system at least two hours.	284,85	284,85
Geothermal Energy low enthalpy (Law 3175/2003).	150	150
Geothermal Energy high enthalpy (Law 3175/2003).	99,45	99,45
Biomass is used by stations ≤ 1 MW.	200	200
Biomass harvested from plants > 1 MW and ≤ 5 MW	175	175
Biomass is used by stations > 5 MW.	150	150

Source: Modified and relying on Law 3851/2010

Concerning the energy savings field, Greece has already implemented the 1st Energy Efficiency Action Plan, which provides 9% of energy savings in final energy consumption by the year 2016 in accordance with Directive 2006/32/EC. Moreover, in the context of Law 3855/2010, which has been added to the recent regulation on energy performance of buildings, there is advancement in the development of market mechanisms and implementation of specific measures and policies aimed at achieving this national goal (Ministry of Environment, Energy and Climate Change, 2012a).

The Ministerial Decree 19598/01.10.2010 posed the desired ratio of installed capacity and the distribution in time of the various renewable energy technologies. The main characteristic of this Ministerial Decree is the liberation from the constraints of Geothermal Energy, as well as, its participation in the electricity production of the country in the forthcoming years. Besides, in the framework of the interpretative Circular 26928/16.12.2010 some amendments have been implemented concerning the examination of requests for the installation of Renewable Source power plants on agricultural land of high productivity, including the category of professional farmers (Circular 26928/2010; Ministerial Decree 19598/2010). Finally, in 2011, the Joint Ministerial Decree 28287/12.12.2011 posed a special fee and incentives to household consumers in areas where renewable energy technologies had been installed (Common Ministerial Decree 28287/2011).

4.2.2. Renewable Energy Sources

The Wind Energy in Greece is at a high level, with a large number of wind turbines and a significant total installed capacity corresponding to approximately 1800 MW. Furthermore, there are prospects and estimations for the coming years, which are quite encouraging in accordance with the upward trend in recent years. From 1998 and onwards, the growth in wind power is quite high and has not declined during the outbreak and the early years of the global financial crisis (HWEA, 2013).

The wind potential in Greece is quite remarkable, having in several parts of the country average wind speeds that are economically exploitable. The highest wind speed is greater than 10 meters per second (m/s) and is located at the southern part of Evia (east of Karystos), in Skyros, Andros, Laconia, Amorgos, western Samos, in the southwestern island of Rhodes, Karpathos and eastern Crete. Speeds 9 to 10 m/s are found in all islands of the Aegean Sea, south Evia, Corfu, Kefalonia, in southern Attica and in scattered parts of Greece. Offshore wind farms in Greece like in most Mediterranean countries are inferior to the first theoretical steps beginning in 2010. The areas of Alexandroupolis, Thassos, Corfu, Kimi, Lemnos and Samothrace were selected to be included to Wind Energy development projects. The horizon for the first development phase of projects in these areas, was determined to be five years from 2012 to 2017, but at the end of 2012 no project was implemented (Ministry of Environment, Energy and Climate Change, 2011; 2012b).

Analyzing the total installed wind power of Greece in the individual regions of the country, it becomes apparent that Central Greece is leading with the largest share of production. The total installed capacity of the regions of Peloponnese, Eastern Macedonia and Thrace, Crete and Western Greece, is greater than 100 MW (HWEA, 2013).

The Solar Energy in Greece is expanded with very high growth rates in recent years, mainly in the category of photovoltaic (PV) systems. It is noticeable that from 2009 to 2010 the total installed capacity of PV systems was increased almost fivefold and from 2010 to 2011 was tripled while from 2011 to 2012 was more than doubled. Still, PV systems are the locomotive of Renewable Sources in Greece, accounting for 88% of new capacity in 2012 (Hellenic Association of PV Companies, 2013).

The solar potential of Greece is one of the best in the European Union, along with the other Mediterranean countries. The location of the country between 340 and 420 parallel of the northern hemisphere gives a mild Mediterranean climate suitable for systems operating utilizing solar radiation. The maximum average potential, measurable with a photovoltaic system of 1 KW, is located in Dodecanese, Cyclades, Crete, Sporades, East Aegean Islands, Attica, in south Central Greece, in eastern Peloponnese and in Western Macedonia.

In contrast, the lowest rates are located in the north and in eastern Macedonia and Thrace. The exploited potential of the country has rocketed in recent years of only 10,3 MW in 2008 to 1.536 MW in 2012 and 1.862,5 MW as in February 2013, with Greece in the fourth position in Europe and seventh internationally in new PV installed capacity in 2012. In terms of participation within the country, it is estimated that the total production of solar panels, which touched the 1.7 billion kilowatt hours, covered 3% of the electricity needs of Greece in 2012. This trend shows that it is very likely that in 2013 the output of photovoltaic systems will overcome wind power for the first time (Hellenic Association of PV Companies, 2013).

Analyzing the distribution of total installed capacity in 2012 in Greece by photovoltaic systems in regions of the country we conclude that the Peloponnese is leading with Central and Western Greece to follow. In contrast, concerning the total installed capacity of photovoltaic systems on roofs of houses, the Region of eastern Macedonia and Thrace holds the primacy, with the Peloponnese and central Greece to follow (Hellenic Association of PV Companies, 2013).

Hydropower in Greece has several large, economically exploited potential, which is estimated at around 80 TWh. Until today, the rate of capacity utilization that is around 40% was derived from 16 major hydropower projects and many small which are all under the operation of the Public Power Corporation (PPC), while private investors do not participate in the production until now. Greece is a fairly mountainous country with a rich potential of waterfalls due to the configuration of the basin, but also due to several rainfalls, creating a considerable hydropower potential, quite capable of significant generation of electricity. The active and under-construction facilities, as well as, areas of interest, for large and small-scale hydropower stations respectively, are accumulated mainly in Western Greece where annual rainfall is around 260 cm. The locations where the rain gets the highest values are found in the prefectures of Ioannina, Grevena, Trikala, Arta, Karditsa, Evrytania, Phocis and Achaia (Athens Water Supply and Sewerage Company, 2010).

Unlike large-scale hydroelectric power plants, small plants, that by 2013 their total installed capacity reached only the 218 MW, have several pending applications for new stations that are in various procedural stages. Thus, there would be an increase of power in the coming years, which, due to the fact that as small-scale stations are those who have a capacity below 10 MW, is not expected to be a large-scale annual increase (Operator of Electricity Market S.A., 2012).

4.3 Utilization of LEAP System

The Long range Energy Alternatives Planning System (hereafter **LEAP**) is a widely-used software tool for energy policy analysis and climate change mitigation assessment developed by the Stockholm Environment Institute. LEAP has been adopted by thousands of organizations in more than 190 countries worldwide. LEAP is fast becoming the de facto standard for countries undertaking integrated resource planning, greenhouse gases (hereafter **GHG**) mitigation assessments, and Low Emission Development Strategies (LEDS) especially in the developing world. Many countries have also chosen to use LEAP as part of their commitment to report to the United Nations Framework Convention on Climate Change (UNFCCC).

There are various studies in Greece that have been conducted in order to provide the literature with long-term projections in the energy sector using LEAP. Giatrakos et al. (2009) evaluated the present electrical energy status, and examine the possibility of further penetration of sustainable energy for Crete. Analysis shows that even the most modest and realistic RES implementation scenarios, combined with a partially successful demand restriction, could indeed contract the island’s environmental footprint. RES penetration into

Crete's electric system seems to be able to surpass 30% by 2020, satisfying even the optimistic European targets. Roinioti et al. (2012) constructed energy scenarios for the future with a focus on the Greek electricity production system and explore how these scenarios are reflected in economic and environmental terms as well as in terms of energy efficiency.

Papagiannis et al. (2008) present the results of an analysis on the economic and environmental impacts of the application of an intelligent demand side management system, called the Energy Consumption Management System (ECMS), in the European countries. The long-term impacts following the application of the system are evaluated using the LEAP platform. Results show that under a reasonable market penetration, a reduction of 1–4% in primary energy, of 1.5–5% in CO_2 emissions and a 2–8% savings in investment costs for power generation expansion is to be expected for the EU-15.

4.3.1 Construction of scenarios

Scenarios are self-consistent story lines of the evolution of future energy systems in the context of a specific set of conditions. Scenarios assemble information about different trends and possibilities into internally consistent images of plausible alternative futures (Wiseman et al., 2011; Carter, 2007; Moss et al., 2010). The main concept of LEAP is an end-use driven scenario analysis with a baseline scenario and alternative scenarios. The scenarios are used for a number of "what if" questions under the arrangement of user-defined assumptions. The set of conditions is detailed in the scenarios and are constructed in order to encompass some factors (parameters) that are anticipated to change.

In our case there are three scenarios generated under different options. The policy options and key assumptions that the scenarios are based on are depicted in Table 4.2. That is:

Baseline Scenario: The first scenario is the "Baseline", which is based on historical trends from 1990 till 2010. The Gross Domestic Product (GDP) in current prices and its annual growth rates are presented in Tables 3a and 3b. The projected potential withdrawals of Power Plants are given in Table 4 (Ministry of Environment, Energy and Climate Change, 2013).

Target 2020 Scenario: The second scenario is based on the European target set in 2007, in order to develop an energy efficient and low carbon Europe via an increase in the share of EU energy consumption produced from renewable resources to 20%. According to the government, Law L3851/2010 states that the protection of the climate or the reduction of GHG emissions, through the promotion of electrical energy production from RES is a crucial element of the energy sector of the country. The further specific targets include RES electricity share (40%), RES heating and cooling share for the household sector (20%), and RES transport share (10%) in order to achieve the national target of 20% contribution of the energy produced from RES to the gross final energy consumption. This target will be achieved through the large penetration of RES technologies in electricity production, heat supply and transport sector.

The GDP in current prices and its annual growth rates are presented in Tables 4.3 and 4.4, as for the *Baseline scenario*. Finally, we assume a 50% increase of RES capacity, which corresponds to 5.311,7 MW. Specifically, as the Hellenic Transmission System Operator S.A. publishes binding and final Offers for Connection System or Network for power stations of Renewable Energy and Stations and cogeneration plants of Electricity & Heat and High Performance (CHP), we assume that till 2020 will be achieved half of the non binding offers. Table 5 describes in details the structure of the assumed generated capacity per RES category.

Table 4.2: Policy options and assumptions for scenario generation

Scenario	Policy options	Assumptions
Baseline		The historical trends will continue. Changes in GDP and annual growth are given in Table 3 and potential withdrawals of Power Plants are given in Table 4.
Target 2020	European target: 20 % penetration of RES in final consumption till 2020. Greek Government target: The enactment of Law 3851/2010 RES specializes in a 40 % increase of electricity, 20% increase of the thermal RES and 10 % increase of biofuels.	Changes in GDP and annual growth are given in Table 3 and the potential withdrawals of Power Plants are given in detail in Table 4. Increase of Renewable Sources utilization up to 5.311,7 MW is presented in details in Table 5
Target 2030	European target: 27% increase of RES penetration in final consumption in 2030. This will be achieved by the introduction of RES in industry.	Changes in GDP and annual growth are given in Table 3 and potential withdrawals of Power Plants are given in Table 4. Increase of Renewable Sources utilization up to 10.563,2 MW is presented in details in Table 5

Table 4.3: GDP (in current prices) forecasts according to the IMF optimistic scenario

Year				**GDP (in billion €)**	**Annual Growth Rate**
1980				6.690	
1981				8.009	19.7%
1982				10.073	25.8%
1983				12.018	19.3%
1984				14.947	24.4%
1985				18.238	22.0%
1986				21.793	19.5%
1987				24.550	12.7%
1988				29.873	21.7%
1989				35.504	18.8%
1990				42.851	20.7%
1991				52.921	23.5%
1992				61.178	15.6%
1993				68.885	12.6%
1994				78.119	13.4%
1995				89.555	14.6%
1996				98.397	9.9%
1997				108.886	10.7%
1998				118.398	8.7%
1999				126.155	6.6%
2000				136.282	8.0%
2001				146.428	7.4%
2002				156.614	7.0%

2003				172.432	10.1%
2004				185.266	7.4%
2005				193.050	4.2%
2006				208.622	8.1%
2007				223.160	7.0%
2008				233.198	4.5%
2009				231.081	-0.9%
2010				222.152	-3.9%
2011				208.532	-6.1%
2012				193.347	-7.3%
2013				182.054	-5.8%
2014				182,229	0,1%
2015				188,286	3,3%
2016				197,406	4,8%
2017				206,944	4,8%
2018				216,695	4,7%
2019				226,487	4,5%
	Forecasts				
	Double Exponential Smoothing	**ARIMA (0,2,1) without constant term**	**ARIMA (2,2,1) with constant term**	**Maximum**	
2020	236.270	236.217	236.364	236,364	4,4%
2021	246.049	245.948	246.444	246,444	4,3%
2022	255.827	255.678	256.727	256,727	4,2%
2023	265.606	265.408	267.224	267,224	4,1%
2024	275.385	275.138	277.936	277,936	4,0%
2025	285.164	284.869	288.863	288,863	3,9%
2026	294.942	294.599	300.007	300,007	3,9%
2027	304.721	304.329	311.366	311,366	3,8%
2028	314.500	314.060	322.940	322,940	3,7%
2029	324.278	323.790	334.731	334,731	3,7%
2030	334.057	333.520	346.737	346,737	3,6%

Table 4.4: GDP (in current prices) forecasts according to the OECD conservative scenario

Year				**GDP (in billion €)**	**Annual Growth Rate**
1980				6.690	
1981				8.009	19.7%
1982				10.073	25.8%
1983				12.018	19.3%
1984				14.947	24.4%
1985				18.238	22.0%
1986				21.793	19.5%
1987				24.550	12.7%
1988				29.873	21.7%

1989				35.504	18.8%
1990				42.851	20.7%
1991				52.921	23.5%
1992				61.178	15.6%
1993				68.885	12.6%
1994				78.119	13.4%
1995				89.555	14.6%
1996				98.397	9.9%
1997				108.886	10.7%
1998				118.398	8.7%
1999				126.155	6.6%
2000				136.282	8.0%
2001				146.428	7.4%
2002				156.614	7.0%
2003				172.432	10.1%
2004				185.266	7.4%
2005				193.050	4.2%
2006				208.622	8.1%
2007				223.160	7.0%
2008				233.198	4.5%
2009				231.081	-0.9%
2010				222.152	-3.9%
2011				208.532	-6.1%
2012				193.347	-7.3%
2013				182.054	-5.8%
2014				178.959	-1.7%
2015				180.212	0.7%
	Forecasts				
	Double Exponential Smoothing	**ARIMA (0,2,1) without constant term**	**ARIMA (2,2,2) with constant term**	**Average**	
2016	182.209	182.142	181.817	182.056	1.0%
2017	184.227	184.072	184.576	184.292	1.2%
2018	186.246	186.003	186.918	186.389	1.1%
2019	188.264	187.933	189.853	188.683	1.2%
2020	190.282	189.863	192.415	190.853	1.2%
2021	192.300	191.793	195.379	193.157	1.2%
2022	194.319	193.723	198.077	195.373	1.1%
2023	196.337	195.653	201.068	197.686	1.2%
2024	198.355	197.584	203.878	199.939	1.1%
2025	200.373	199.514	206.907	202.265	1.2%
2026	202.392	201.444	209.816	204.551	1.1%
2027	204.410	203.374	212.892	206.892	1.1%
2028	206.428	205.304	215.893	209.208	1.1%
2029	208.446	207.235	219.023	211.568	1.1%
2030	210.465	209.165	222.109	213.913	1.1%

Table 4.5: Projected potential withdrawals of power stations

Withdrawal of Power Units	Power Output (MW)	Power Units	Fuel
2011	64	Ptolemaida 1	Lignite
2011	113	Megalopoli 1	Lignite
2011	113	Megalopoli 2	Lignite
2012	117	Ptolemaida 2	Lignite
2012	33	Liptol	Fuel oil
2013	144	Aliveri 3	Fuel oil
2013	145	Aliveri 4	Fuel oil
2014	145	Laurio 1	Fuel oil
2014	285	Laurio 2	Fuel oil
2014	173	Laurio 3	Natural Gas
2014	117	Ptolemaida 3	Lignite
2015	153	Ag. Geor. 8	Natural Gas
2015	185	Ag. Geor. 9	Natural Gas
2015	276	Ptolemaida 4	Lignite
2019	275	Kardia 1	Lignite
2019	275	Kardia 2	Lignite
2019	300	Kardia 3	Lignite
2019	275	Kardia 4	Lignite
2019	273	Amintaio 1	Lignite
2019	273	Amintaio 2	Lignite
2022	274	Ag. Dimitrios 1	Lignite
2022	274	Ag. Dimitrios 2	Lignite
2022	283	Ag. Dimitrios 3	Lignite
2022	283	Ag. Dimitrios 4	Lignite
2024	260	Megalopoli 4	Lignite
2024	270	Megalopoli 3	Lignite

Source: Ministry of Environment, Energy and Climate Change (2013)

Table 4.6: Generation capacity projections per RES category till 2020 and 2030

RES	Capacity (MW) 2020	Capacity (MW) 2030
Photovoltaics	207,5 MW	415 MW
Wind Park	4.666,5 MW	9.333 MW
Small Hydro	350,2 MW	640,2 MW
Biomass	87,5 MW	175 MW
TOTAL	5.311,7 MW	10.563,2 MW

http://www.desmie.gr/ape-sithya/stathmoi-ape-sithya-me-prosfora-syndesis/

Target 2030 Scenario: We follow the target set in 22 January 2014 by the European Commission towards a renewable energy economy. Specifically, the share of renewable energy penetration in final consumption is set to increase at least 27% by 2030. This will be achieved by the introduction of RES in industry. Following Heaps et al. (2009) concerning the industry sector, CO_2 emissions can be further reduced through the increased use of biomass, natural gas and increased participation of RES in electricity, the iron and steel production sector, the cement production, chemicals production and other industrial subsectors. As far as the changes in GDP which are used in *target 2030 scenario,* these are given in Tables 4.2 and 4.3, as for the *Baseline* and *target 2020 scenarios*. Finally, we assume a 100% increase of RES capacity, which corresponds to 10.563,2 MW. Specifically, as in the previous scenario and relying on the Hellenic Transmission System Operator S.A., the last column of Table 4.6 describes in details the structure of the assumed generated capacity per RES category.

4.3.1.1 GDP scenarios

Reporting the assumptions for the three scenarios, «Baseline», «Target 2020» και «Target 2030», forecasts were made for the Greek GDP in current prices for the period 2014-2030. The GDP time series in current prices is available from either EL.STAT[30] or from the International Monetary Fund (IMF)[31] as «Expenditure-based GDP Expressed in billions of national currency units» within the topic Data and Statistics in the revised databases for April 2014 «World Economic Outlook Databases». To develop the forecasts, estimates for the Greek GDP growth reported from both the IMF and the Organization for Economic Co-operation and Development (OECD, 2014) were used. According to the size of estimates, two scenarios were created, the «optimistic» based on the IMF estimates, and the «conservative» according to OECD estimates.

Particularly, the IMF gave the following estimates for the Greek GDP in billion €: 182,229, 188,286, 197,406, 206,944, 216,695 and 226,487 for the years 2014, 2015, 2016, 2017, 2018 and 2019 respectively. Incorporating these estimates into the existing GDP time

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[30] http://www.statistics.gr/portal/page/portal/ESYE/PAGE-themes?p_param=A0702

[31] http://www.imf.org/external/data.htm

series for the period 1980-2013, the final time series 1980-2019 of actual GDP values was produced, which was used to forecast GDP for the period 2020-2030. On the other hand, in April 2014, OECD gave the annual growth rates of the Greek GDP at current prices, which were -1,7% for 2014 and 0,7% for 2015. As in the case of IMF, the OECD estimates, which were for 2014

$$182.054 - 0.017 \times 182.054 = 178.959 \text{ δις. €},$$

and for 2015

$$178.959 + 0.007 \times 178.959 = 180.212 \text{ δις. €},$$

were incorporated into the GPD time series 1980-2013. So in the case of the conservative scenario for the GDP growth, forecasts for the period 2016-2030 were made based on the GDP series 1980-2015 by using the OECD estimates for the years 2014 and 2015.

In both GDP time series, which were developed under «*the IMF optimistic scenario*» for the period 1980-2019 and under «*the OECD conservative scenario*» for the period 1980-2015, at a first stage, forecasts for the periods 2020-2030 and 2016-2030 were developed by using the double exponential smoothing method (e.g. Makridakis et al., 1998). At a second stage, to identify the "best" stochastic ARIMA model describing each series, the augmented Dickey-Fuller test, including in the test equation both a trend term and an intercept (Halkos and Kevork, 2005), was applied to the first and second differences of the GDP series of each scenario. The test results are presented in Tables A1 and A2 of the Appendix for the optimistic and the conservative scenario respectively. It was realized that for both GDP series, the null hypothesis of a unit root is rejected at 5% level of significance after taking the second differences.

Following the augmented Dickey-Fuller test results, alternative ARIMA models (p,2,q) were fitted (Box et al., 2008; Harvey, 1993) to the GDP series, and in each model residual diagnostic tests were performed. These tests included the Jarque-Bera test for Normality, the Breusch-Godfrey Serial Correlation LM Test, and the ARCH LM-test.[32] For each scenario, the results of these tests are reported in Tables A3 and A4 of the Appendix. For those ARIMA models in which the aforementioned residual diagnostic tests passed successfully, the values of the criteria Akaike Info, Schwarz, Hannan-Quinn, MAE (Mean Absolute Error) and MAPE (Mean Absolute Percentage Error) were obtained. For each scenario, the examination of these criteria values, which are reported in Tables A5 and A6 of the Appendix, leads to the following findings:

<u>“Best Models” for «the IMF optimistic scenario»</u>

(a) The ARIMA (0,2,1) model without constant term gives the lowest values for the Akaike Info, Schwarz, and Hannan-Quinn criteria,

(b) The double exponential smoothing gives the lowest MAE value, and

(c) The ARIMA (2,2,1) model with constant term gives the lowest MAPE value.

<u>“Best Models” for «the OECD conservative scenario»</u>

(a) The ARIMA (0,2,1) model without constant term gives the lowest values for the Akaike Info, Schwarz, and Hannan-Quinn criteria,

(b) The double exponential smoothing gives the lowest MAE value, and

(c) The ARIMA (2,2,2) model with constant term gives the lowest MAPE value.

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[32] For more information on the tests see among others Halkos (2006).

For each "best model" within each scenario, in Figures A1 and A2 of the Appendix, the time series plot of actual values versus the corresponding fitted ones is displayed. Observe that in all graphs the fitted values simulate very satisfactory the actual values.

As in both scenarios no model predominates against the others according to the reported criteria values, to make the forecasts we acted as follows. Accompanying the IMF optimistic scenario with the best-case forecast, for each year of the period 2020-2030, the highest forecast between those obtained from the aforementioned best three best models was taken. It was found that for the whole period 2020-2030 the ARIMA (2,2,1) model with constant term gave the highest forecasts. On the other hand, considering the OECD conservative scenario as more likely to occur according to the Greek reality, for this scenario the forecasts for each year of the period 2016-2030 were taken as the average of the corresponding forecasts produced by the corresponding three best models. For the two scenarios of the Greek GDP growth, the available actual series for the period 1980-2013, the estimates of IMF and OECD, as well as, the corresponding forecasts together with the annual growth rates were presented in Table 3a and 3b respectively.

4.3.2 Structure of LEAP dataset

4.3.2.1 LEAP "tree"

The LEAP "tree" in the case of Greece includes a demand dataset describing the energy use in each branch "tree'' in the base year and through 2030. It also includes various demographic and economic indicators. The sources used for energy demand data include the Hellenic Statistical Authority (El. Stat)[33], the Eurostat[34], the Bank of Greece[35], the World

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[33] http://www.statistics.gr/

[34] http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/

[35] http://www.bankofgreece.gr/Pages/default.aspx

Bank, and the OECD[36]. The dataset depicted in Table 4.7 includes activities such as number of households, economic output, fuel shares and energy intensities. The demand includes six sectors: Households, Agriculture and Fishing, Services, Industry, Transport and the Non-Energy Fuel Use. This is accompanied by various demographic and economic indicators.

Table 4.7: Energy Demand Structure

Sectors/ Indicators	**Sub-sectors**	**Fuel categories**	**Sources**
Households		Natural gas, solar, wind, biomass, heat, electricity, coal	El.Stat, Eurostat, World Bank, OECD
Agriculture and Fishing		Petroleum products, geothermal, electricity, biomass	El.Stat, Eurostat, World Bank, OECD
Services		Petroleum products, solar, wind, electricity, biomass, natural gas	El.Stat, Eurostat, World Bank, OECD
Industry	Iron and Steel, Chemical and Petrochemical, Non Ferrous Metals, Non Metallic Minerals, Transport equipment, Paper Pulp and Printing, Wood and Wood Products, Textile and Leather, Construction, Mining and Quarrying, Other Industry	Lignite, coal, electricity, natural gas, biomass–biogas	El.Stat, Eurostat, World Bank, OECD
Transport	Road, Rail, Domestic Aviation, Domestic Shipping, Pipelines, Other Transport	Petroleum products, electricity, natural gas, biomass– biogas	El.stat, Eurostat, World Bank, OECD
Non Energy Fuel Use		Petroleum products, natural gas	El.Stat, Eurostat, World Bank, OECD

As it can be seen from Table 4.7, Households' sector fuel categories used in the model include natural gas, solar, wind, biomass, heat, electricity and coal. Agriculture and Fishing fuel categories include petroleum products, geothermal, electricity, and biomass. Services fuel categories include petroleum products, solar, wind, electricity, biomass and natural gas. Industry is further divided into sub-sectors, such as iron and steel, chemical and

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[36] http://www.oecd.org/

petrochemical, non- ferrous metals, non-metallic minerals, transport equipment, paper pulp and printing, wood and wood products, textile and leather, construction, mining and quarrying, and other industry. Transport is divided into road, rail, domestic aviation, domestic shipping, pipelines, and other Transport. Non Energy Fuel Use includes petroleum products and natural gas.

4.3.2.2. Transformation Modules

The fuel supply portion of the dataset is divided into five transformation modules: Distribution Losses, Own Use, Combined Heat and Power (CHP) Production, Electricity Generation and Oil Refining (see Table 4.8). The LEAP model of Greece includes primary resources, such as crude oil, lignite, or wind energy and secondary resources such as electricity or oil products.

Table 4.8: Fuel supply dataset of Greece

Module	Process types	Fuels	Sources
Distribution Losses	Process	Electricity, natural gas	El. Stat, Eurostat, PPC[37]
Own Use	Process	Electricity, natural gas, Lignite, Petroleum products	El. Stat, Eurostat, PPC
CHP Production	Output Fuels	Electricity	El. Stat, Eurostat, PPC
	Process	Natural gas, Lignite, Oil, Biomass	El. Stat, Eurostat, PPC
Electricity Generation	Output Fuels	Electricity	El. Stat, Eurostat, PPC
	Process	Natural gas, Lignite, Oil, Biomass-Biogas, Wind, Photovoltaic, Large_Hydro, Small Hydro, Geothermal	El. Stat, PPC, CRES[38], RAE[39], H.T.S.O.S.A[40]
Oil Refining	Process	Crude oil	El. Stat, Eurostat, PPC

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[37] http://www.dei.gr/

[38] http://www.cres.gr/kape/index.htm

[39] http://www.rae.gr/site/portal.csp

[40] http://www.desmie.gr/nc/en/home/

4.4 Results

4.4.1 Baseline scenario with the OECD conservative scenario of GDP growth

In the Baseline Scenario, the historical trends will continue to be the same without any change. All three scenarios take into account the economic crisis and consequent decrease in energy consumption. Figure 4.2 presents the total installed capacity in the Electricity sector. The changes in fuel use in Figure 4.2 are described in details in table 4.9. As it can be observed the use of lignite in the electricity sector in 2020 will decrease by 22% and in 2030 by 44% compared to the use in 2010. Oil products will decrease by 18% in 2020 and by 35% in 2030. However, there will be a substantial increase in the use of natural gas, biomass, geothermal wind, photovoltaic and small hydro energy. The category large hydro is not included in the renewable energy resources. The international trend is to exclude large hydropower projects from the national planning due to the large construction costs and the intense deterioration of the environment (PPC, 2012;.WWF Greece, 2010).[41]

Without any implementation of measures to reduce primary sources of energy production in electricity sector, such as lignite, based on the current data RES share of electricity production will increase by 25% in 2020 and by 29% in 2030 as it is shown in Table 4.10. The total energy requirements by fuel source over the modeling period are shown in Figure 4.3. The RES primary energy demand increases at the expense of fossil fuels such as lignite because of the announced withdrawals of Power Stations by the Public Power Corporation. Table 4.11 depicts the demand energy requirements share per fuel in details as shown graphically in Figure 4.3. Generally, without any environmental policy to increase the

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[41] Scale is important when the effect of hydropower on the environment is considered. Large-scale hydropower sources with dams are a renewable energy source (under the condition that water is preserved and does not decline) but create serious environmental problems. That is *hydropower* is considered as a RES but construction of dams in both large-scale and run of river installations has a negative effect on the aquatic ecosystem by blocking fish migration and water flows. This leads among others to reduction in fish populations and to serious environmental problems. Small, micro- and mini-hydro installations have much lower environmental effects and in cases of areas without grid access may be an important source of electricity.

share of renewable energy sources in total energy consumption, their percentages will raise up to 7,3% in 2020 and 8% in 2030.

Figure 4.2: Capacity projection in Electricity sector (in MW)

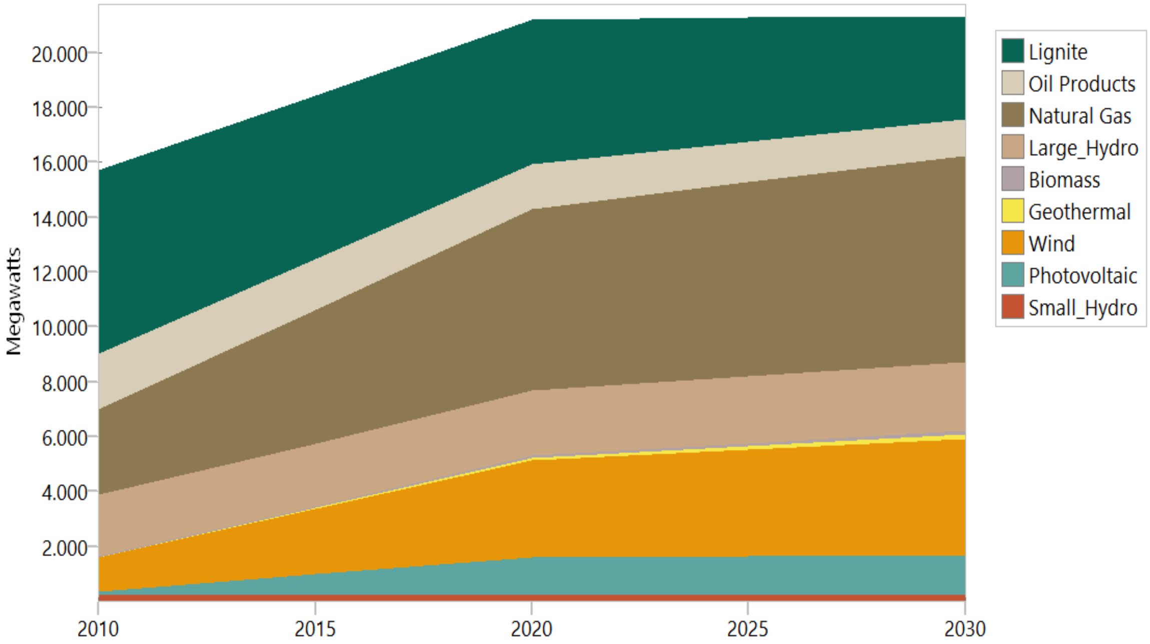

Table 4.9: Capacity projection in Electricity sector (in MW)

	2010	2015	2020	2025	2030
Lignite	6716	5982.3	5248.5	4514.8	3781
Oil Products	2016	1838	1660	1482	1304
Natural Gas	3123	4866.5	6610	7072.5	7535
Large_Hydro	2237	2305	2373	2441	2509
Biomass	43	63.3	83.5	100.5	117.6
Geothermal	0	24	79.3	134.7	190
Wind	1230.9	2386.3	3541.6	3885.8	4230
Photovoltaic	158.5	773	1387.5	1411.8	1436
Small_Hydro	205	211.3	217.5	223.8	230
Total	15729.4	18449.7	21200.9	21266.9	21332.6

Table 4.10: RES share in electricity sector

	2010	2015	2020	2025	2030
RES share in electricity production (MW)	1637.4	3457.9	5309.4	5756.6	6203.6
% RES share in electricity production	10.4%	18.7%	**25%**	27%	**29%**

Figure 4.3: Demand Energy requirements per fuel

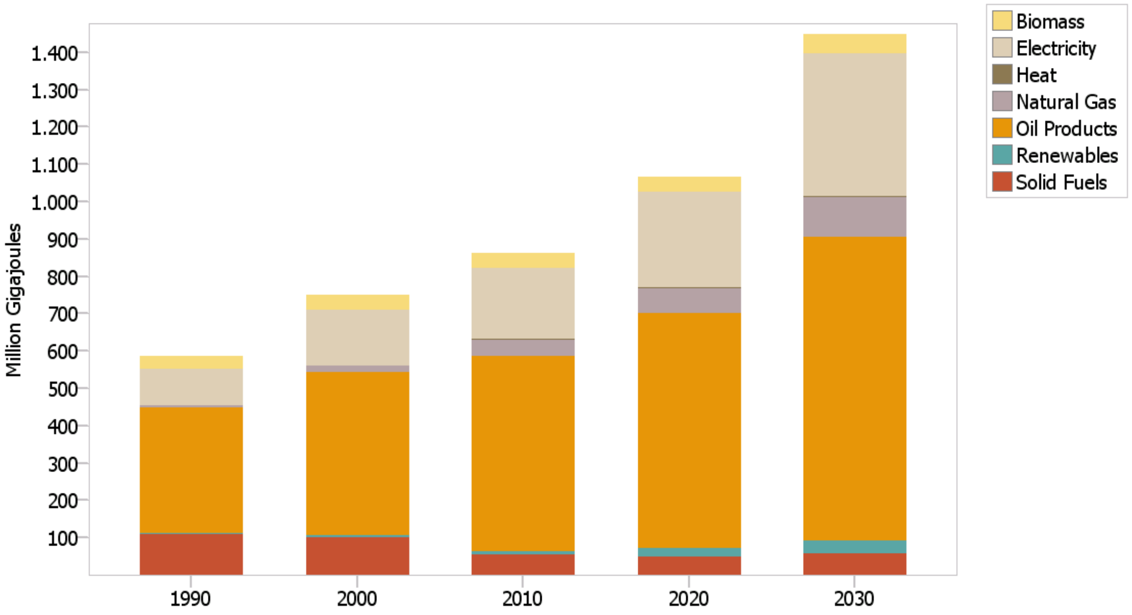

Table 4.11: Demand Energy requirements share per fuel

	1990	2000	2010	2020	2030
Biomass	3.5	4	4.7	5.3	5.6
Electricity	16.9	20	22.1	22.5	25.5
Heat	0	0.2	0.2	0.2	0.2
Natural Gas	0.7	2.1	5.1	6.2	7.2
Oil Products	59.7	58.7	60.6	59.1	51.2
Other Renewable	0.4	0.6	1.1	2	2.4
Solid Fuels	18.8	14.4	6.3	4.7	3.9
Total Renewable	3.9	4.6	5.8	**7.3**	**8**

4.4.2 Target 2020 scenario with the OECD conservative scenario of GDP growth

As it is mentioned, the second scenario is based on the European target to develop energy efficient and low carbon Europe via an increase to 20% in the share of EU energy consumption produced from renewable sources. The Greek government promotes the specific European targets which include RES electricity share (40%), RES heating and cooling share for household (20%), and RES transport share (10%) in order to achieve the national target of 20% contribution of the energy produced from RES to the gross final energy consumption. Figure 4.4 shows the total installed capacity in the electricity sector till 2030. As it can be seen the use of lignite will decrease by 22% in 2020 and by 44% in 2030 compared to the year 2010 as in the baseline scenario.

The difference in this scenario is the smooth increase of energy demand for natural gas and a greater increase in small hydro, biomass, geothermal, wind, and photovoltaic compared to the baseline scenario as it is depicted in detail in Table 4.12. In Target 2020 scenario RES share in electricity sector will increase by 40.8% in 2020 and by 42.4% in 2030 as it is shown in Table 4.13. RES heating and cooling share (20%) and RES transport share (10%) targets are depicted in Figures 4.5 and 4.6. The primary energy requirements by fuel source over the modeling period are shown in Figure 4.7. Specifically, Table 4.14 shows the percentage share of total energy consumption demand per fuel. Total renewable share in energy consumption amounts 20,3% in 2020 and 22,7% in 2030 in the framework of Target 2020 Scenario. In renewable energy resources category only the small-scale hydropower projects are included and not the large hydro.

Table 4.12: Capacity projection in Electricity sector (in MW)

	2010	**2015**	**2020**	**2025**	**2030**
Lignite	6716	5474	4232	4006.5	3781
Oil Products	2016	1808	1600	1452	1304
Natural Gas	3123	3616.5	4110	5822.5	7535
Large_Hydro	2237	2305	2373	2441	2509
Biomass	43	107.3	171.5	194.6	217.6
Geothermal	0	24	79.3	134.7	190
Wind	1230.9	3719.7	6208.5	7208.3	8208
Photovoltaic	158.5	926.9	1695.2	1800.6	1906
Small_Hydro	205	277.6	350.2	495.2	640.2
Total	15729.4	18259	20819.7	23555.4	26290.8

Table 4.13: RES share in electricity sector

	2010	**2015**	**2020**	**2025**	**2030**
RES share of electricity production (MW)	1637.4	5055.5	8504.7	9833.4	11161.8
% RES share of electricity production	10.4%	27.7%	**40.8%**	41.7%	**42.4%**

Figure 4.4: Capacity projection in Electricity sector (in MW)

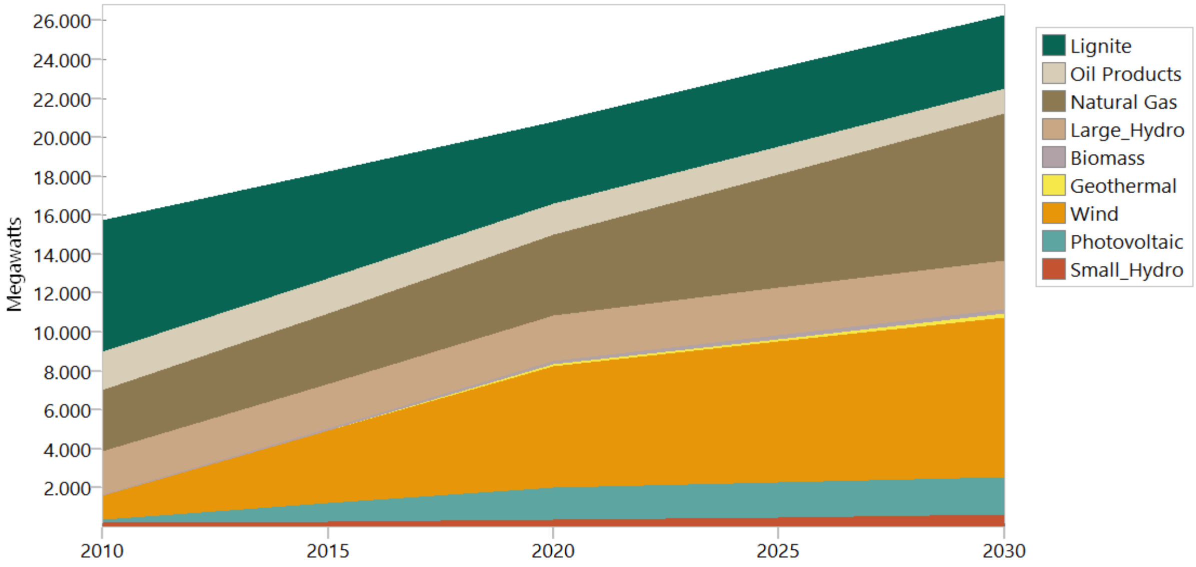

Figure 4.5: Households Energy Consumption per fuel

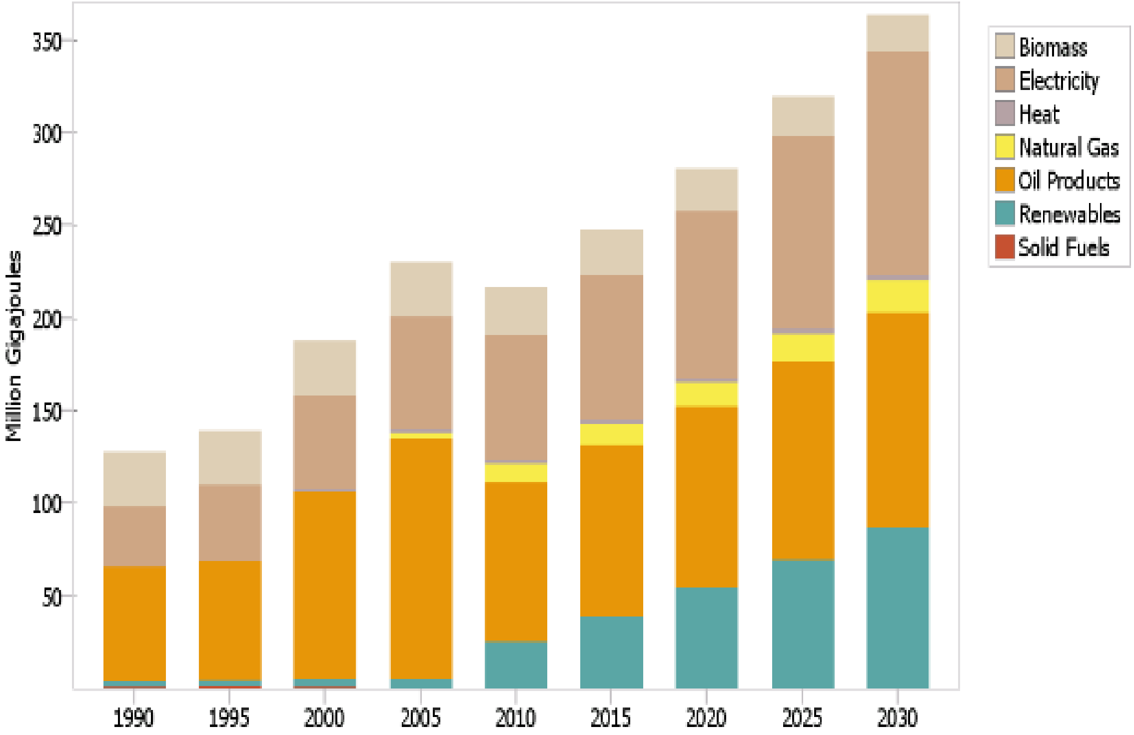

Figure 4.6: Transport Energy Consumption per fuel

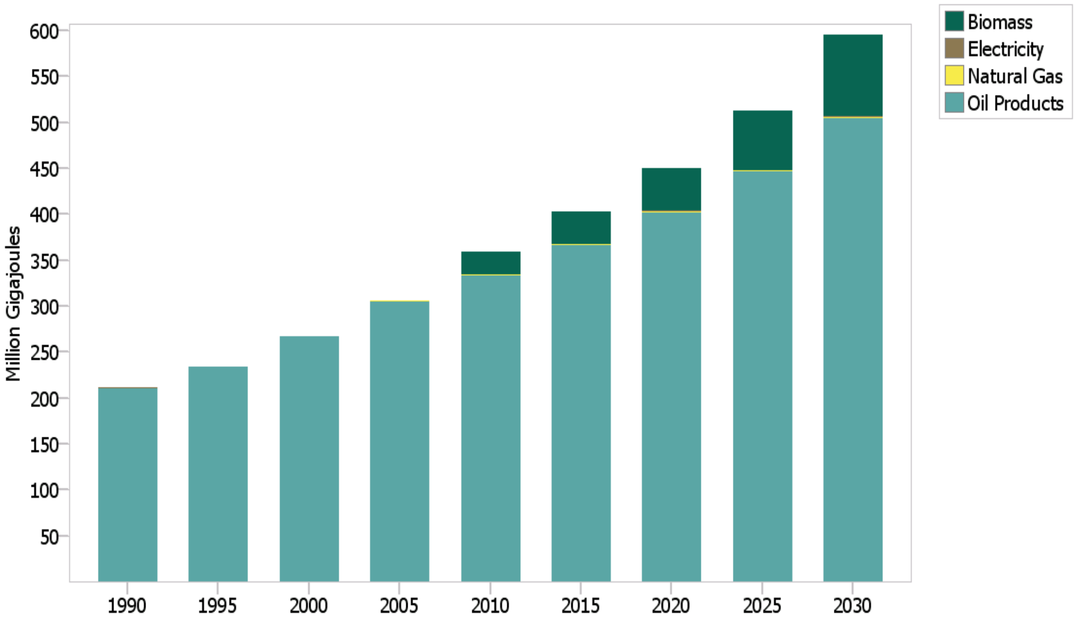

Figure 4.7: Total Energy Consumption per fuel

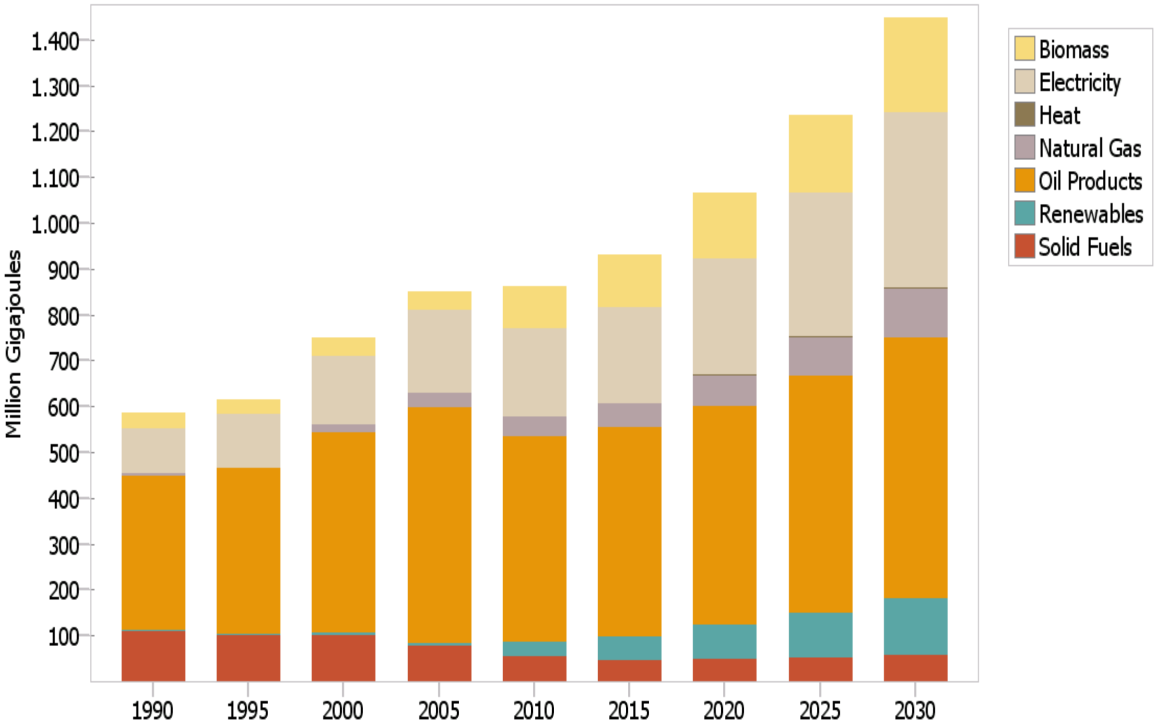

Table 4.14: Total Energy Consumption share per fuel (%)

	2010	**2015**	**2020**	**2025**	**2030**
Biomass	10.7	12.3	13.5	13.8	14.2
Electricity	22.1	22.3	23.9	25.2	26.5
Heat	0.2	0.2	0.2	0.2	0.2
Natural Gas	5.1	5.5	6.2	6.7	7.2
Oil Products	51.8	49.1	44.8	42	39.4
Other Renewable	3.9	5.5	6.8	7.7	8.5
Solid Fuels	6.3	5	4.7	4.3	3.9
Total Renewable	14.6	17.8	**20.3**	21.5	22.7

4.4.3 Target 2030 scenario with the OECD conservative scenario of GDP growth

In Target 2030 scenario we follow the target set by the European Commission to increase the share of renewable energy penetration by at least 27% in 2030. This will be achieved by the introduction of RES in industry. Following Heaps et al. (2009) concerning the industry sector scenario generation, CO_2 emissions can be further reduced through the increased use of natural gas, biomass and higher participation of RES in electricity, iron and steel, cement and chemicals production sectors and in other industrial subsectors. Finally, we assume a 100% increase of Renewable Energy Sources capacity, which corresponds to 10.563,2 MW. Specifically, as it is mentioned above relying on the Hellenic Transmission System Operator S.A. we assume that till 2030 100% of the non-binding offers will be achieved. Figure 4.8 and table 4.15 depict the energy consumption per fuel in the industry sector. Figure 4.9 depicts the total energy consumption requirements per fuel. As it can be seen in Table 4.16, the total renewable share in 2030 will amount for 29%.

Figure 4.8: Industry's Energy Consumption per fuel

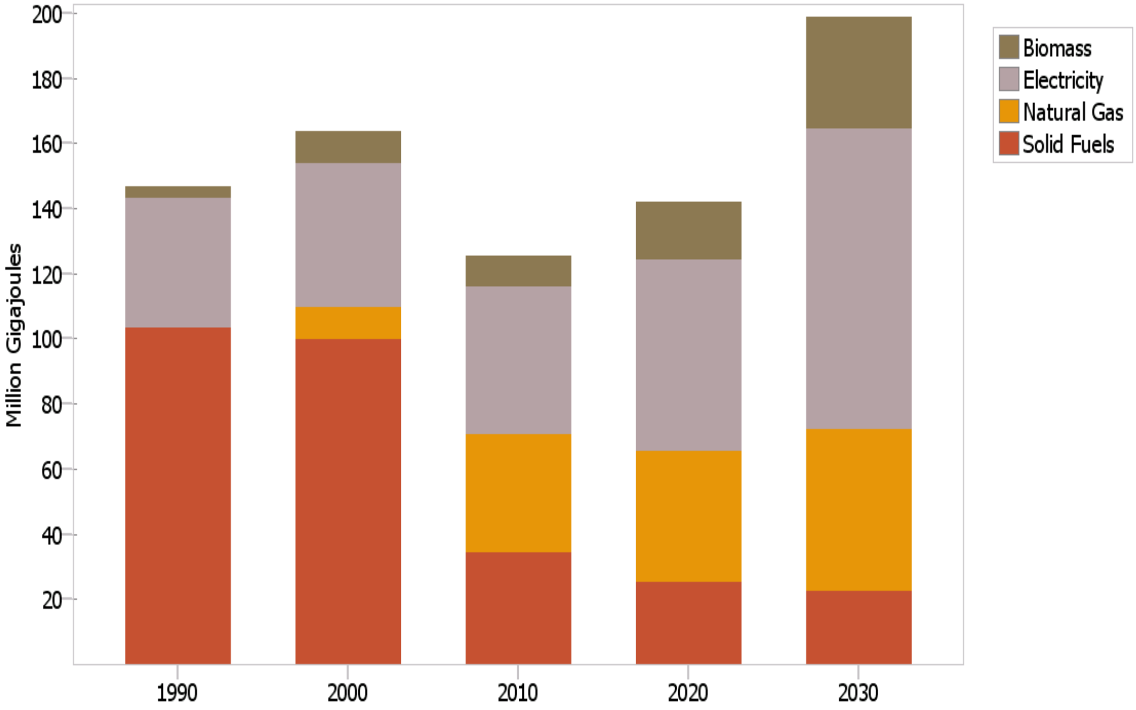

Figure 4.9: Energy Consumption per fuel

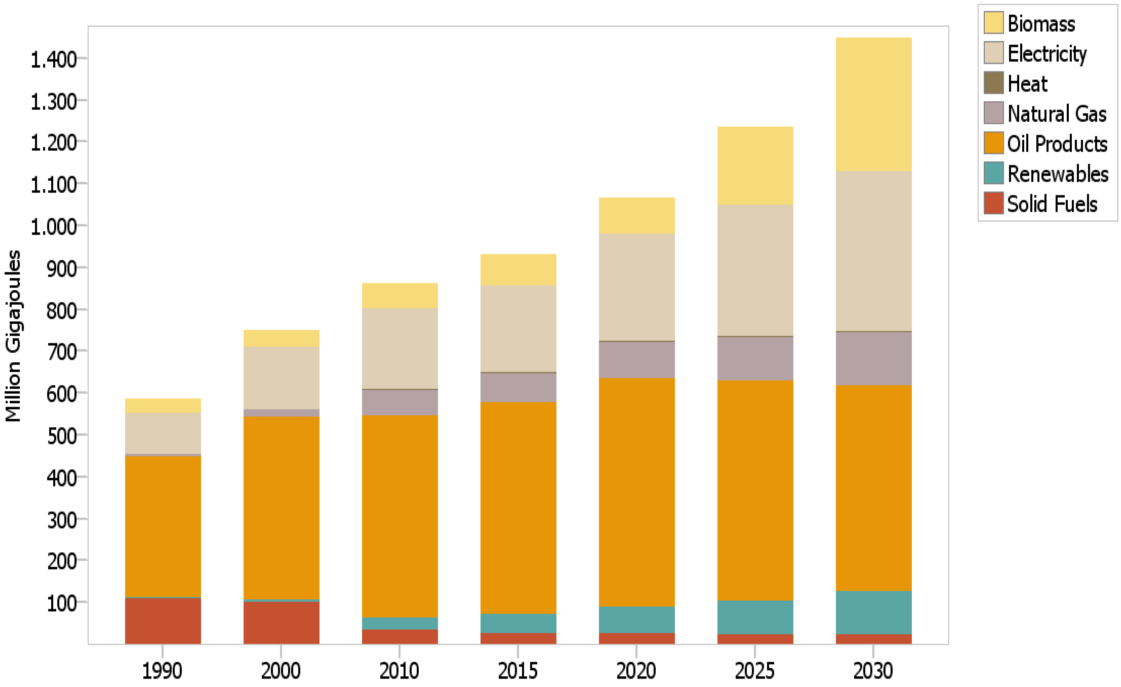

Table 4.15: Industry's Energy Consumption share per fuel

	1990	2000	2010	2020	2030
Biomass	2.4	6	7.6	12.4	17.2
Electricity	27.1	27	36.2	41	43.4
Natural Gas	0	6.1	28.3	28.8	31
Solid Fuels	70.4	60.9	27.9	17.7	8.3

Table 4.16: Energy Consumption share per fuel

	2010	2015	2020	2025	2030
Biomass	10.7	12.3	13.5	15.2	21.9
Electricity	22.1	22.3	23.9	25.3	26.5
Heat	0.2	0.2	0.2	0.2	0.2
Natural Gas	5.1	5.5	6.2	8.5	8.7
Oil Products	51.8	49.1	44.8	42.4	33.9
Other Renewable	3.9	5.5	6.8	6.6	7.1
Solid Fuels	6.3	5	4.7	1.9	1.6
Total Renewable	14.6	17.8	20.3	21.8	**29**

4.4.4 Baseline scenario with the IMF optimistic scenario of GDP growth

In the Baseline Scenario, the historical trends will continue to be the same without any change. All three scenarios take into account the economic crisis and consequent decrease in energy consumption. Figure 4.10 presents the total installed capacity in the Electricity sector. The changes in fuels use in Figure 4.10 are described in detail in table 4.16. As it can be observed the use of lignite in the electricity sector in 2020 will decrease by 23% and in 2030 by 45% compared to the use in 2010. Oil products will decrease by 17% in 2020 and by 34% in 2030. However, there will be a substantial increase in the use of natural gas, biomass, geothermal wind, photovoltaic and small hydro energy. The category large hydro is not included in the renewable energy resources. The international trend is to exclude large hydropower projects from the national planning due to the large construction costs and the intense deterioration of the environment (PPC, 2012;.WWF Greece, 2010).[42]

Without any implementation of measures to reduce primary sources of energy production in electricity sector, such as lignite, based on the current data RES share of electricity production will increase by 24.7% in 2020 and by 28.4% in 2030 as it is shown in Table 4.17. The total energy requirements by fuel source over the modeling period are shown in Figure 4.10. The RES primary energy demand increases at the expense of fossil fuels such as lignite because of the announced withdrawals of Power Stations by the Public Power Corporation. Table 4.18, depicts the demand energy requirements share per fuel in details as shown graphically in Figure 4.10. Generally, without any environmental policy to increase the share of renewable energy sources in total energy consumption, their percentages will raise up to 5.8% in 2020 and 5.9% in 2030.

Table 4.16: Capacity projection in Electricity sector (in MW)

	2010	2015	2020	2025	2030
Lignite	6716	6107,3	5498,5	4889,8	4281
Oil Products	2016	1838	1660	1482	1304
Natural Gas	3123	4866,5	6610	7072,5	7535
Large_Hydro	2237	2305	2373	2441	2509
Biomass	43	63,3	83,5	100,5	117,6
Geothermal	0	24	79,3	134,7	190
Wind	1230,9	2386,3	3541,6	3885,8	4230
Photovoltaic	158,5	773	1387,5	1411,8	1436
Small_Hydro	205	211,3	217,5	223,8	230
Total	15729,4	18574,5	21450,9	21641,8	21832,6

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[42] Scale is important when the effect of hydropower on the environment is considered. Large-scale hydropower sources with dams are a renewable energy source (under the condition that water is preserved and does not decline) but create serious environmental problems. That is *hydropower* is considered as a RES but construction of dams in both large-scale and run of river installations has a negative effect on the aquatic ecosystem by blocking fish migration and water flows. This leads among others to reduction in fish populations and to serious environmental problems. Small, micro- and mini-hydro installations have much lower environmental effects and in cases of areas without grid access may be an important source of electricity.

Figure 4.9: Capacity projection in Electricity sector (in MW)

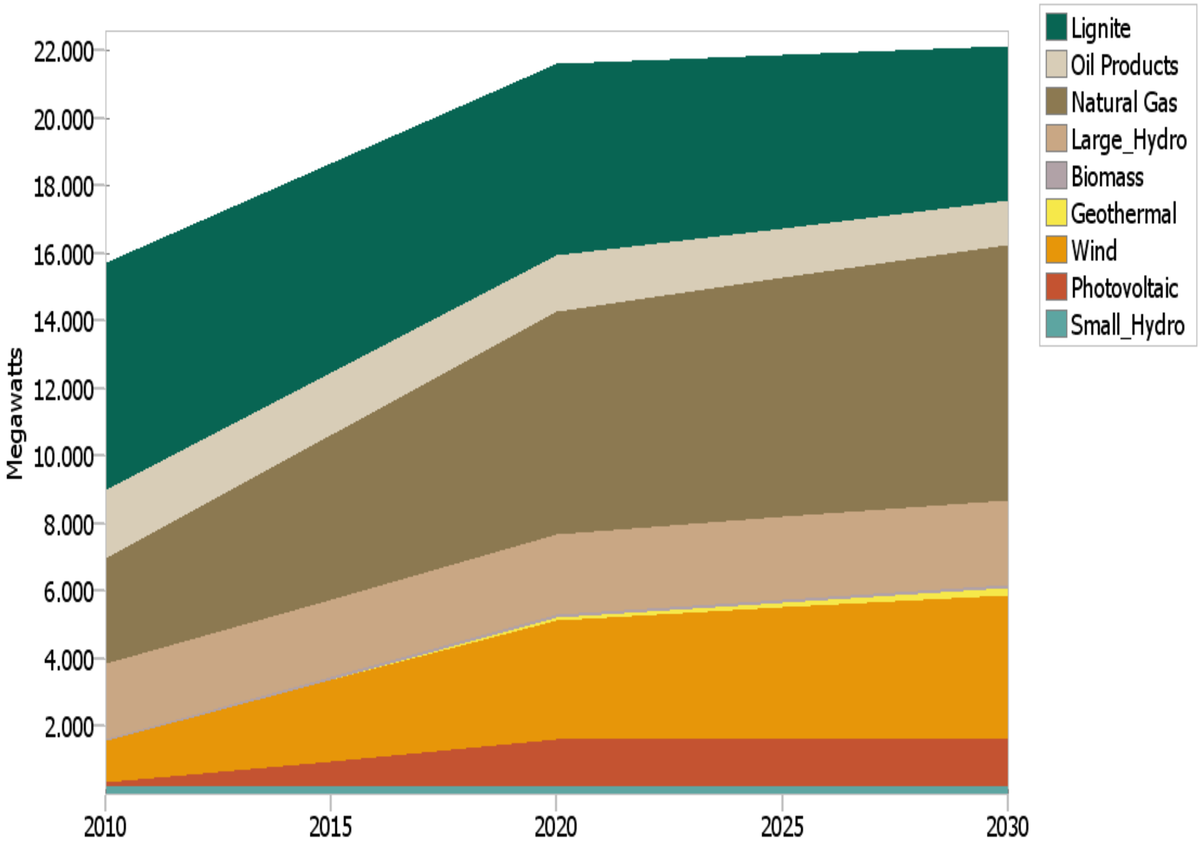


Table 4.17: RES share in electricity sector

	2010	2015	2020	2025	2030
RES share in electricity production (MW)	1637.4	3457.9	5309.4	5756.6	6203.6
% RES share in electricity production	10.4%	18.6%	24.7%	26.5%	28.4%

Figure 4.10: Demand Energy requirements per fuel

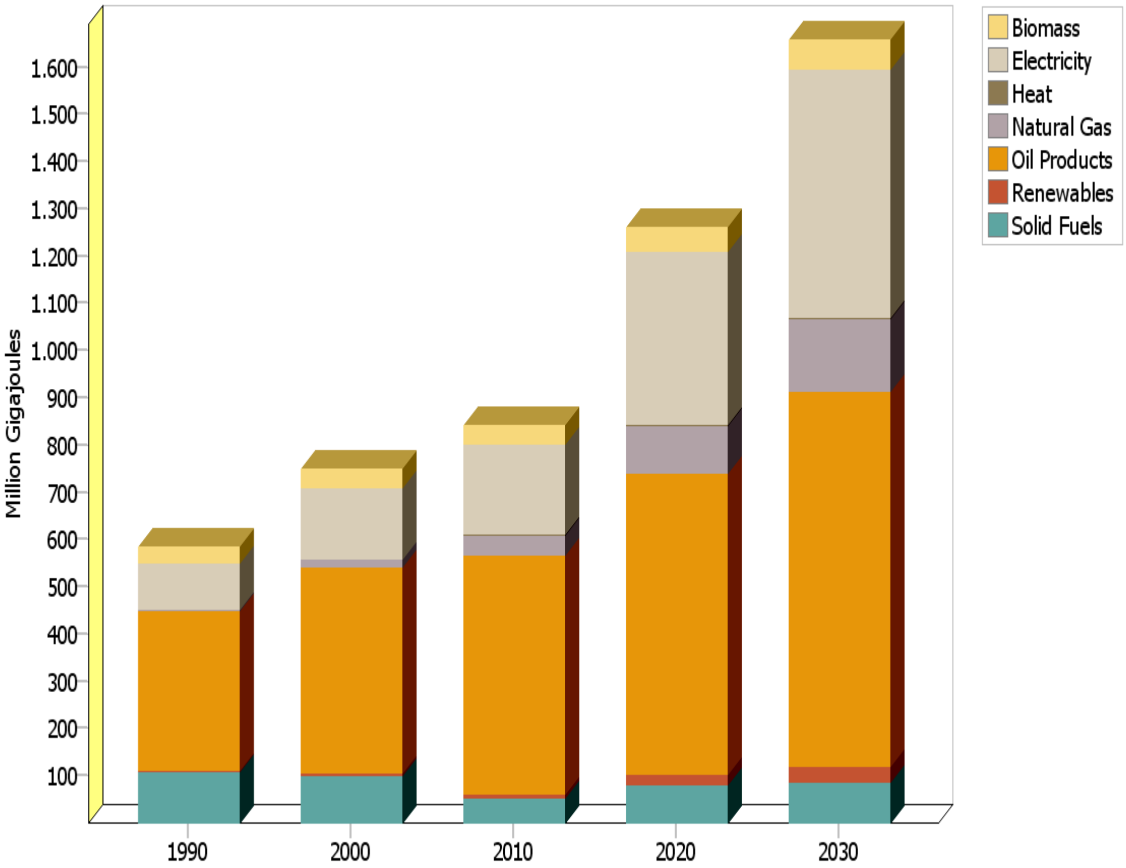


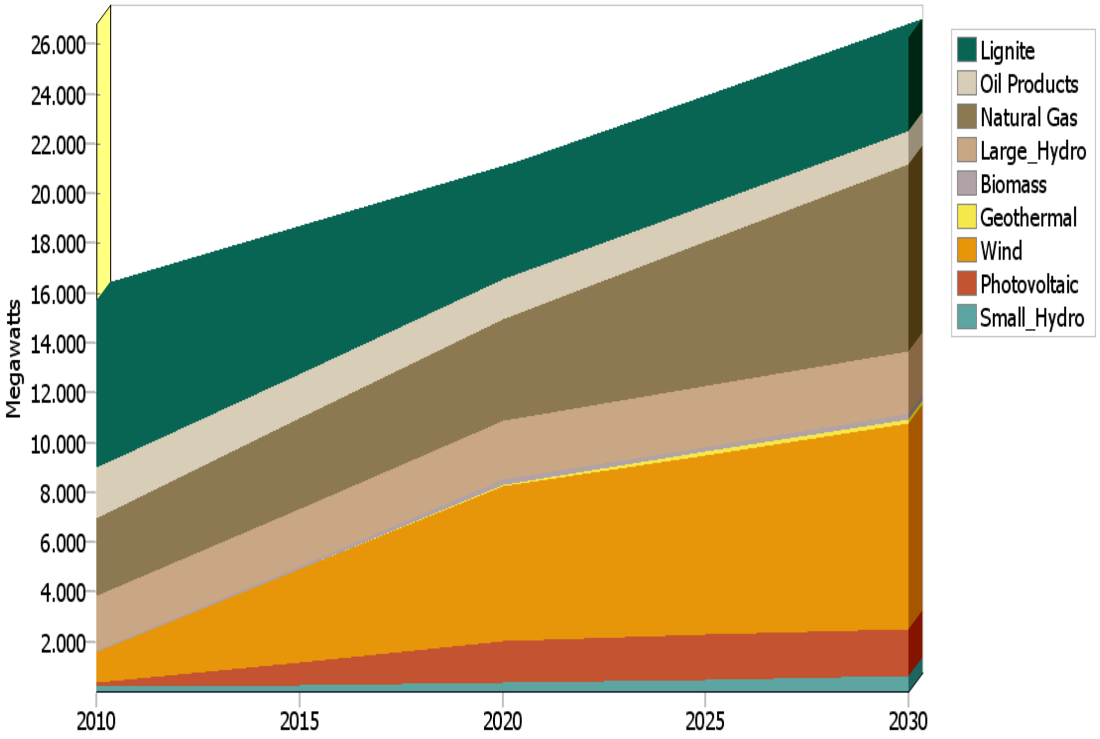
Table 4.18: Demand Energy requirements share per fuel

	1990	2000	2010	2020	2030
Biomass	3.5	4	4.7	4,1	3,7
Electricity	16.9	20	22.1	29	31,7
Heat	0	0.2	0.2	0,2	0,2
Natural Gas	0.7	2.1	5.1	8	9,3
Oil Products	59.7	58.7	60.6	50,5	47,8
Other Renewable	0.4	0.6	1.1	1,7	2,1
Solid Fuels	18.8	14.4	6.3	6,5	5,2
Total Renewable	3.9	4.6	5.8	**5.8**	**5.9**

4.4.5 Target 2020 scenario with the IMF optimistic scenario of GDP growth

As it is mentioned, the second scenario is based on the European target to develop energy efficient and low carbon Europe via an increase to 20% in the share of EU energy consumption produced from renewable sources. The Greek government promotes the specific European targets which include RES electricity share (40%), RES heating and cooling share for household (20%), and RES transport share (10%) in order to achieve the national target of 20% contribution of the energy produced from RES to the gross final energy consumption. Figure 4.11 shows the total installed capacity in the electricity sector till 2030. As it can be seen the use of lignite will decrease by 22% in 2020 and by 44% in 2030 compared to the year 2010 as in the baseline scenario.

Figure 4.11: Capacity projection in Electricity sector (in MW)



The difference in this scenario is the smooth increase of energy demand for natural gas and a greater increase in small hydro, biomass, geothermal, wind, and photovoltaic compared to the baseline scenario as it is depicted in detail in Table 4.19. In Target 2020 scenario RES share in electricity sector will increase by 41.4% in 2020 and by 42.5% in 2030 as it is shown in Table 4.20. RES heating and cooling share (20%) and RES transport share (10%) targets are depicted in Figures 4.19 and 4.20. The primary energy requirements by fuel source over the modeling period are shown in Figure 4.21. Specifically, Table 4.21 shows the percentage share of total energy consumption demand per fuel. Total renewable share in energy consumption amounts 21.3% in 2020 and 23.4% in 2030 in the framework of Target 2020 Scenario. In renewable energy resources category only the small-scale hydropower projects are included and not the large hydro.

Table 4.19: Capacity projection in Electricity sector (in MW)

	2010	**2015**	**2020**	**2025**	**2030**
Lignite	6716	5324	3932	3856,5	3781
Oil Products	2016	1808	1600	1452	1304
Natural Gas	3123	3616,5	4110	5822,5	7535
Large_Hydro	2237	2305	2373	2441	2509
Biomass	43	107,3	171,5	194,6	217,6
Geothermal	0	24	79,3	134,7	190
Wind	1230,9	3719,7	6208,5	7208,3	8208
Photovoltaic	158,5	926,9	1695,2	1800,6	1906
Small_Hydro	205	277,6	350,2	495,2	640,2
Total	15729,4	18108,9	20519,7	23405,3	26290,8

Figure 4.19: Households Energy Consumption per fuel

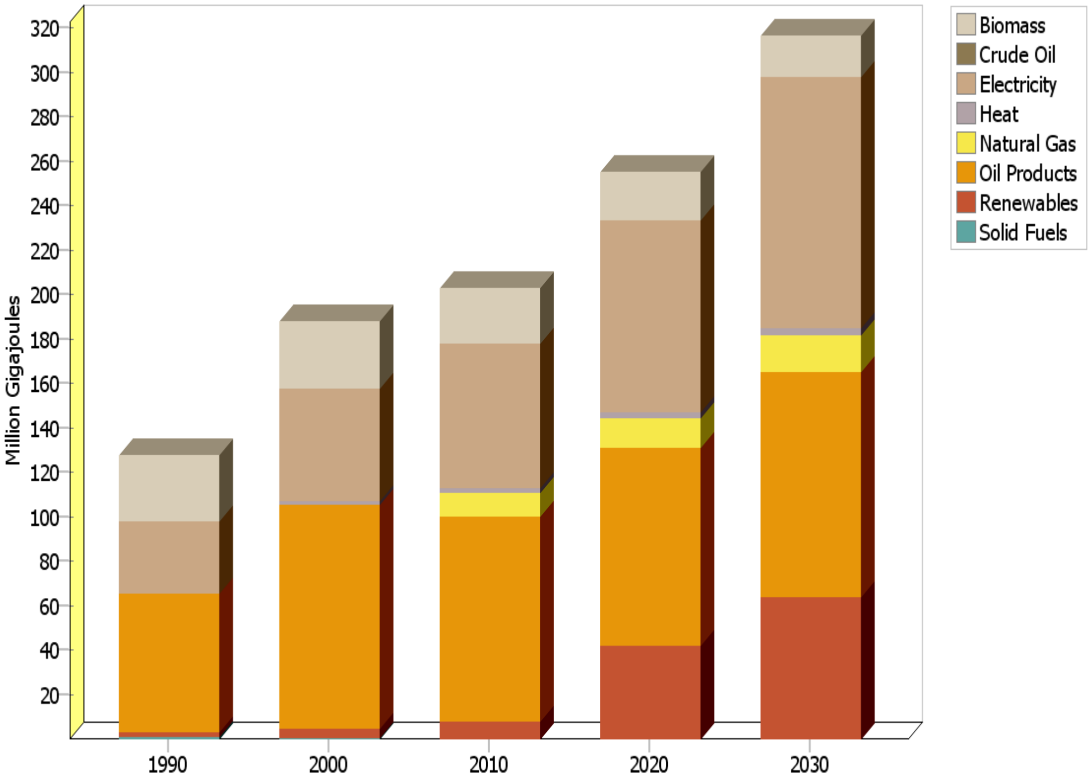


Table 4.20: RES share in electricity sector

	2010	2015	2020	2025	2030
RES share of electricity production (MW)	1637.4	5055.5	8504.7	9833.4	11161.8
% RES share of electricity production	10.4%	27.9%	**41.4%**	42%	42.5%

Figure 4.20: Transport Energy Consumption per fuel

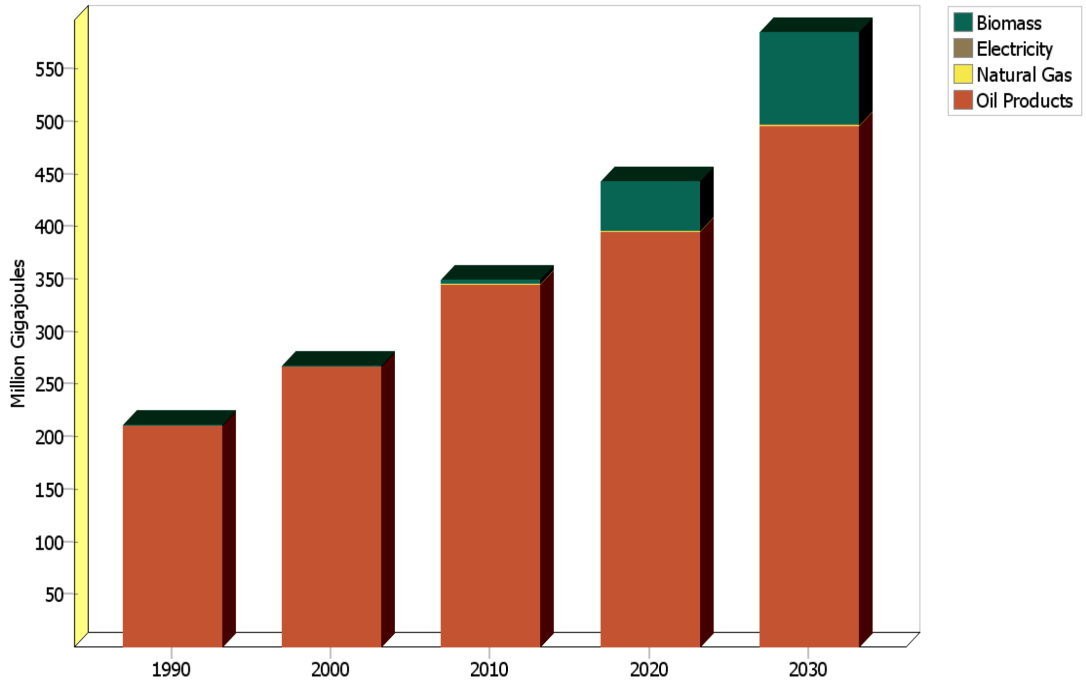


Figure 4.21: Total Energy Consumption per fuel

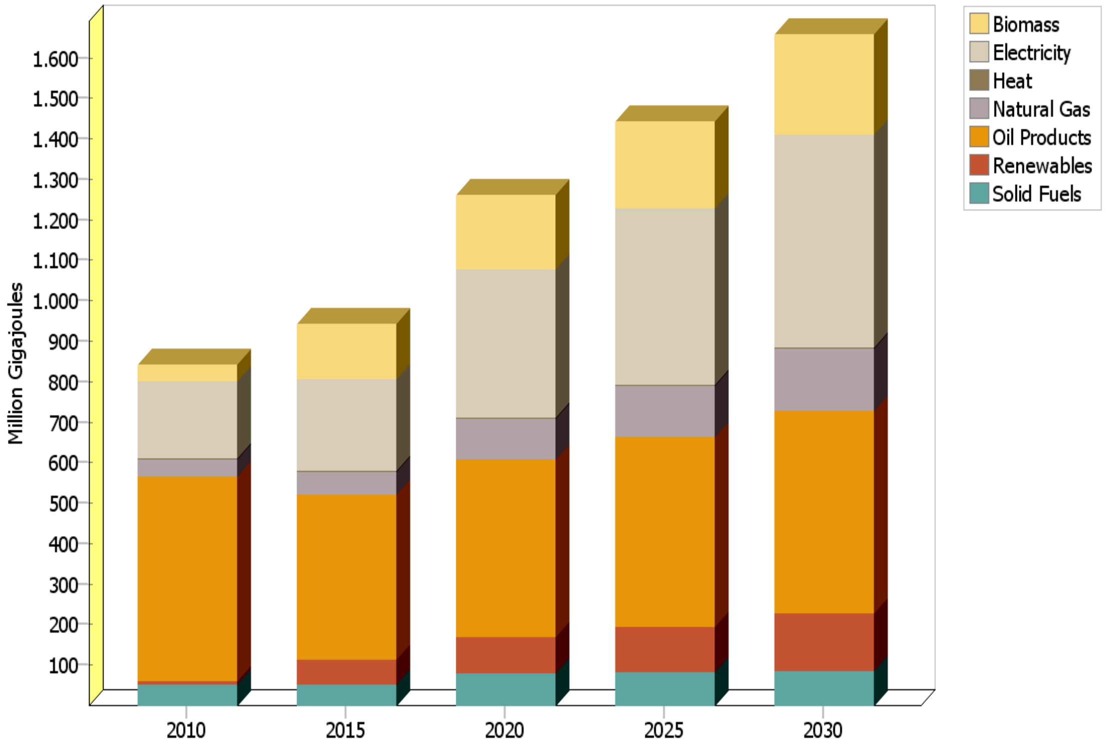


Table 4.21: Total Energy Consumption share per fuel (%)

	2010	**2015**	**2020**	**2025**	**2030**
Biomass	10.7	12,4	14,4	14,6	14,8
Electricity	22.1	23,9	29	30,4	31,7
Heat	0.2	0,2	0,2	0,2	0,2
Natural Gas	5.1	6	8	8,7	9,3
Oil Products	51.8	43,4	34,9	32,6	30,3
Other Renewable	3.9	5,4	6,9	7,8	8,6
Solid Fuels	6.3	5,6	6,5	5,8	5,2
Total Renewable	14.6	17.8	**21.3**	22.4	23.4

4.4.6 Target 2030 scenario with the IMF optimistic scenario of GDP growth

In Target 2030 scenario we follow the target set by the European Commission to increase the share of renewable energy penetration by at least 27% in 2030. This will be achieved by the introduction of RES in industry. Following Heaps et al. (2009) concerning the industry sector scenario generation, CO_2 emissions can be further reduced through the increased use of natural gas, biomass and higher participation of RES in electricity, iron and steel, cement and chemicals production sectors and in other industrial subsectors. Finally, we assume a 100% increase of Renewable Energy Sources capacity, which corresponds to 10.563,2 MW. Specifically, as mentioned above relying on the Hellenic Transmission System Operator S.A. we assume that till 2030 100% of the non binding offers will be achieved. Figure 4.22 and table 4.22 depict the energy consumption per fuel in the industry sector. Figure 4.23 depicts the total energy consumption requirements per fuel. As it can be seen in Table 4.23, the total renewable in 2030 will reach 29.8%.

Table 4.22: Industry's Energy Consumption share per fuel

	1990	**2000**	**2010**	**2020**	**2030**
Biomass	2.4	6	7.6	13,6	20
Electricity	27.1	27	36.2	40	43,9
Natural Gas	0	6.1	28.3	29	27
Solid Fuels	70.4	60.9	27.9	17,4	9,2

Figure 4.22: Industry's Energy Consumption per fuel

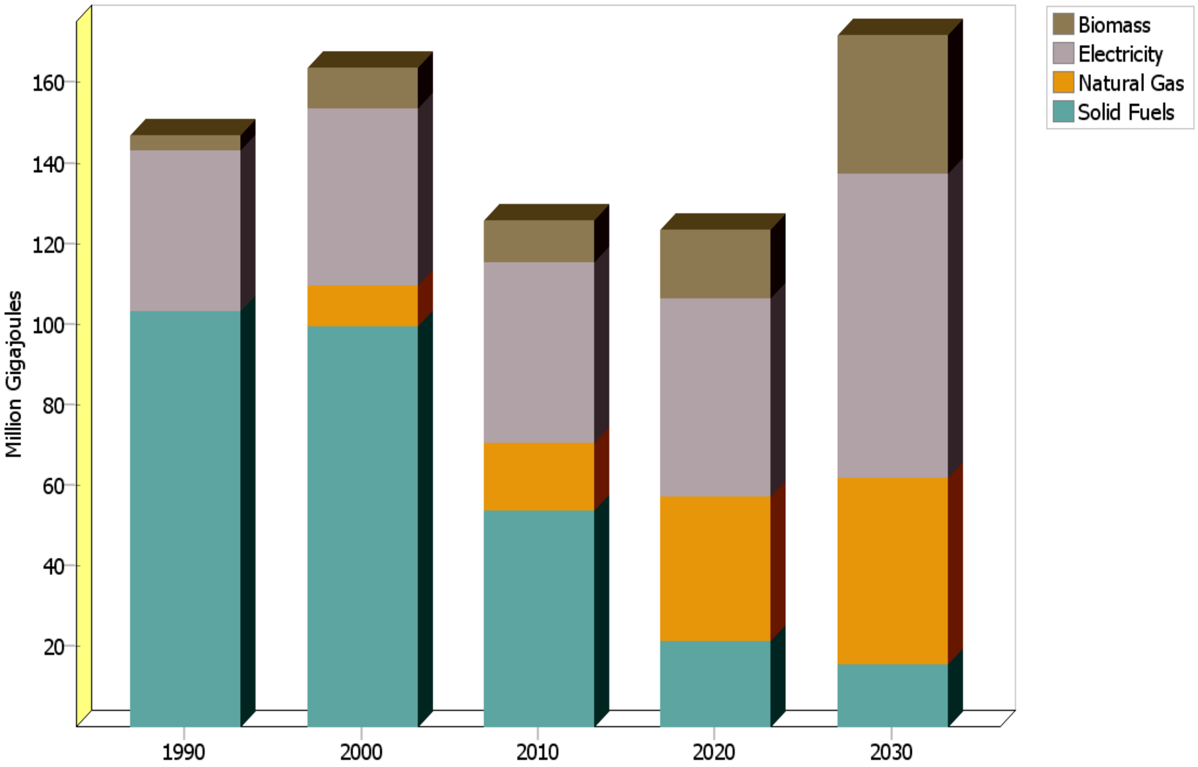


Figure 4.23: Energy Consumption per fuel

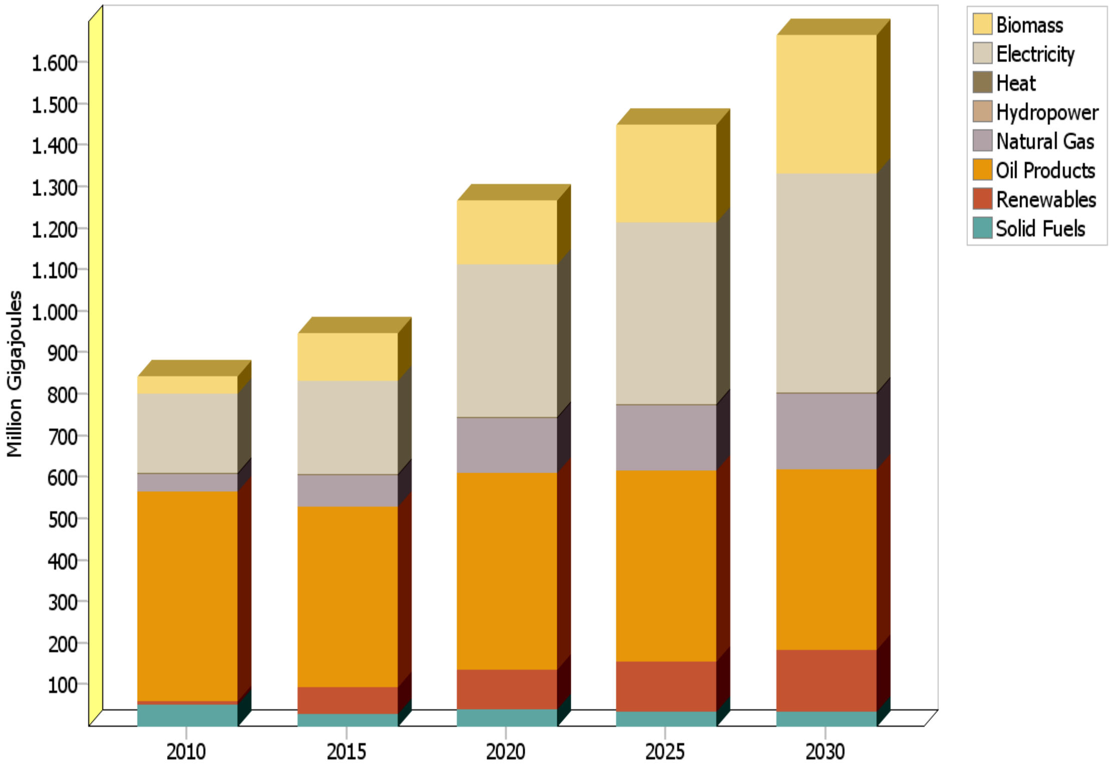


Table 4.23: Energy Consumption share per fuel

	2010	**2015**	**2020**	**2025**	**2030**
Biomass	10.7	11,8	14,1	16,1	20.5
Electricity	22.1	23,8	28,8	30,3	31,6
Heat	0.2	0,2	0,2	0,2	0,2
Natural Gas	5.1	8,1	10,5	10,8	11
Oil Products	51.8	45,9	37,5	31,8	26,1
Other Renewable	3.9	6,8	7,4	8,2	9.3
Solid Fuels	6.3	3,3	3,4	2,6	2,1
Total Renewable	14.6	18.6	21.5	24.3	**29.8**

4.4.7 Environment

LEAP allows each technology within the demand (Hhouseholds, Agriculture and Fishing, Services, Industry, Transport and Non-Energy Fuel Use) and supply (PPC, Energy) by the various sectors to be directly linked to emission factors in the Technology and Environmental Database (hereafter TED). Thus, the model calculates the resulting emissions from energy demand based on emission factors and other technical characteristics taken from TED. The Greek power system has been always considered as particularly polluting because of the large quantities of CO_2 emitted by lignite plants.

The OECD conservative scenario of GDP growth: As it is shown in Figure 4.24, in the framework of the Baseline scenario, CO_2 emissions are projected to grow from 39.7 $MtCO_2$ to 46.7 $MtCO_2$ by 2020 and to 59.6 $MtCO_2$ by 2030 (see Table 24).[43] Observing the cumulative emissions we notice that the Target 2030 is more favourable in environmental terms than Target 2020 and Baseline scenarios. The CO_2 emitted by the energy demand system will increase compared to 1990 levels. However, carbon intensity in the electricity generation sector in Greece, as shown in Figure 4.25 and Table 4.25, will diminish by 2030 compared to 1990 levels if the policy makers follow the Target 2030 scenario.

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[43] Global Warming Potential (GWP) is an index measuring different GHGs emissions with different lifetimes and different radiative properties. CO_2 has a GWP equal to 1 for comparison reasons, CH_4 and N_2O have GWPs equal to 25 and 298 respectively (Halkos, 2010, 2014).

Table 4.24: Emissions (MtCO$_2$e) per scenario in 2020 and 2030

	2010	2015	2020	2025	2030
Baseline	39.7	41.9	**46.7**	52.5	**59.6**
Target 2020	39.7	38.5	**41.9**	46	**51**
Target 2030	39.7	37.9	**41**	43.6	**46.6**

Figure 4.24: Carbon intensity of Greek energy demand per scenario for the OECD conservative scenario of GDP growth

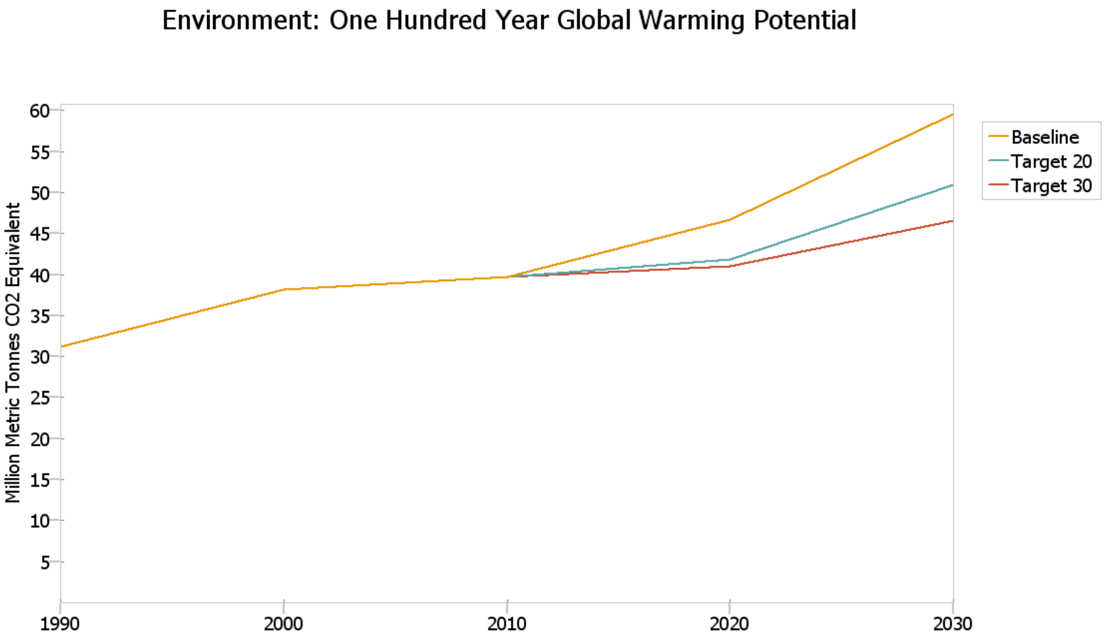
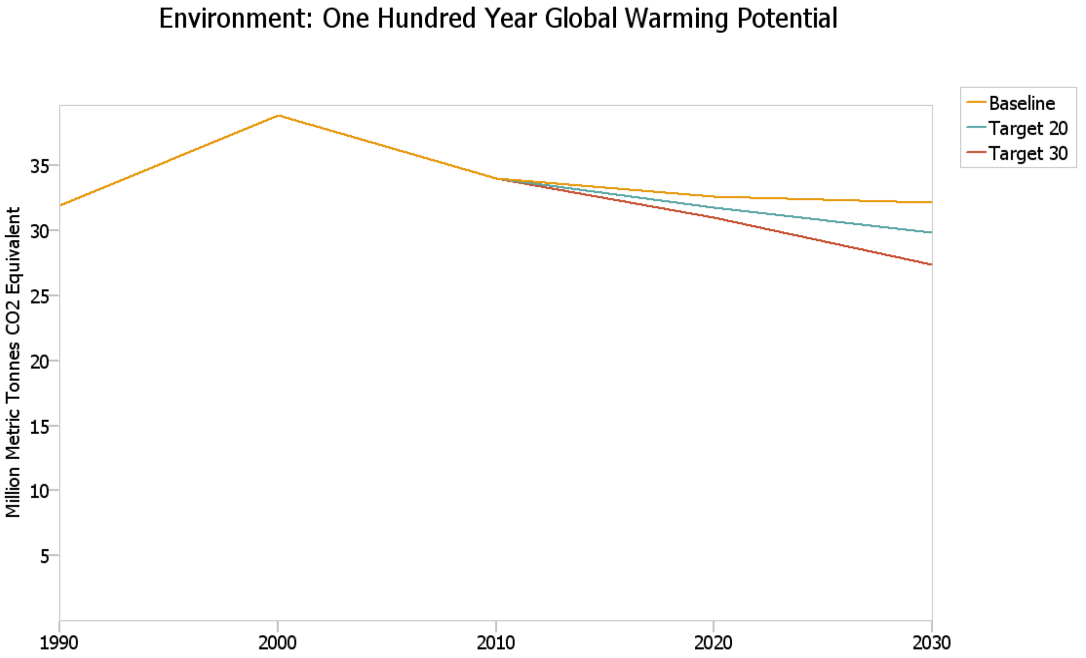


Figure 4.25: Carbon intensity in Greek electricity generation sector per scenario for the OECD conservative scenario of GDP grow



The IMF optimistic scenario of GDP growth: As it is shown in Figure 4.26 in the framework of the Baseline scenario CO_2 emissions are projected to grow from 39.7 $MtCO_2$ to 51.9 $MtCO_2$ by 2020 and to 64.5 $MtCO_2$ by 2030 (see Table 4.25). Observing the cumulative emissions we notice that the Target 2030 is more favourable in environmental terms than Target 2020 and Baseline scenarios. The CO_2 emitted by the energy demand system will increase compared to 1990 levels. However, carbon intensity in the electricity generation sector in Greece, as shown in Figure 4.27 and Table 4.26, will slightly increase by 2030 compared to 1990 levels if the policy makers follow the Target 2030 scenario.

Figure 4.26: Carbon intensity of Greek energy demand per scenario for the IMF optimistic scenario of GDP growth

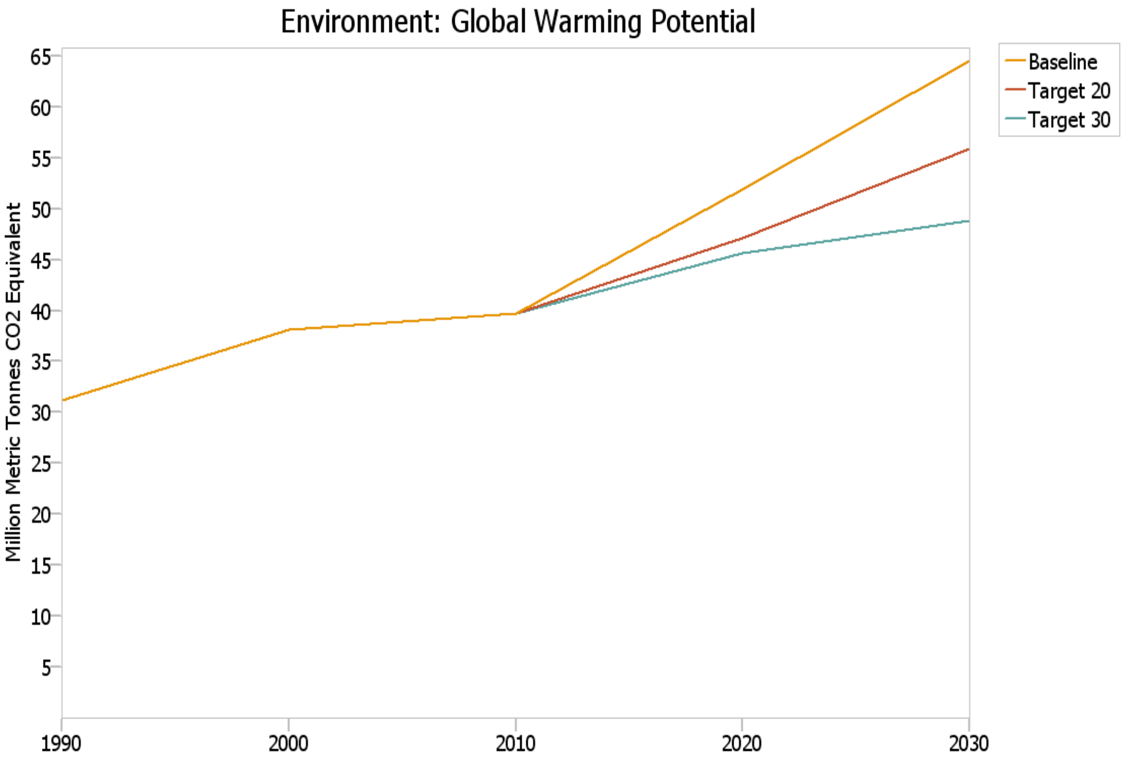


Table 4.25: Emissions (MtCO$_2$e) per scenario in 2020 and 2030 for the IMF optimistic scenario of GDP growth

	1990	2000	2010	**2020**	**2030**
Baseline	31,2	38,2	39,7	**51,9**	**64,5**
Target 20	31,2	38,2	39,7	**47,1**	**55,9**
Target 30	31,2	38,2	39,7	**45,6**	**48,8**

Figure 4.27: Carbon intensity in Greek electricity generation sector per scenario for the IMF optimistic scenario of GDP growth

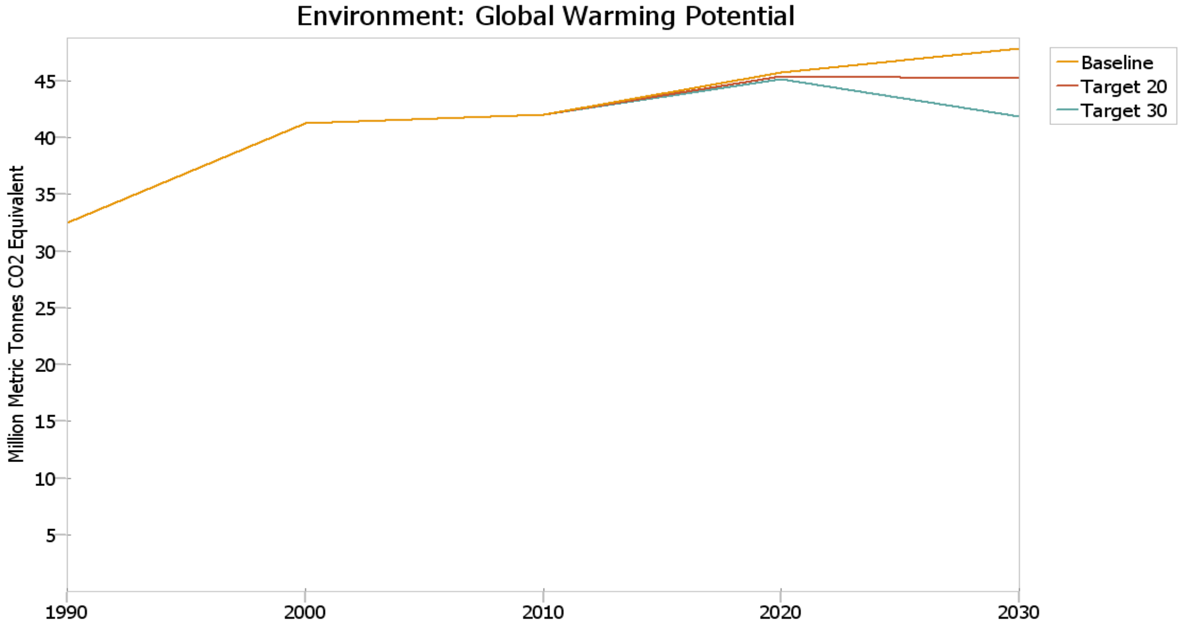


Table 4.26: Emissions (MtCO$_2$e) per scenario in 2020 and 2030 for the IMF optimistic scenario of GDP growth

	1990	2000	2010	**2020**	**2030**
Baseline	32,5	41,3	42,1	**45,7**	**47,8**
Target 20	32,5	41,3	42,1	**45,4**	**45,2**
Target 30	32,5	41,3	42,1	**45,2**	**41,9**

4.4.8 Costs

The types of costs considered are capital costs and operating and maintenance costs as shown in Table 4.27. Obviously, the capital cost is the main driver of the annualized electricity generation cost. As expected, Target 2030 is the most expensive throughout the projection period as it necessitates more innovative and decisive changes. It also assumes large investments in clean energy forms. The second most expensive scenario is the Target

2020 scenario throughout the projection period. As it is clearly observed in Figure 4.28, the low cost scenario is the Baseline as it does not require large changes. Specifically, the total cost of Baseline scenario amounts to €1.4 bn in 2020 and €2.2 bn in 2030. The total cost of Target 2020 amounts to €1.8 bn in 2020 and €2.9 bn in 2020 respectively. Finally, Target 2030 costs €2 bn in 2020 and €3.4 bn in 2030 respectively[44].

Figure 4.28: Total costs per scenario in 2020 and 2030

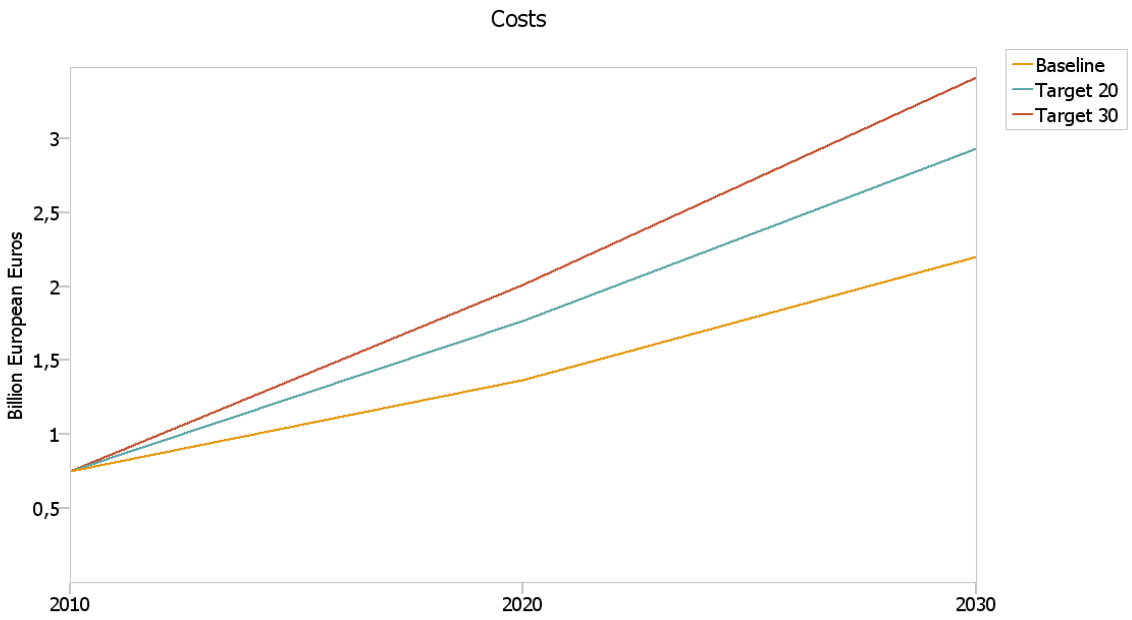


Table 4.27: Capital costs, fixed Operating and Maintenance (O&M) costs per scenario in 2020 and 2030 (in billion €)

	2020		
	Baseline	**Target 2020**	**Target 2030**
Capital costs	0.7	0.9	1.1
Fixed O&M costs	0.7	0.8	0.9
Total cost	**1.4**	**1.8**	**2**
	2030		
	Baseline	**Target 2020**	**Target 2030**
Capital costs	1.3	1.8	2.2
Fixed O&M costs	0.9	1.1	1.2
Total cost	**2.2**	**2.9**	**3.4**

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[44] Part of the data used for costs (capital cost and fixed cost) and operating characteristics (efficiency, availability, etc.) are extracted from IPA Energy and Water Economics (2010).

4.5 Concluding Remarks

The increasing trend in energy demand worldwide, combined with the predicted exhaustion of the energy reserves of the planet in conventional energy sources and the associated environmental problems caused, lead to the necessity of increasing use of RES. Most countries worldwide and mainly the developed ones are investing heavily in infrastructure, development and production of energy, from clean sources such as the wind and the sun. The European Union sets and updates the goals, forwards EU directives and at the same time supervises the progress of each country-member on the evolution and future directions in the use of RES.

The aim of this research was to provide a look to the 2030 horizon on the energy and power system in Greece. From an environmental perspective, the Target 2030 scenario is the most favorable as it offers the highest decrease in CO_2 emissions but at the highest cost. Target 2030 is the most expensive throughout the projection period as it necessitates more innovative and decisive changes. Although the Baseline scenario is the most emissive scenario, from an economic point of view is the most favorable. Nonetheless, all the scenarios include a considerable increase in RES installed capacity. According to Law L3851/2010, the protection of the climate or the reduction of GHG emissions through the promotion of electrical energy production from RES, is a crucial element of the energy sector of the country. The further specific targets include RES electricity share (40%), RES heating and cooling share (20%), and RES transport share (10%) in order to achieve the national target of 20% contribution of the energy produced from RES to the gross final energy consumption. Additionally, the European Commission has set a target to increase the share of renewable energy penetration at least 27% by 2030.

The dominant role of lignite in electricity generation has to be reversed. The reduction of the obsolete lignite stations of the Greek energy system will provide environmental benefits. The redeployment of lignite stations from the power sector, in the long run, will contribute to climate change mitigation. The scenarios that occurred assume a substantial shift in the electricity generation mix by 2030, which is anticipated to pose several challenges. Taking into account the economic recession and the diminished investments on positive environmental solutions and policies it is of crucial importance to attract private capital and promote partnership that motivates the utilization of large scale RES. The RES integration consequently will have positive effects on the reduction of unemployment and the mobilization of economic activity. Thus securing a clean energy future for Greece will contribute to create positive perspectives on the economy and the environment as well.

Appendix

Table A1: Augmented Dickey-Fuller results, including in the test equation trend and intercept, for the IMF «optimistic scenario» of GDP growth

First differences of the GDP series 1980-2019		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.795002	0.2080
Test critical values:	1% level	-4.226815	
	5% level	-3.536601	
	10% level	-3.200320	

Second Differences of the GDP series 1980-2019		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.797304	0.0280
Test critical values:	1% level	-4.226815	
	5% level	-3.536601	
	10% level	-3.200320	

Table A2: Augmented Dickey-Fuller results, including in the test equation trend and intercept, for the OECD «conservative scenario» of GDP growth

First differences of the GDP series 1980-2015		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.426528	0.3601
Test critical values:	1% level	-4.262735	
	5% level	-3.552973	
	10% level	-3.209642	

Second differences of the GDP series 1980-2015		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.634452	0.0420
Test critical values:	1% level	-4.262735	
	5% level	-3.552973	
	10% level	-3.209642	

*MacKinnon (1996) one-sided p-values.

Table A3: p-values of residual diagnostic tests after fitting ARIMA (p,2,q) models to GDP data 1980-2019 under the IMF «optimistic scenario»

	Normality Test	Breusch-Godfrey Serial Correlation LM Test		ARCH LM-test	
	Jarque-Bera	F-statistic	Obs R^2	F-statistic	Obs R^2
ARIMA with constant term					
ARIMA (1,2,0)	0.0535	0.8184	0.7998	0.6012	0.5887
ARIMA (1,2,1)	0.0734	0.9075	0.8942	0.7959	0.7887
ARIMA (0,2,1)	0.0269	0.8975	0.8865	0.9174	0.9144
ARIMA (2,2,0)	0.1364	0.6320	0.5915	0.7463	0.7373
ARIMA (2,2,1)	0.0748	0.8249	0.7950	0.8722	0.8674
ARIMA (1,2,2)	0.0717	0.7843	0.7500	0.7999	0.7929
ARIMA (2,2,2)	0.0793	0.5159	0.5418	0.9674	0.9662
ARIMA (0,2,2)	0.0529	0.9484	0.9410	0.7720	0.7643
ARIMA without constant term					
ARIMA (1,2,0)	0.0538	0.8207	0.8223	0.6404	0.6288
ARIMA (1,2,1)	0.0739	0.9275	0.9414	0.8291	0.8230
ARIMA (0,2,1)	0.0270	0.8894	0.9106	0.9569	0.9554
ARIMA (2,2,0)	0.1356	0.5218	0.5012	0.7916	0.7841
ARIMA (2,2,1)	0.0743	0.8444	0.8405	0.9063	0.9028
ARIMA (1,2,2)	0.0716	0.7919	0.7829	0.8341	0.8282
ARIMA (2,2,2) Estimated AR process in nonstationary Estimated MA process is noninvertible	0.4172	0.0000	0.0000	0.3717	0.3569
ARIMA (0,2,2)	0.0538	0.9376	0.9588	0.8129	0.8064

Table A4: p-values of residual diagnostic tests after fitting ARIMA (p,2,q) models to GDP data 1980-2015 under the OECD «conservative scenario»

	Normality Test	Breusch-Godfrey Serial Correlation LM Test		ARCH LM-test	
	Jarque-Bera	F-statistic	Obs R^2	F-statistic	Obs R^2
ARIMA with constant term					
ARIMA (1,2,0)	0.3248	0.8470	0.8287	0.6190	0.6053
ARIMA (1,2,1)	0.2008	0.9642	0.9580	0.9451	0.9428
ARIMA (0,2,1)	0.1289	0.9624	0.9576	0.9191	0.9159
ARIMA (2,2,0)	0.4603	0.4638	0.4126	0.8101	0.8022
ARIMA (2,2,1) Estimated MA process is noninvertible	0.4311	0.0000	0.0000	0.2260	0.2126

ARIMA (1,2,2)	0.0917	0.9109	0.8927	0.8635	0.8579
ARIMA (2,2,2)	0.4761	0.9287	0.9105	0.8803	0.8752
ARIMA (0,2,2)	0.1502	0.9549	0.9474	0.8911	0.8868
ARIMA without constant term					
ARIMA (1,2,0)	0.3247	0.8417	0.8288	0.6314	0.6180
ARIMA (1,2,1)	0.2009	0.9636	0.9587	0.9435	0.9412
ARIMA (0,2,1)	0.1289	0.9616	0.9582	0.9256	0.9226
ARIMA (2,2,0)	0.4603	0.4522	0.4140	0.8092	0.8013
ARIMA (2,2,1) Estimated AR process in nonstationary Estimated MA process is noninvertible	0.6120	0.0000	0.0000	0.4273	0.4104
ARIMA (1,2,2)	0.0916	0.9078	0.8929	0.8661	0.8607
ARIMA (2,2,2) Estimated AR process in nonstationary Estimated MA process is noninvertible	0.5660	0.0000	0.0000	0.3643	0.3476
ARIMA (0,2,2)	0.1499	0.9531	0.9473	0.8987	0.8947

Table A5: Criteria values of fitted models to GDP data 1980-2019 under the IMF «optimistic scenario»

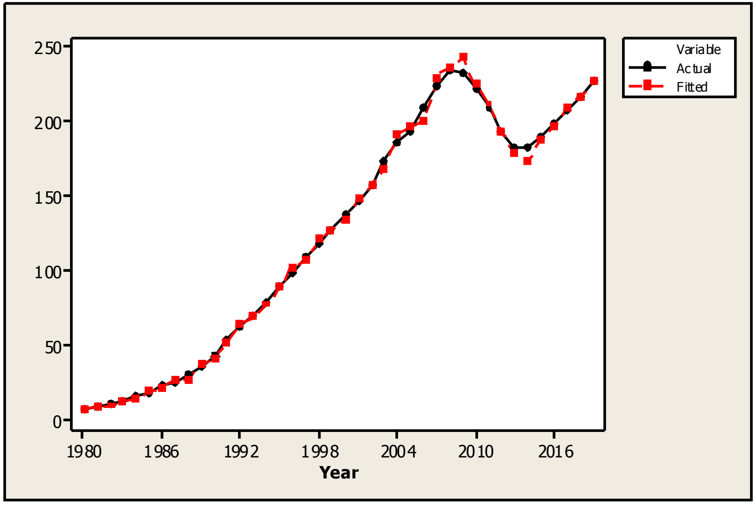
	Akaike Info	**Schwarz**	**Hannan-Quinn**	**MAE**	**MAPE (%)**
Double Exponential Smoothing				2.5386 (1)	3.0532
ARIMA with constant term					
ARIMA (1,2,0)	5.5713	5.6620	5.6018	2.6921	2.5222
ARIMA (1,2,1)	5.6174	5.7535	5.6632	2.6977	2.5086
ARIMA (0,2,1)	5.5253	5.6151	5.5559	2.6490	2.7075
ARIMA (2,2,0)	5.6570	5.7944	5.7025	2.8151	2.5970
ARIMA (1,2,2)	5.6664	5.8478	5.7275	2.6063	2.3678
ARIMA (2,2,2)	5.7258	5.9548	5.8017	2.6336	2.2878 (1)
ARIMA (0,2,2)	5.5840	5.7186	5.6299	2.6510	2.7089
ARIMA without constant term					
ARIMA (1,2,0)	5.5108	5.5561	5.5260	2.6929	2.5220
ARIMA (1,2,1)	5.5568	5.6475	5.5874	2.6978	2.5092
ARIMA (0,2,1)	5.4665 (1)	5.5114 (1)	5.4818 (1)	2.6492	2.7130
ARIMA (2,2,0)	5.5945	5.6861	5.6248	2.8151	2.5966
ARIMA (1,2,2)	5.6058	5.7419	5.6516	2.6055	2.3653
ARIMA (0,2,2)	5.5252	5.6150	5.5558	2.6512	2.7150

Table A6: Criteria values of fitted models to GDP data 1980-2015 under the OECD «conservative scenario»

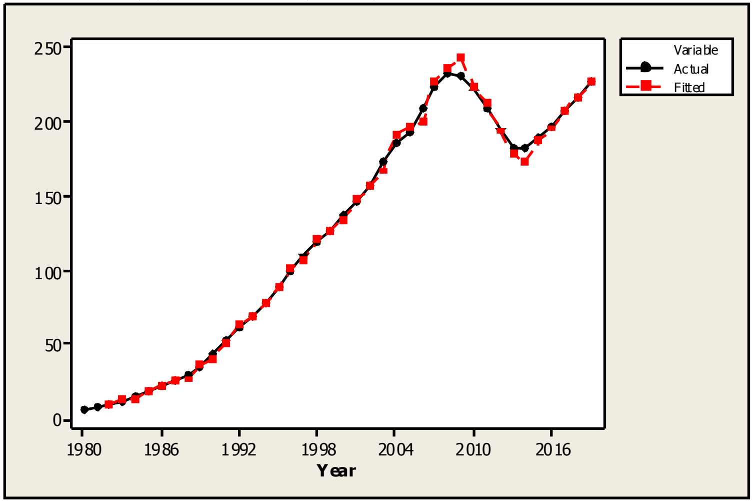
	Akaike Info	**Schwarz**	**Hannan-Quinn**	**MAE**	**MAPE (%)**
Double Exponential Smoothing				2.4407 (1)	2.8361
ARIMA with constant term					
ARIMA (1,2,0)	5.5609	5.6480	5.5916	2.5456	2.3518
ARIMA (1,2,1)	5.6040	5.7346	5.6501	2.5735	2.3895
ARIMA (0,2,1)	5.5271	5.6133	5.5578	2.5462	2.4776
ARIMA (2,2,0)	5.6357	5.7677	5.6818	2.6422	2.3718
ARIMA (2,2,1)	5.6893	5.8652	5.7507	2.6034	2.2305 (1)
ARIMA (1,2,2)	5.6580	5.8322	5.7194	2.5726	2.3932
ARIMA (2,2,2)	5.6051	5.8250	5.6818	2.6011	2.3451
ARIMA (0,2,2)	5.5749	5.7042	5.6209	2.5357	2.4818
ARIMA without constant term					
ARIMA (1,2,0)	5.5078	5.5514	5.5514	2.5400	2.3457
ARIMA (1,2,1)	5.5512	5.6383	5.5819	2.5731	2.3798
ARIMA (0,2,1)	5.4764 (1)	5.5195 (1)	5.4917 (1)	2.5491	2.5280
ARIMA (2,2,0)	5.5817	5.6697	5.6124	2.6405	2.3976
ARIMA (2,2,1)	5.6351	5.7670	5.6811	2.6155	2.2895
ARIMA (1,2,2)	5.6052	5.7358	5.6513	2.5737	2.3863
ARIMA (0,2,2)	5.5240	5.6101	5.5546	2.5371	2.5295

Figure A1: Actual versus fitted values for the "best" models predicting GDP under the IMF «optimistic scenario»

(a) Double Exponential Smoothing



(b) ARIMA (0,2,1) without constant term



(c) ARIMA (2,2,1) with constant term

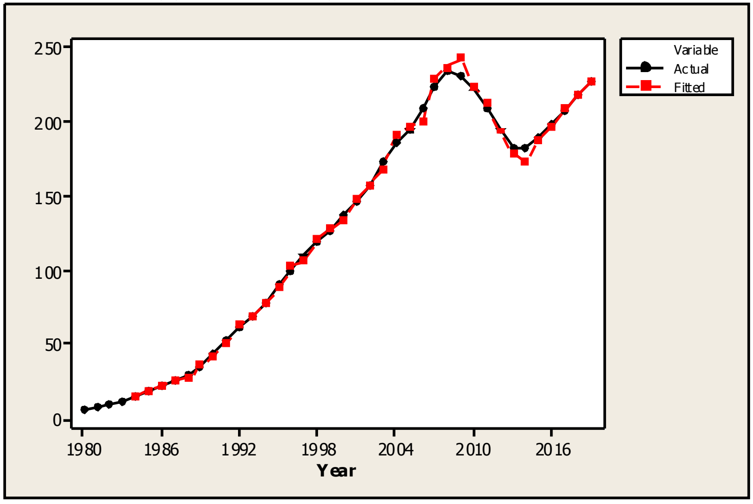
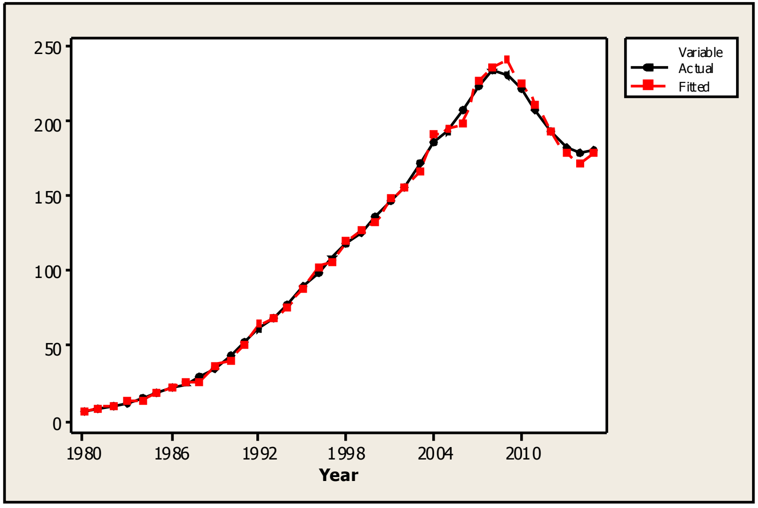
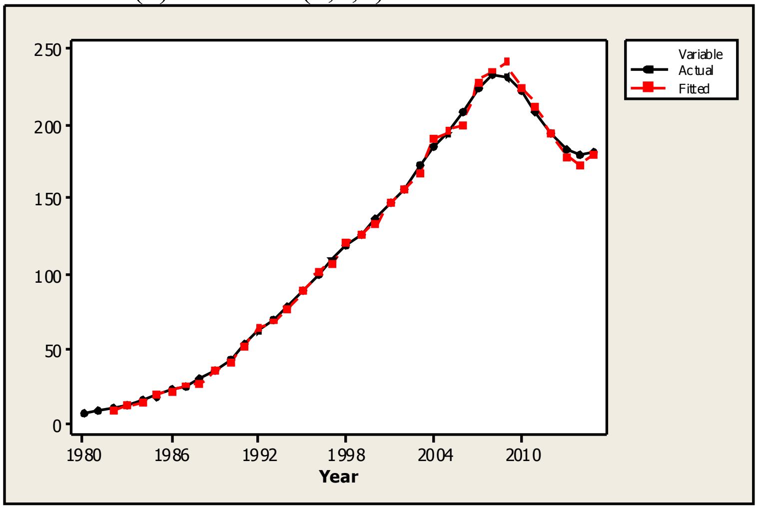


Figure A2: Actual versus fitted values for the "best" models predicting GDP under the OECD «conservative scenario»

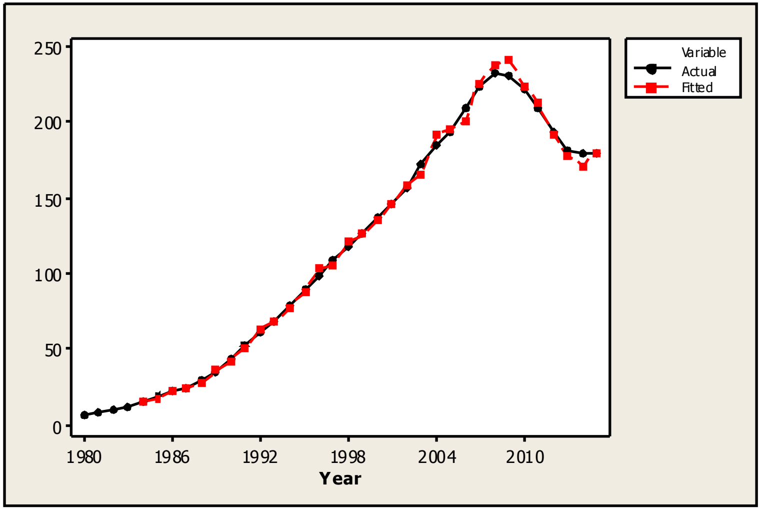
(a) Double Exponential Smoothing



(b) ARIMA (0,2,1) without constant term



(c) ARIMA (2,2,2) with constant term



SECTION 5

Greenhouse gas emissions and marginal abatement cost (MAC) curves for Energy and Industry sectors

5.1. Energy sector

The last decades the target of Greek national energy policy is the relevant independence of the country from the petroleum. In that manner, other energy sources have been exploited such as lignite and hydro energy and others have been imported such as natural gas. Lignite is the primary energy source for electricity in Greece. Petroleum remains the largest source regarding the total primary energy supply (57.8%), in the second place are the fossil fuels such as lignite (26.6%), in the third place are the aerial fuels such as natural gas (8.7%) and last are the renewable energy sources (5.5%). Next we will present eight abatement options for the Greek energy sector. Due to data availability we finally use only five of those abatement options. The annual load factor of the electricity in Greece is 62%[45]. In addition, as fuel cost we have used the cost of the Brent crude oil barrel which is 581.27 €/t[46]. We have also assumed 2013 as a starting year and a loan interest 1.5%[47].

5.1.1. Wind Power

Wind power refers to the power which comes from the wind. Wind turbines, windmills and windpumps are used to convert the wind into energy such as electrical or mechanical power. In order to produce a considerable amount of energy, large wind farms are needed which consist of hundreds of wind turbines. When these constructions are onshore, the cost is very low and in most cases it is considerable cheaper than fossil fuels. On the other hand, when the farms are offshore, the cost of construction and maintenance is significantly higher; however the construction is better and more efficient. Wind is plenty in Greece and wind power is a good alternative option. Furthermore, it is a clean energy and produces no greenhouse gases. The average efficiency wind power is 35% (EURELECTRIC, 2003).

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[45] The annual load factor was extracted from LEAP software.

[46] http://www.bloomberg.com/

[47] http://www.indexmundi.com/

In this abatement option we assume that ten wind parks which have already been announced or are in the process of planning, will be constructed. These parks are located in Karditsa, Pelis, Lefkada, Rethymno, Andros, Tinos, Kefallonia, Samos, Mykonos and Sifnos. The total installed capacity of these ten wind parks is 94.4 MW[48]. The capital cost of these plants in average is 2500 €/kWe and the fixed operation and maintenance cost is 90 €/kWe (IPA, 2010). Two years[49] are needed for the parks to be constructed while the amortization period is five years (Karagiorgas et al., 2010). Table 5.1 presents the data.

Figure 5.1: Onshore wind farm

Figure 5.2: Offshore wind farm

Table 5.1: Data for wind energy abatement option

Input parameters		
Installed capacity	94.4	MW
Average efficiency	35%	%
Annual load factor	62	%
Capital cost	2500	€/kW
Number of years before installation	2	Years
Service life	16	Years
Annual capital cost amortization	5	Years
Fuel annual cost	581.27	€/t
Fixed om cost	90	€/kW
Discount rate	1.5	%

Moreover, maximum wind production growth rate assumed at 20% per year. Note that for less than 10% the penetration is considered as low and for more than 10% it is considered

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[48] http://www.ppcr.gr/Home.aspx?C=2

[49] http://www.ppcr.gr/Home.aspx?C=2

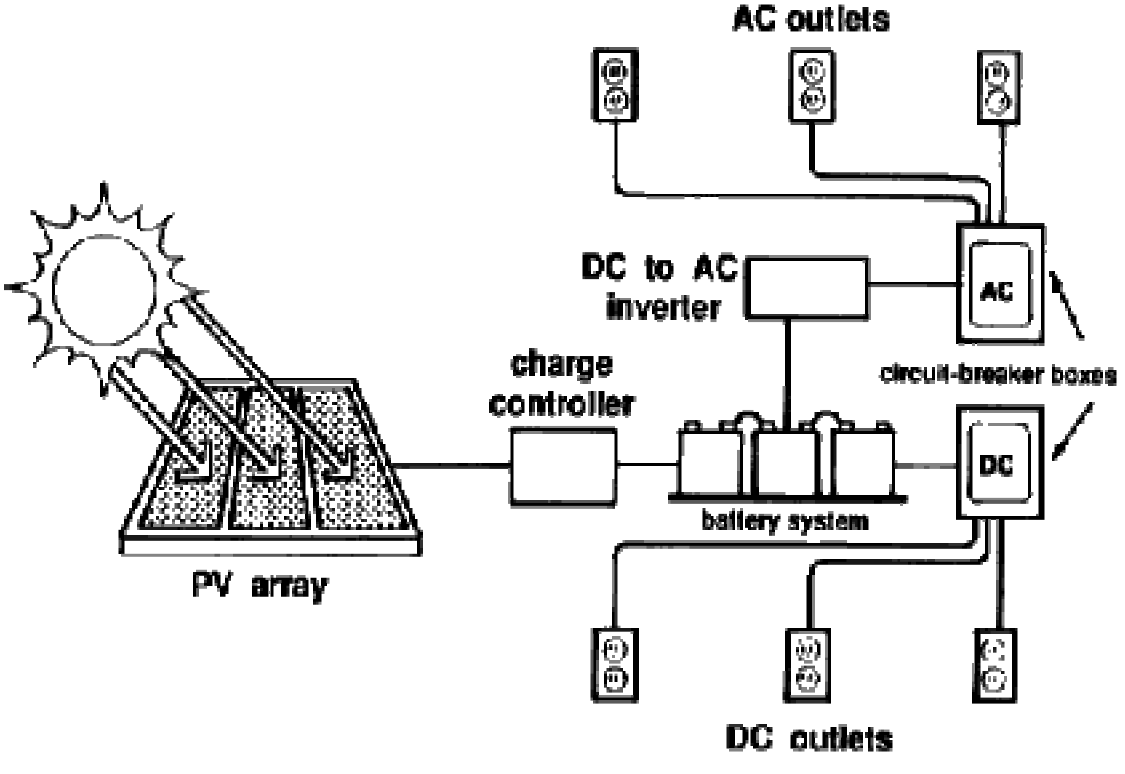
as high. Overall cost/unit of electricity produced is decreased by 5% every time the cumulative installed capacity is doubled.

5.1.2. Solar Photovoltaic

A Photovoltaic system uses the sun as a source of power in order to produce electric power. Photovoltaic cells are made usually from silicon. When the sun is shining the light hits on the cells and an electric field is created. On hotter and more shinny days more electricity is produced, however electricity is still produced on cloudy days. The efficiency of a photovoltaic panel is at 27%[50]. A photovoltaic module is a connected assembly of about 40 solar cells ad a solar panel or solar array is consists of multiple photovoltaic modules.

The use of photovoltaic systems offers multiple advantages. Sunlight is free and as a result, after the initial capital cost, the operational cost for electricity will be significantly reduced. In addition, solar energy is a renewable energy source and do not release any greenhouse gases.

Figure 5.3: A photovoltaic system



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[50] http://www.cres.gr/kape/index.htm

Solar energy is another abundant energy source in Greece. This abatement option assumes that five photovoltaic parks which have already been announced or are in the process of planning will be constructed. The locations of these parks are: Agrinio, Megalopoli, Ptolemaida, Athina and Thessaloniki with total installed capacity at 260.84 MWh[51]. The capital cost of a photovoltaic park is at 4500 €/kWe and the fixed operation and maintenance cost is at 30 €/kWe (IPA, 2010). Two years are needed for the parks to be constructed (PPC, 2012) while the amortization period is seven years (Karagiorgas et al., 2010). Table 5.2 presents the data.

Table 5.2: Data for solar photovoltaic energy abatement option

Input parameters		
Installed capacity	260.84	MW
Average efficiency	27	%
Annual load factor	62	%
Capital cost	4500	€/kW
Number of years before installation	2	Years
Service life	16	Years
Annual capital cost amortization	7	Years
Fuel annual cost	581.27	€/t
Fixed om cost	30	€/kW
Discount rate	1.5	%

Note that for less than 10% the penetration is considered as low and for more than 10% it is considered as high.

5.1.3. Geothermal energy

Geothermal energy is produced and stored inside the earth. The sources of thermal energy are primarily the decay of uranium and potassium (80%) and also the formation of the earth (20%). Beneath the surface of the earth there is the magma layer which is a very hot mixture of molten and semi-molten rocks, volatiles and solids. Most of the decay of radioactive materials takes place here. When the crust of the earth is very thin, the heat can come up to the surface. These places are seismically active and as a result earthquakes can break the rocks on the surface, letting hot water out. These areas are called hot springs. This is the natural expression of geothermal energy. However, geothermal energy can be found everywhere. Geothermal power plants can exploit the geothermal energy almost anywhere in the world using hydrothermal convection. The geothermal plant sends cool water into the

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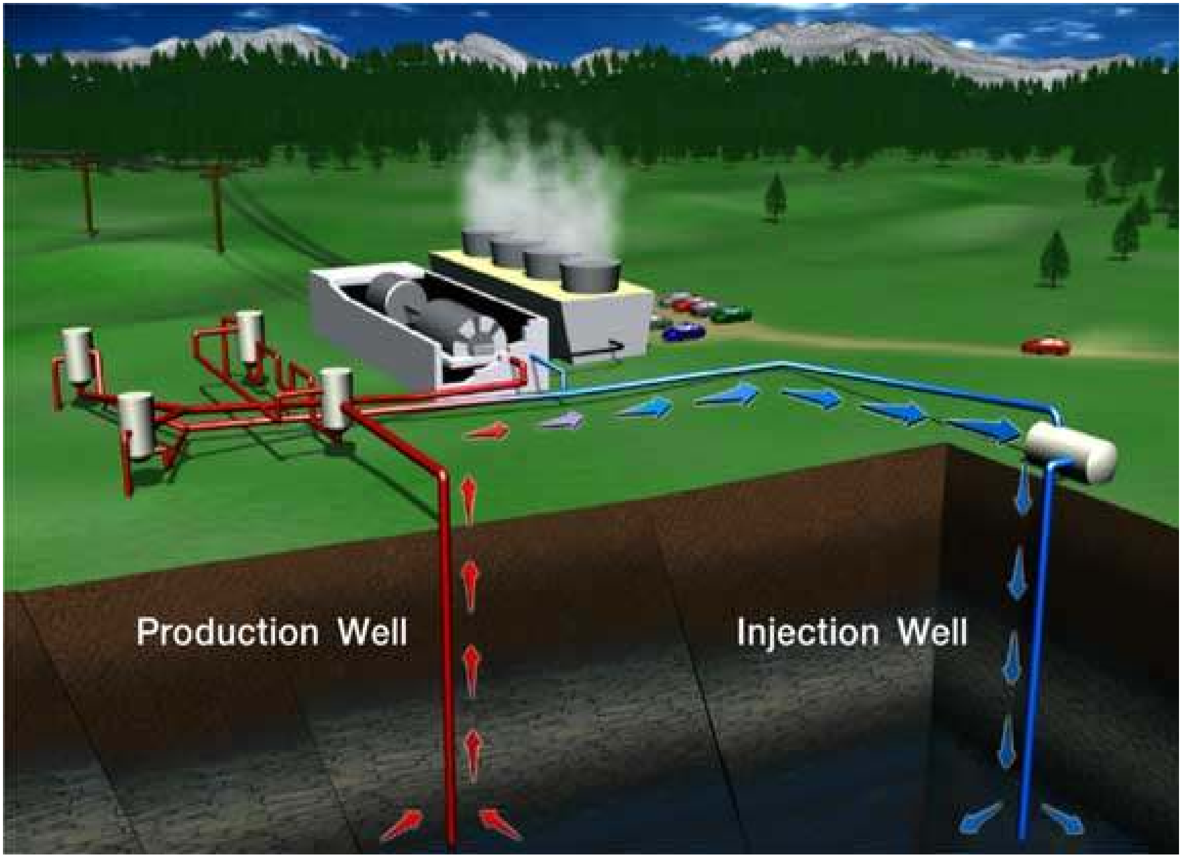
[51] http://www.ppcr.gr/Home.aspx?C=2

earth where it is heated and then rises up to the surface. The heated water produces steam which powers the electrical generators. The average efficiency of a geothermal power plant is 55% (Karagiorgas et al., 2010).

Figure 5.4: Geothermal power plant



Greece meets the geological standards in order to produce geothermal energy in large scale. Geothermal energy is currently used in Greece for residential, industrial and agricultural use. This abatement option assumes that four geothermal plants which have already been announced or are in the process of planning will be constructed. The locations of these power plants are: Kimolos, Lesvos, Nisyros and Methana with total installed capacity at 23 MWh[52]. The capital cost of a geothermal power plant is at 2600 €/kWe and the fixed operation and maintenance cost is at 110 €/kWe (IPA, 2010). Three years are needed for the plants to be constructed (PPC, 2012) while the amortization period is five years (Karagiorgas et al., 2010). Table 5.3 presents the data.

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[52] http://www.ppcr.gr/Home.aspx?C=2

Table 5.3: Data for geothermal energy abatement option

Input parameters		
Installed capacity	23	MW
Average efficiency	55	%
Annual load factor	62	%
Capital cost	2600	€/kW
Number of years before installation	3	Years
Service life	15	Years
Annual capital cost amortization	5	Years
Fuel annual cost	581.27	€/t
Fixed om cost	110	€/kW
Discount rate	1.5	%

Globally, current operating capacity of this option is 30% for US and developing Asia. In future developing countries assumed to account for a large share of the capacity. In 2030 the global potential capacity is assumed at 60-80 GW.

5.1.4. Biomass

Biomass is a carbon neutral source of energy and it is created from organic waste which comes from living or recently living organisms which can be either plants or animals. Biomass can be directly used for energy purposes or it can be used to produce biofuels. The biomass which comes from plants called lignocellulosic biomass and currently its largest source is wood such as forest debris. The biomass power plants burn the organic waste in order to produce steam which drives a turbine to produce electricity and heat. The average efficiency of a geothermal power plant is 34% (Karagiorgas et al., 2010). There are various types of biomass plants which use alternative sources to produce biomass such as wood (bark, brash, logs, sawdust, wood chips, wood pellets and briquettes), energy crops (Miscanthus, switchgrass, reed canary grass, rye, giant reed, hemp, poplar, willow, Eucalyptus, Nothofagus, sycamore, ash, sugar crops, starch crops, oil crops, microalgae, macroalgae, pond and lake weeds, etc), agricultural residues (straw, corn stover, poultry litter, animal slurry, grass silage, dying biomass material), food waste and industrial waste and co-products (untreated wood, treated wood and residues, wood composites and laminates, paper pulp and wastes, textiles and sewage sludge)[53].

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[53] http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,17304&_dad=portal&_schema=PORTAL

Figure 5.5: The conversion of biomass into electricity

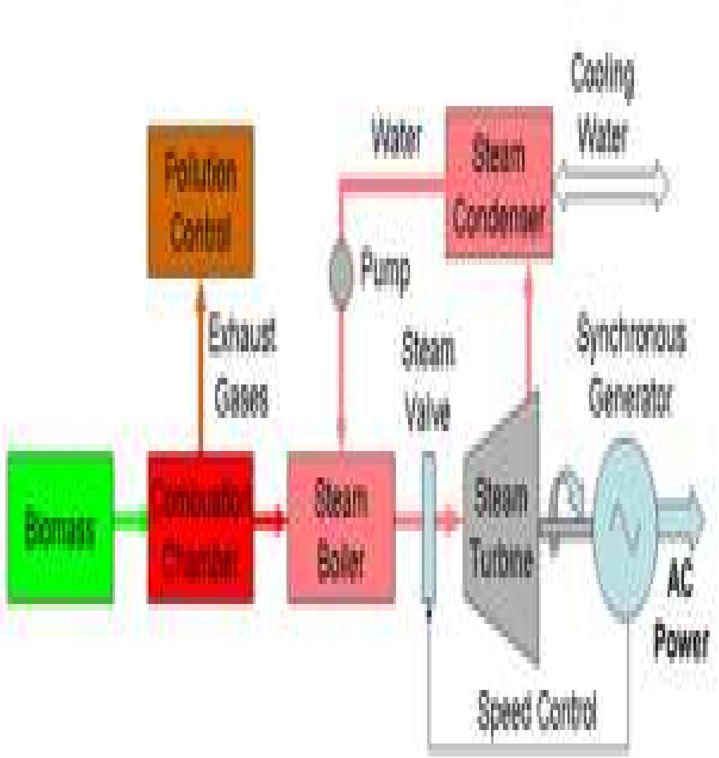
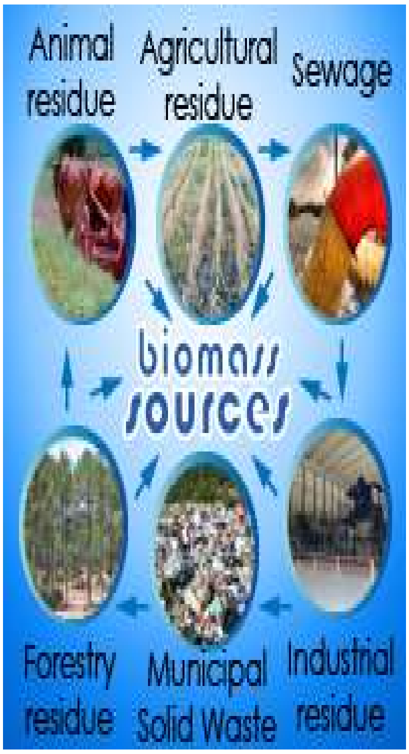


Figure 5.6: Various sources of biomass



Greece has abundance of raw materials for the production of biomass and an agricultural sector which accounts for 5.2% of GDP which is significantly above the average of the European Union (1.8%). Furthermore, the country is obliged to replace 10% of the conventional fuels with biofuels by 2020. This abatement option assumes that a biomass power plant in Kozani which have already been announced will be constructed with total installed capacity at 25 MWh[54]. The capital cost of a biomass power plant is at 2000 €/kWe and the fixed operation and maintenance cost is at 50 €/kWe (IPA, 2010). Four years are needed for the plants to be constructed (PPC, 2012) while the amortization period is three years (Karagiorgas et al., 2010). Table 5.4 presents the data.

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[54] http://www.ppcr.gr/Home.aspx?C=2

Table 5.4: Data for biomass abatement option

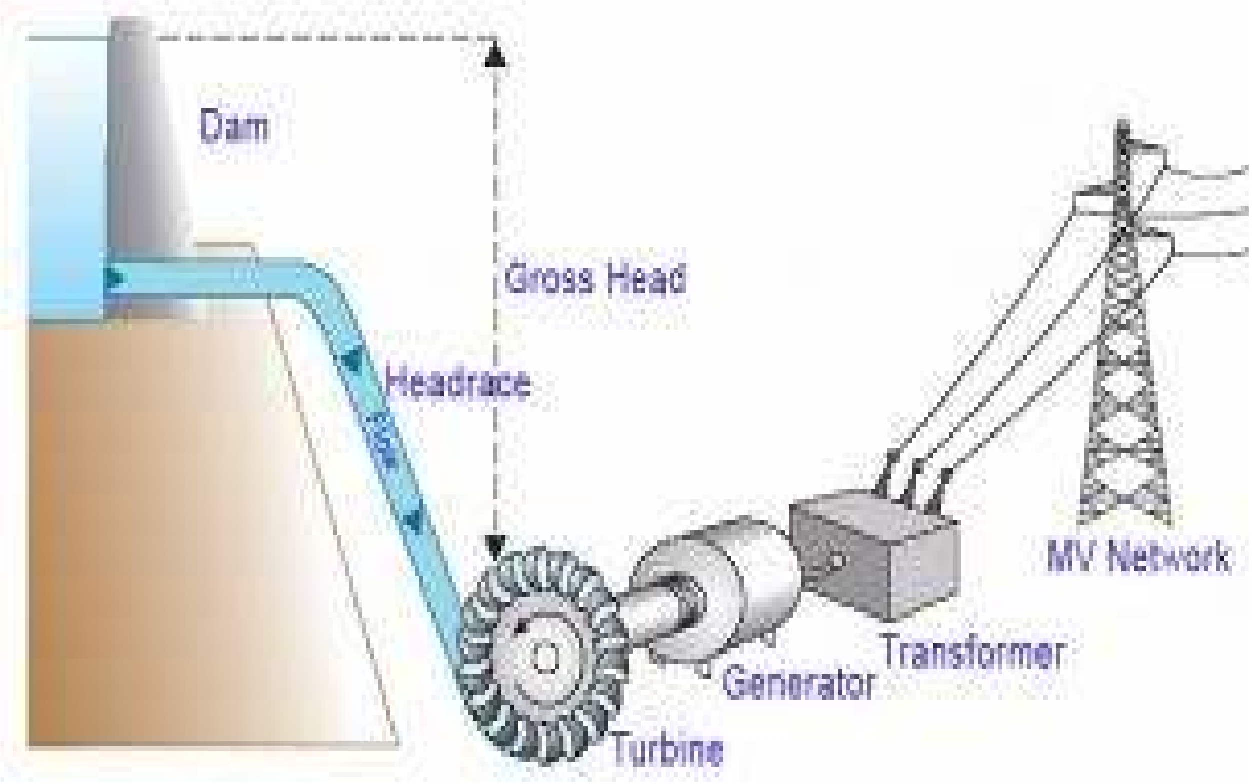
Input parameters		
Installed capacity	25	MW
Average efficiency	34	%
Fuel calorific value	16	GJ/t
Annual load factor	62	%
Capital cost	2000	€/kW
Number of years before installation	4	Years
Service life	14	Years
Annual capital cost amortization	3	Years
Fuel annual cost	581.27	€/t
Fixed om cost	50	€/kW
Discount rate	1.5	%
Fuel carbon content	45	%

This option assumes 10% biomass co-firing on 50% of coal plants. Co-firing is the combustion of two different types of materials at the same time, in this case biomass and coal. Biomass plants are most attractive when they are large-scale and equipped with carbon capture and storage technology.

5.1.5. Small-hydro

Small hydro refers to plants which generate hydroelectric power in order to power an industrial plant or a small community. By definition, a small hydro plant has a generation capacity up to 10 MW. Hydroelectric power uses the movement of water (falling or flowing) in order to produce electricity. The power plant needs a reasonable flow and a height in order the water to fall. Then the water flows or falls inside a pipe and drives a turbine which generates the electrical power. A common place for a small hydro is an existing or a newly developed dam. The most challenging aspect of small hydro power plants is their high average efficiency (90%) (Karagiorgas et al., 2010). Small hydro offers a number of advantages such as it do not pollute the environment and do not rise the water temperature. Also, their construction usually benefits other activities such as pumping, fishing and leisure.

Figure 5.7: The conversion of hydro power to electricity



The geographical and geological shape of Greece fosters the development of small hydro power plants under certain circumstances and planning. This abatement option assumes that eight small hydro power plants which have already been announced or are in the process of planning will be constructed. The locations of these power plants are: Alatopetra Grevena, Ilariona Kozani, Kalamata, Ladona, Makrohori, Mesohora Trikala, Pournari and Smokovo with total installed capacity at 24.62 MWh[55]. The capital cost of a small hydro power plant is at 3000 €/kWe and the fixed operation and maintenance cost is at 50 €/kWe (IPA, 2010). Three years are needed for the plants to be constructed (PPC, 2009) while the amortization period is five years (Karagiorgas et al., 2010). Table 5.5 presents the data.

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[55] http://www.ppcr.gr/Home.aspx?C=2

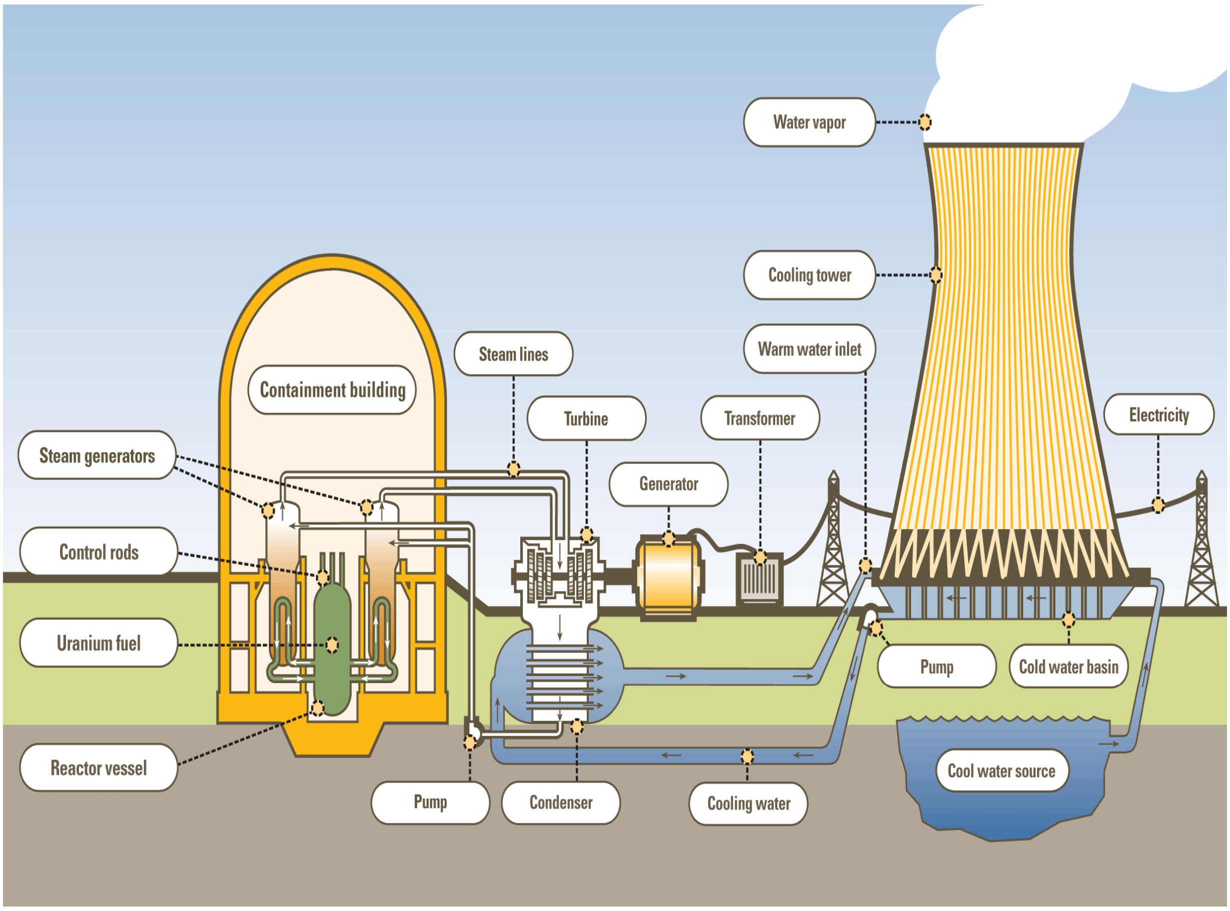
Table 5.5: Data for small hydro abatement option

Input parameters		
Installed capacity	24.62	MW
Average efficiency	90	%
Annual load factor	62	%
Capital cost	3000	€/kW
Number of years before installation	3	Years
Service life	15	Years
Annual capital cost amortization	5	Years
Fuel annual cost	581.27	€/t
Fixed om cost	50	€/kW
Discount rate	1.5	%

5.1.6. Nuclear energy

Nuclear energy is produced during a nuclear reaction. Specifically, nuclear is the energy produced during a change in the nuclei of an atom and it can be produced by nuclear fission and by nuclear fusion. Nuclear fission happens when we shoot neutrons in order to split the nuclei of uranium atoms. Nuclear fusion is exactly the opposite and happens when we join the nuclei of two atoms. Nuclear fission is the process which is currently used to produce electricity and heat while nuclear fusion is the process the sun uses to produce heat and also the process to develop an atomic bomb. It is unlikely that nuclear fusion will be used for heating and electricity commercially before 2050. France and Japan are the largest nuclear producers (50% of the global nuclear generated electricity). In 2030 the installed base globally will be 750 GW. The total amount of nuclear power produced could rise from 2700 TWh to 4900 TWh from 2005 to 2030. Long lead times and supply constraints deter from even more nuclear capacity until 2030. Nuclear power is a clean and sustainable energy source which has a positive effect in the reduction of carbon emissions. However, nuclear power plant accidents such as in Chernobyl and Fukushima have revealed the safety threats of nuclear energy.

Figure 5.8: Nuclear reaction inside the nuclear plant.



5.1.7. Solar concentrated

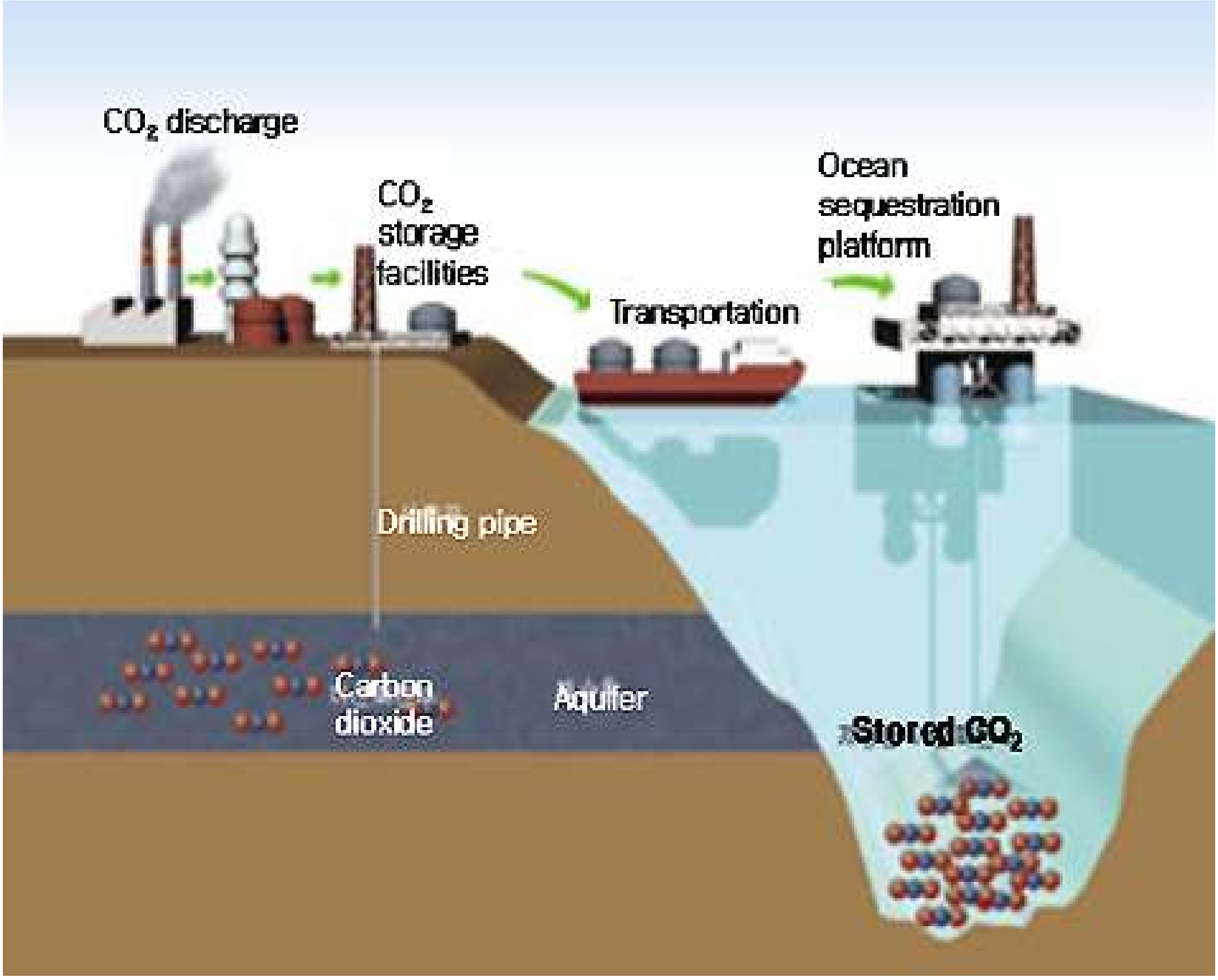
Concentrated solar power (CSP) is the technology which uses mirrors to concentrate sunlight into a small area and then to convert it into heat. The heat drives a steam turbine which produces electrical power. The difference between photovoltaic and CSP is that the former utilizes the sunlight directly while the later utilizes the focused sunlight. In 2005 the installed base globally is very low however in 2030 it will grow to 200 GW. Industry will grow by 30% until 2015 and 20% from there on. This option assumes significant storage capabilities. Capacity factors are 50-60% in 2020 and 70-90% in 2030.

Figure 5.9: The CSP tower concentrates the light which is then utilized.

5.1.8. Carbon capture and storage technology

Carbon capture and storage (CCS) is applied at large emission sources and captures CO_2 which otherwise would have been emitted to the environment. The captured CO_2 is then transported to a storage site and is disposed back to the environment but in a way which it can not enter the atmosphere (e.g. underground). So, the three steps for CCS are capture, transportation and storage. It is widely used at fossil fuels power plants and is a method to decrease carbon dioxide emissions, global warming and ocean acidification. It is the only currently feasible technology that allows for continued use of coal for power generation and at the same time it reduces the emissions substantially. EU target is 50 plants until 2020. CCS industry will grow 30% until 2030. Here we choose abatement options which convert existing thermal plants into renewable energy sources plants, for example we convert (close) lignite thermal plant into a new biomass plant. CCS is a very promising method however it is applied at the existing thermal plants; therefore we choose not to include it in our analysis. Conversely we do include it at industry sector where our abatement options aim to improve the existing plants.

Figure 5.10: Carbon capture and storage process.



5.2. Industry sector

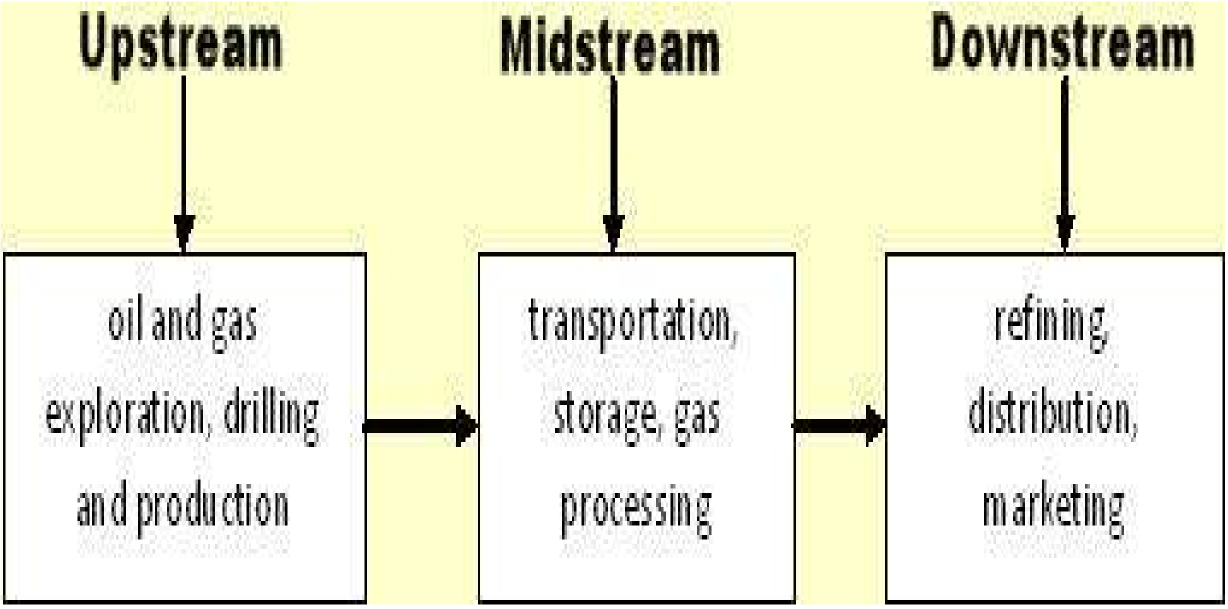
The global financial crisis has a significant negative impact on Greek industry. Until 2007 Greece experienced high industrial growth rates, however since 2008 the industrial annual growth is negative and specifically -10.2 in 2008, -8.5 in 2009, -9.9 in 2010, -12.6 in 2011 and -4.5 in 2012[56]. Industrial sector in Greece contributes 16% to total GDP which is the second largest contribution after services sector (80.6%)[57].

Industrial sector is consisted of various subsectors. Among them the most significant and carbon intensive are petroleum and gas, cement, iron and steel and chemicals (McKinsey, 2009). Next we will present abatement options for all the subsectors and we will focus our analysis at petroleum and gas, cement and iron and steel which are the largest in scale.

5.2.1 Petroleum and Gas

Petroleum and gas sector is consisted of upstream production and processing, midstream gas transportation and storage and downstream refining. We include only downstream refining in our analysis.

Figure 5.11: Petroleum and gas production



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[56] http://data.worldbank.org/indicator/NV.IND.TOTL.KD.ZG

[57] http://www.indexmundi.com/greece/gdp_composition_by_sector.html

5.2.1.1. Petroleum and Gas – Upstream production and processing

The upstream oil sector is the exploration and production (E&P) sector. The upstream sector includes the searching for potential underground or underwater crude oil and natural gas fields, drilling of exploratory wells, and subsequently drilling and operating the wells that recover and bring the crude oil and/or raw natural gas to the surface. We do not include upstream production and process in our analysis because currently the oil production is in a very small scale in Greece. However, due to newly found evidence about oil fields and natural gas fields, upstream production is expected to thrive in the next few years. Next we will present abatement options for upstream production and processing.

Figure 5.12: Small-scale petroleum production in Prinos

Energy efficiency from improved maintenance and process control is assumed

Operators of onshore and offshore oil and gas production facilities must ensure their business is safe, avoids risk from environmental disasters, and is able to produce product at the optimal cost. Sound maintenance and reliability practices are the key to operational excellence. This abatement option assumes replacements, upgrades and additions that do not alter the process flow of an upstream production site. Furthermore, this option assumes more efficient pump impeller and the replacement of boilers, heaters, turbines and motors.

Energy efficiency from improved behavior, maintenance and process control on retrofits

Retrofitting refers to the addition of new technology or features to older systems. Retrofitting existing plants has significantly lower cost than building a new plant. This option assumes the implementation of energy conservation awareness programs. Also it assumes additional and/or improved maintenance which ensures the optimal condition of the equipment. In addition, improved process control is assumed which reduces suboptimal performance. The improved behavior, maintenance and process control on retrofits results in reduced energy and other costs and improved reliability.

More efficient new builds

Along with retrofitting the existing plants and constructions, improving the efficiency of new plants is also crucial. To plan a new oil production facility, geologists, geophysicists, engineers and others are employed in order to achieve the best possible results. Among other things, they're trying to predict the best locations for the wells and how quickly the oil or gas will flow out of the reservoirs. This option is about new build production units which use both process units with best-in-class energy efficiency and also maintenance and process controls with best-in-class energy efficiency.

Reduction of continuous flaring

Flaring is the combustion of gas. This option assumes actions towards the reduction of continuous flaring. It requires gas recovery, treatment of units for oil associated gasses and a pipeline network to transport gas. Namely a number of alternative technology considerations towards the reduction of continuous flaring are condensate recovery, gas recovery from atmospheric separators or tanks, gas recovery/transfer as a multiphase stream, gas re-injection or enhanced oil recovery, gas recovery using an internal combustion (IC) engine, gas recovery via a gas ejector, gas recovery in a vapour recovery unit, gas recovery in vapour recovery compressors and dehydrator flash gas recovery.

Carbon capture and storage

Carbon capture and storage (CCS) captures CO_2 which otherwise would have been emitted to the environment. The captured CO_2 is then transported to a storage site and is disposed back to the environment but in a way which it can not enter the atmosphere (e.g.

underground). It is a method to decrease carbon dioxide emissions, global warming and ocean acidification.

5.2.1.2. Petroleum and Gas - Midstream gas transportation and storage

The midstream sector involves the transportation (by pipeline, rail, barge, or truck), storage, and wholesale marketing of crude or refined petroleum products. We do not include midstream transportation and storage in our analysis. Up to 90% of oil transportation in Europe comes from oil tankers. Natural gas is imported to Greece using gas pipelines and liquefied natural gas. Gas from pipelines covers 84% of the needs (67% from Russian Gazprom and 17% from Turkish BOTAS) and liquefied gas covers 16% (from Algerian Sonatrach)[58]. Currently a number of plans are developed which include Greece as a transporter of natural gas towards Balkans and Italy. Next we will present abatement options for midstream gas transportation and storage.

Replace compressor seals

This option assumes the replacement of traditional wet seals with dry seals which will reduce the methane leakage from compressors. Dry gas seals are non-contacting, dry-running mechanical face seals consist of a mating (rotating) ring and a primary (stationary) ring. When operating, grooves in the rotating ring generate a fluid-dynamic force causing the stationary ring to separate and create a gap between the two rings. Dry gas seals are mechanical seals but use other chemicals and functions so that they do not contaminate a process

Improved maintenance on compressors

This option assumes the implementation of a directed inspection and maintenance program (DI&M) which detects, prioritize and repair equipment leakage in order to reduce methane emissions from compressors and valves. In general the program starts with the identification and quantification of leaks and promotes the most cost-effective solutions. Then, based on this previous knowledge the program concentrates on the components that are most likely to leak and most profitable to repair.

Directed inspection and maintenance on distribution network

Similar as the previous directed inspection and maintenance program, however this focuses on surface and metering stations.

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[58] http://www.depa.gr/content/article/002003006/160.html

Improved planning

This option plans to decrease emissions due to transmission combustion. It reduces the unnecessary pressure by continuously matching compression needs with natural gas demand. Also, it promotes the running of the compressors at the most efficient point.

5.2.1.3. Petroleum and Gas – Downstream Refining

The downstream sector commonly refers to the refining of petroleum crude oil and the processing and purifying of raw natural gas, as well as the marketing and distribution of products derived from crude oil and natural gas. The Greek market consists of two companies, namely Hellenic Petroleum and Motor Oil Hellas. Hellenic Petroleum operates three refineries in Aspopyrgos, Thessaloniki and Elefsina and Motor Oil Hellas operates one refinery in Agioi Theodoroi. The total installed capacity of these four refineries is 726.96 MW and the annual load factor is 79.4% (Ministry of Development, 2008). In addition, as fuel cost we have used the cost of the Brent crude oil barrel which is 581.27 €/t[59]. We have also assumed 2013 as a starting year and a loan interest 1.5%[60]. Next we will present six abatement options for the Greek downstream refining petroleum sector. We finally choose only four of those abatement options for the needs of our study.

Figure 5.13: Motor Oil refinery in Agioi Theodoroi, Korinthos

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[59] http://www.bloomberg.com/

[60] http://www.indexmundi.com/

Energy efficiency from behavioral changes

This option assumes the implementation of energy conservation awareness programs such as energy and GHG awareness of personnel, a management system which includes monitoring and an energy management which focuses on all processes. The average efficiency of behavioural changes is assumed at 100% and we assume that there are no losses due to human factor.The capital cost and the fixed operation and maintenance cost is 0 €/kW (McKinsey, 2009). We assume that behavioral changes are applied immediately. Table 5.6 presents the data.

Table 5.6: Data for energy efficiency from behavioral changes abatement option

Input parameters		
Installed capacity	726.96	MW
Average efficiency	100	%
Annual load factor	79.4	%
Capital cost	0	€/kW
Number of years before installation	0	Years
Service life	18	Years
Annual capital cost amortization	0	Years
Fuel annual cost	581.27	€/t
Fixed om cost	0	€/kW
Discount rate	1.5	%

Energy efficiency from improved maintenance and process control

This option assumes additional and/or improved maintenance which ensures optimal condition for the equipment. In addition, improved process control is assumed which reduces suboptimal performance. The average efficiency of improved maintenance and process control is assumed at 100% and we assume that there are no losses due to human factor. The capital cost is at 1.65 €/kW and the fixed operation and maintenance cost is at 0.25 €/kW (McKinsey, 2009). We assume that improved maintenance and process control is applied immediately while the amortization period is assumed to be one year. Table 5.7 presents the data.

Table 5.7: Data for energy efficiency from improved maintenance and process control abatement option

Input parameters		
Installed capacity	726.96	MW
Average efficiency	100	%
Annual load factor	79.4	%
Capital cost	1.65	€/kW
Number of years before installation	0	Years
Service life	18	Years
Annual capital cost amortization	1	Years
Fuel annual cost	581.27	€/t
Fixed om cost	0.25	€/kW
Discount rate	1.5	%

Energy efficiency requiring Capital expenses at process unit level

This abatement option assumes replacements, upgrades and additions which do not alter the process flow of a refinery. Also, it assumes replacement of boilers, heaters, turbines and motors and waste heat recovery through heat integration. The average efficiency of energy efficiency changes which require capital expenses at process unit level is assumed at 100% and we assume that there are no losses due to human factor. The capital cost is at 82.51 €/kW and the fixed operation and maintenance cost is at 4.13 €/kW (McKinsey, 2009). We assume that changes are applied immediately while the amortization period is assumed to be one year. Table 5.8 presents the data.

Table 5.8: Data for energy efficiency requiring Capital expenses at process unit level abatement option

Input parameters		
Installed capacity	726.96	MW
Average efficiency	100	%
Annual load factor	79.4	%
Capital cost	82.51	€/kW
Number of years before installation	0	Years
Service life	18	Years
Annual capital cost amortization	1	Years
Fuel annual cost	581.27	€/t
Fixed om cost	4.13	€/kW
Discount rate	1.5	%

Carbon capture and storage

It is applied to the exhaust emissions coming from the direct energy use in the downstream refineries and at the emissions which are coming from the hydrogen generation unit. Carbon capture and storage (CCS) captures CO_2 which otherwise would have been emitted to the environment. The captured CO_2 is then transported to a storage site and is disposed back to the environment but in a way which it can not enter the atmosphere (e.g. underground). It is a method to decrease carbon dioxide emissions, global warming and ocean acidification. The average efficiency of carbon capture and storage is at 72% (McKinsey, 2009). The capital cost is at 3.16 €/kW and the fixed operation and maintenance cost is at 0.137 €/kW[61]. Nine years are needed for the plants to be constructed[62] while the amortization period is assumed to be one year. Table 5.9 presents the data.

Table 5.9: Data for carbon capture and storage abatement option

Input parameters		
Installed capacity	726.96	MW
Average efficiency	72	%
Annual load factor	79.4	%
Capital cost	3.16	€/kW
Number of years before installation	9	Years
Service life	9	Years
Annual capital cost amortization	1	Years
Fuel annual cost	581.27	€/t
Fixed om cost	0.137	€/kW
Discount rate	1.5	%

Co-generation

This abatement option generates useful heat and electricity simultaneously. Waste heat from the production is used in the refinery. Co-generation is assumed to be a thermodynamically efficient use of fuel because instead of dispose the waste heat which is produced in the process, it employs it in a good use. Co-generation capacity is assumed to replace thermal energy at 30%. The 60% of refineries are assumed as capable of implementing co-generation.

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[61] Calculated based on McKinsey (2009) data.

[62] http://www.iea.org/publications/freepublications/publication/CCS_roadmap_foldout.pdf

Flaring instead of venting gas at a petroleum refinery

Venting is the process of direct releasing of natural gas into the atmosphere without flaring or incineration. The quantities released at any given refinery are small, however the total amount released from every refinery is significant. On the other hand, flaring is the burning of natural gas in open air. The process disposes of the gas, however it releases emissions into the atmosphere. The process of gas flaring in oil and gas production is a safety measure. Various types of flaring include flaring during extraction and first treatment of both gaseous and liquid fossil fuels and flaring in oil refineries. Among the different types of flares, the steam-assisted elevated flaring is the most commonly used at petroleum refineries. During the process, steam is injected in the combustion zone of the flare to provide turbulence and inject air to the flame.

5.2.2. Cement

Cement sector is one of the leaders of Greek industry. Three companies operate in this sector, Heracles GCC of Lafarge Group with cement plants in Volos and Milaki[63] and a total installed capacity of 6.7 million tons[64], TITAN with cement plants at Thessaloniki, Drepano, Kamari and Elefsina and a total installed capacity of 7,04 million tons[65] and Halyps Cement of Italcementi Group with a total installed capacity of 1 millions tons[66]. The total installed capacity of the sector is 14.74 million ton of cement. The annual load factor is estimated at 39.8 % with an annual production of 5.86 million tons[67]. As fuel cost we have used the cost of the Brent crude oil barrel which is 581.27 €/t[68]. We have also assumed 2013 as a starting year and a loan interest 1.5%[69]. Next we will present six abatement options for the Greek cement sector. We finally choose only four of those abatement options for the needs of our study

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[63] The company has a third plant in Halkida with installed capacity at 2.9 million tons which was recently closed.

[64] http://www.lava.gr/en/whoweare/

[65] http://www.cemnet.com/GCR/country/Greece

[66] http://www.sepan.gr/index.php/el/xalyps

[67] http://www.kathimerini.gr/30873/article/oikonomia/epixeirhseis/hellastat-ypoxwrhsh-ths-paragwghs-skyrodematos

[68] http://www.bloomberg.com/

[69] http://www.indexmundi.com/

Figure 5.14: Halyps cement plant in Aspropyrgos

Clinker replacement with fly ash and slag

This option assumes the reduction of clinker component in cement by substitution with fly ash or slag. Clinkers are formed by heating cement elements in a kiln. Limestone, clay, bauxite and iron ore sand in specific proportions are heated in a rotating kiln until they begin to form clinkers. Fly ash is one of the two by-products burning coal. When coal is burned it produces coal ash which is a non-combustible byproduct. Two types of coal ash are produced, bottom ash which is collected at the bottom of coal furnaces and fly ash which is collected at the smokestacks. Slag is a byproduct of iron production. During the iron blast furnace, slag and iron both are collected at the bottom of the furnace in molten form and are separated from each other. The molten slag is drenched with water until it turns into a raw material called granules, which then are cooled and dried in order to be ready for cement use.

The substitution of clinker with other elements such as fly ash and slag helps towards the reduction of process and fuel combustion emissions and also the reduction of electric power used for clinker production. These emissions account for the 90% of total emissions in the cement industry. Max replacement of clinker with fly ash is 25% and with slag is 40% (McKinsey, 2009). Based on max replacement the total installed capacity for fly ash is calculated at 3.685 million tones and for slag is calculated at 5.896 million tones. The average efficiency of clinker replacement with fly ash is at 80% (Tsakalakis, 2010) and with slag is at 95%[70]. Fuel calorific value for the abatement option of fly ash is 25.3 GJ/tonne (coal burning) and for the abatement option of slag is 29.5 GJ/tonne (coke burning). The capital cost is at 5 €/tonne for fly ash and at 145 €/tonne for slag (McKinsey, 2009). The fixed operation and maintenance cost is at 17.5 €/tonne for fly ash and 21.5 €/tonne for slag (McKinsey, 2009). We assume one year for both replacements to fully take place and an amortization period of one year. Tables 5.10 and 5.11 present the data.

Table 5.10: Data for replacement of clinker with fly ash abatement option

Input parameters		
Installed capacity	3.685	million tonnes
Average efficiency	80	%
Fuel calorific value	25.3	GJ/t
Annual load factor	39.8	%
Capital cost	5	€/tonne
Number of years before installation	1	Years
Service life	17	Years
Annual capital cost amortization	1	Years
Fuel annual cost	581.27	€/t
Fixed om cost	17.5	€/tonne
Discount rate	1.5	%

Table 5.11: Data for replacement of clinker with slag abatement option

Input parameters		
Installed capacity	5.896	million tonnes
Average efficiency	95	%
Fuel calorific value	29.5	GJ/t
Annual load factor	39.8	%
Capital cost	145	€/tonne
Number of years before installation	1	Years
Service life	17	Years
Annual capital cost amortization	1	Years
Fuel annual cost	581.27	€/t
Fixed om cost	21.5	€/tonne
Discount rate	1.5	%

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[70] http://en.wikipedia.org/wiki/Ground_granulated_blast-furnace_slag

Increased share of waste or biomass as kiln fuel

This option assumes the substitution of fossil fuels in the cement kiln with alternative fuels (municipal and industrial fossil waste or biomass). This will reduce the average fuel combustion emissions of the clinker making process. It is assumed that CO2 from biomass is climate-neutral. The real reductions of CO2 emissions at the alternative waste-disposal operations are attributed to the cement sector and sufficient amount of biomass and waste are available to substitute fossil fuels. The average efficiency of increased share of waste as kiln fuel is at 21%[71] and of increased share of biomass as kiln fuel is at 34% (Karagiorgas, 2010). Fuel calorific value for the abatement option of waste as fuel is 21 GJ/tonne (Tsakalakis, 2010) and for the abatement option of biomass as fuel is 16 GJ/tonne[72]. The capital cost is at 200 €/tonne for both the abatement options (McKinsey, 2009). The fixed operation and maintenance cost is at 12 €/tonne for waste as fuel and 27 €/tonne for biomass as fuel (McKinsey, 2009). For the increased share of waste as fuel we assume one year for the abatement option to fully take place and an amortization period of one year. For increased share of biomass as fuel four years are needed for biomass plants to be constructed (PPC, 2012) while the amortization period is three years (Karagiorgas et al., 2010). Tables 5.12 and 5.13 present the data.

Table 5.12: Data for increased share of waste as fuel abatement option

Input parameters		
Installed capacity	14.74	million tonnes
Average efficiency	21	%
Fuel calorific value	21	GJ/t
Annual load factor	39.8	%
Capital cost	200	€/tonne
Number of years before installation	1	Years
Service life	17	Years
Annual capital cost amortization	1	Years
Fuel annual cost	581.27	€/t
Fixed om cost	12	€/tonne
Discount rate	1.5	%

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[71] http://en.wikipedia.org/wiki/Waste-to-energy

[72] http://www.omafra.gov.on.ca/english/index.html

Table 5.13: Data for increased share of biomass as fuel abatement option

Input parameters		
Installed capacity	14.74	million tonnes
Average efficiency	34	%
Fuel calorific value	16	GJ/t
Annual load factor	39.8	%
Capital cost	200	€/tonne
Number of years before installation	4	Years
Service life	14	Years
Annual capital cost amortization	3	Years
Fuel annual cost	581.27	€/t
Fixed om cost	27	€/tonne
Discount rate	1.5	%

Carbon capture and storage

It is applied to the exhaust emissions coming from the cement production. Carbon capture and storage (CCS) captures CO_2 at the emission point and separates it. Otherwise these emissions would have been emitted to the environment. The captured CO_2 is then transported to a storage site and is disposed back to the environment but in a way which it can not enter the atmosphere (e.g. underground). It is a method to decrease carbon dioxide emissions, global warming and ocean acidification. Implementation for newbuilds will start at 2021 and for retrofits at 2026.

Waste heat recovery

This option uses the excess heat from clinker burning process for electricity generation. Specifically, it recovers the unused heat available from the grate cooler and generates electricity on a continuous basis without interfering with the core, clinker production process. Waste heat recovery operation reduces the electricity generation and indirect CO2 emissions.

5.2.3. Iron and Steel

Since 1937, iron and steel sector is one of the leaders in Greek industry. After 2000 the sector experienced a rapid growth, however the last couple of years it has been highly affected by the global financial crisis. The three major companies of iron and steel industry are Hellenic Halyvourgia, Sidenor S.A. and Hellenic Steel[73] with total installed capacity at 4,445 million tones. Specifically, Hellenic Halyvoyrgia operates two plants in Volos and Velestinos[74] with total installed capacity of 1.3 million tons[75]. Sidenor S.A. operates two plants in Thessaloniki and Almyros with total installed capacity of 2 million tons[76]. Hellenic Steel operates one plant in Thessaloniki with installed capacity of 1,145 million tons[77]. A distinctive mark of the financial crisis is the low annual load factor which is only 5.6%[78]. As fuel cost we have used the cost of the Brent crude oil barrel which is 581.27 €/t[79]. We have also assumed 2013 as a starting year and a loan interest 1.5%[80]. Next we will present seven abatement options for the Greek iron and steel sector We finally choose only four of those abatement options for the needs of our study.

Figure 5.15: Halyvourgiki iron and steel plant in Elefsina.

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[73] Halivourgiki is another major company which however it does not operate for the last year and we do not include this company into our analysis.

74 Aspropyrgos plant with installed capacity of 0,4 million tons was closed.

75 http://www.hlv.gr/company-facilities-en.html

76 http://www.sidenor.gr/PlainText.aspx?MenuTxtId=20&lang=GR

77 https://www.steelbb.com/?PageID=157&article_id=84264

78 http://www.greenpeace.org/greece/el/blog/blog_dimitris_ibrahim/blog/48287/

79 http://www.bloomberg.com/

80 http://www.indexmundi.com/

Energy efficiency improvements

This option includes continuous improvement measures, preventative and better planning maintenance, insulation of furnaces, improved process flows, sinter plant heat recovery, coal-moisture control and pulverized coal injection. The average efficiency of improvements in energy efficiency is assumed at 100%[81]. The capital cost is at 35 €/tonne and the fixed operation and maintenance cost is at 0 €/tonne (McKinsey, 2009). We assume that improvements in energy efficiency are applied immediately while the amortization period is assumed to be one year. Table 5.14 presents the data.

Table 5.14: Data for improvements in energy efficiency abatement option

Input parameters		
Installed capacity	4.445	million tonnes
Average efficiency	100	%
Annual load factor	5.6	%
Capital cost	35	€/tonne
Number of years before installation	0	Years
Service life	18	Years
Annual capital cost amortization	1	Years
Fuel annual cost	581.27	€/t
Fixed om cost	0	€/tonne
Discount rate	1.5	%

Co-generation

The Blast furnace (BF) and Basic Oxygen furnace (BOF) in steel manufacturing process generate waste gas as a by-product. This abatement option recovers the gas and cleans it and then uses it for power generation. Co-generation is assumed to be a thermodynamically efficient use of fuel because instead of dispose the waste heat which is produced in the process, it employs it in a good use. This option is integrated into the furnaces and helps towards the reduction of the total energy demand. All energy plants which use BF and BOF can be generated internally without the need of an outside generation at all. The average efficiency of co-generation is at 80%[82]. Fuel calorific value for the co-generation due to burning of natural gas is 38.1 GJ/tonne[83]. The capital cost is at 70 €/tonne and the fixed

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[81] We assume that there are no losses due to human factor.

[82] http://en.wikipedia.org/wiki/Cogeneration

[83] http://setis.ec.europa.eu/technologies/Cogeneration-of-heat/info

operation and maintenance cost is at 0 €/tonne (McKinsey, 2009). We assume that co-generation is applied after one year while the amortization period is four years[84]. Table 5.15 presents the data.

Table 5.15: Data for co-generation abatement option

Input parameters		
Installed capacity	4.445	Million tonnes
Average efficiency	80	%
Fuel calorific value	38.1	GJ/t
Annual load factor	5.6	%
Capital cost	70	€/tonne
Number of years before installation	1	Years
Service life	17	Years
Annual capital cost amortization	4	Years
Fuel annual cost	581.27	€/t
Fixed om cost	0	€/tonne
Discount rate	1.5	%

Direct casting

Current techniques in steel casting favor the continuous casting into slabs, billets and blooms. After the casting and during the rolling, they need to be reheated in order to take the final shape. This abatement option integrates the casting and hot rolling into one step and reduces the heat needed. In addition, it incorporates two newly developed direct casting techniques, namely the net-shape casting and the strip casting. The only drawback is that it can only be applied to new-builds. The average efficiency of direct casting is at 90%[85]. The capital cost is at 80 €/tonne and the fixed operation and maintenance cost is at 0 €/tonne (McKinsey, 2009). We assume that co-generation is applied after one year and the amortization period is three years. Table 5.16 presents the data.

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[84] http://www.cumminspower.com/www/literature/technicalpapers/PT-7018-EvaluatingCogen-en.pdf

[85] http://climatetechwiki.org/technology/direct-casting

Table 5.16: Data for direct casting abatement option

Input parameters		
Installed capacity	4.445	million tonnes
Average efficiency	90	%
Annual load factor	5.6	%
Capital cost	80	€/tonne
Number of years before installation	1	Years
Service life	17	Years
Annual capital cost amortization	3	Years
Fuel annual cost	581.27	€/t
Fixed om cost	0	€/tonne
Discount rate	1.5	%

Smelt reduction

As smelting reduction abatement option we can group a set of ironmaking processes which aim to surpass certain fundamental problems of the currently in-use blast furnace route. Such problems are the dependence on large scale operation, reliance on coking coal and environmental pollution. Specifically, this abatement option combines upstream hot metal production processes into one step and therefore it completely avoids the coking process. The result is less fuel used and less emissions. The average efficiency of smelt reduction is at 29%[86]. The capital cost is at 100 €/tonne and the fixed operation and maintenance cost is at 0 €/tonne (McKinsey, 2009). Smelt reduction needs up to ten years[87] in order to be available in Greece (currently it is available only in developing countries) and the amortization period is four years. Table 5.17 presents the data.

Table 5.17: Data for smelt reduction abatement option

Input parameters		
Installed capacity	4.445	million tonnes
Average efficiency	29	%
Annual load factor	5.6	%
Capital cost	100	€/tonne
Number of years before installation	10	Years
Service life	8	Years
Annual capital cost amortization	4	Years
Fuel annual cost	581.27	€/t
Fixed om cost	0	€/tonne
Discount rate	1.5	%

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[86] http://climatetechwiki.org/technology/smelt-reduction

[87] http://climatetechwiki.org/technology/smelt-reduction

Carbon capture and storage

Carbon capture and storage (CCS) captures CO_2 which otherwise would have been emitted to the environment. The captured CO_2 is then transported to a storage site and is disposed back to the environment but in a way which it can not enter the atmosphere (e.g. underground). It is a method to decrease carbon dioxide emissions, global warming and ocean acidification. The implementation of this option in iron and steel industry will start in 2021.

Coke substitution

In currently used techniques coal is an important element which can not be removed from the process. During the process in the coking oven, coal is converted into lump coke. Specifically coking coal is the type of coal which is used to create coke. Then the blast furnace takes place, where the oxygen is removed from an iron ore by reacting with coke at a high temperature, and raw iron is created. This abatement option assumes the replacement of coke which is used in Blast furnace and Basic Oxygen furnace with biomass fuel with zero carbon intensity which results in 100% decrease in carbon intensity. A 100% implementation is possible until 2030.

Blast furnace / Basic Oxygen furnace to electric arc furnace - Direct Reduced Iron shift

This option is about the shift from Blast furnace and Basic Oxygen furnace to electric arc furnace (EAR) and Direct Reduced Iron (DRI). It is assumed the increased share of EAR-DRI in the future. EAR is a type of furnace which heats charged materials by means of an electric arc. DRI is used in EAR to replace srap and it is produced by natural gas as ore reducing agent. This option is very costly in the most regions due to the use of gas as a fuel. It is possible to be used at areas such as Siberia, Kazakhstan, Iran and Iraq.

5.2.4. Chemical

Chemical industry is a relatively small but dynamic sector of Greek economy, with around 400 enterprises mainly small in size and with high dispersion with over 19.000 employees (HACI, 2009). A distinctive characteristic of the sector is its significant contribution to national exports, up to 15% (HACI, 2009). Chemical industry includes companies which produce industrial chemicals such as basic chemicals, fertilizers, paints, detergents, asphalt, polymers, industrial gases and plant protection products. Also, chemical industry includes transport and storage companies and waste management companies.

Motor systems

Motor systems are used in chemical industry in order to convert electrical energy into mechanical energy, which is used for the industrial processes. Motor systems account nearly 60-70% of the electricity consumption. Therefore an improvement in motor system efficiency would provide significant benefits in terms of electricity savings. This abatement option assumes energy savings in motor systems such as adjustable speed drive, more energy efficient motors and mechanical system optimization.

Adipic acid

Adiptic acid is the most important dicarboxylic acid in chemical industry. It is a white crystalline powder and it is primarily used for the production of nylons. Other uses of adiptic acid are for synthetic lubricants, synthetic fibers, plastics and food flavor. Nitrous oxide (N2O) is a by-product of the adiptic acid production process. Adiptic acid and nitric acid are assumed the primary sources of industrial N2O emissions worldwide. This abatement option is about the decomposition of N2O which produced in the adipic acid process, into oxygen and nitrogen using catalysts. This option is vital towards the reduction of N2O emissions.

Nitric acid

Nitric acid is a highly corrosive strong mineral acid. It is colorless and it is primarily used for the production of synthetic commercial fertilizer. Other uses of nitric acid are for explosives and the production of adiptic acid. Nitrous oxide (N2O) is a by-product of the nitric acid production process. Adiptic acid and nitric acid are assumed the primary sources of industrial N2O emissions worldwide. This option is about the decomposition of N2O which produced in the nitric acid production using filtering measures. This option is vital towards the reduction of N2O emissions.

Fuel shift

This abatement option assumes a shift from coal to biomass and from oil to gas. The benefits from such conversions are multiple. Biomass is a carbon neutral source of energy and it is created from organic waste which comes from living or recently living organisms which can be either plants or animals. In addition, converting coal to biomass offers further benefits such as the reduction of nitrogen oxides, sulphur dioxide, particulate matter and mercury. Compared to oil, natural gas has lower carbon emissions and it also has lower costs.

This abatement option results in reducing carbon intensity per MWh of energy produced. It is low cost and offers a net benefit to society.

Carbon capture and storage

Carbon capture and storage (CCS) captures CO_2 which otherwise would have been emitted to the environment. The captured CO_2 is then transported to a storage site and is disposed back to the environment but in a way which it can not enter the atmosphere (e.g. underground). It is a method to decrease carbon dioxide emissions, global warming and ocean acidification. The implementation of this option in iron and steel industry will start in 2021.

CHP

The conventional way of generating electricity generates heat which instead of being utilized it is wasted leading to energy losses. The combined heat and power (CHP) integrates the production of electricity and heat into one process. This abatement option diminishes the energy losses and the needed fuel and the resulting process can be described as highly efficient.

5.3. Methodology for least cost options

In order to find the least cost of each candidate technology we use the cost function which is given by Eq. (1)

$$L = \frac{\sum_{t=1}^{N} \frac{C_t + FOM_t + VOM_t + F_t}{(1+i)^{t-1}}}{\sum_{t=1}^{N} \frac{P_t}{(1+i)^{t-1}}} \tag{1}$$

where

C_t: annual Capital cost

FOM_t: annual Fixed Operating and Maintenance cost

VOM_t: annual Variable Operating and Maintenance cost

F_t: annual Fuel cost

P_t : represents the amount of energy produced from the candidate power technology in year t

i : represents the discount rate

N: represents the number of years.

More specifically, we explain below the calculation method of this cost function.

ANNUAL ENERGY PRODUCTION

E : Installed capacity (in MWe)

LF_t : Annual Load Factor or Annual Capacity Factor (in %)

The Annual Energy Poduction (in GWh) is calculated by Eq. (2)

$$\begin{bmatrix}\text{Production of Energy}\\ \text{in Year t in GWh}\end{bmatrix} = \begin{bmatrix}\text{Number of}\\ \text{hours per year}\end{bmatrix} \times \begin{bmatrix}\text{Installed}\\ \text{Capacity in GW}\end{bmatrix} \times \begin{bmatrix}\text{Annual}\\ \text{Load Factor}\end{bmatrix}$$

or

$$P_t = 8760 \times \left(10^{-3} \cdot E\right) \times \frac{LF_t}{100} = \frac{8760 \times E \times \frac{LF_t}{100}}{1000}. \qquad (2)$$

ANNUAL CAPITAL COST

E : Installed capacity (in MWe)

CP : Capital Cost (in €/kWe)

m : Loan Interest (in %)

q_t : Amortization factor per year

The Annual Capital Cost (in million €) is given by Eq. (3)

$$C_t = \frac{\begin{bmatrix}\text{Amortization}\\ \text{Factor in year t}\end{bmatrix} \times \begin{bmatrix}\text{Future Value of CP}\\ \text{in year t in €/kW}\end{bmatrix} \times \begin{bmatrix}\text{Installed Capacity}\\ \text{in kW}\end{bmatrix}}{1000}$$

or

$$C_t = \frac{q_t \times \left\{ \left(1+\frac{m}{100}\right)^t \times CP \right\} \times \left[10^3 \cdot E\right]}{10^6} = \frac{q_t \times \left(1+\frac{m}{100}\right)^t \times CP \times E}{10^3} . \tag{3}$$

ANNUAL FIXED OPERATING AND MAINTENANCE COST

E : Installed capacity (in MWe)

OM_F : Fixed Operating and Maintenance (O&M) Cost per month (in €/kWe).

r : Inflation (in %)

The Annual Fixed Operating and Maintenance cost (in million €) is given by Eq. (4)

$$FOM_t = \frac{\text{Future Value of O\&M cost}}{\text{in year t in €/kW}} \times \frac{\text{Installed Capacity}}{\text{in kW}}$$

or

$$FOM_t = \frac{\left\{ \left(1+\frac{r}{100}\right)^{t-1} \times \left(12 \times OM_F\right) \right\} \times \left(10^3 \cdot E\right)}{10^6} = \frac{12 \times \left(1+\frac{r}{100}\right)^{t-1} \times OM_F \times E}{10^3} . \tag{4}$$

ANNUAL VARIABLE OPERATING AND MAINTENANCE COST

E : Installed capacity (in MWe)

LF_t : Annual Load Factor or Annual Capacity Factor (in %)

OM_V : Variable Operating and Maintenance (O&M) Cost (in €/MWh)

r : Inflation (in %)

The Annual Variable Operating and Maintenance cost (in million €) is given by Eq. (5)

$$VOM_t = \frac{\text{Future Value of O\&M cost}}{\text{in year t in €/MWh}} \times \frac{\text{Generated Power in}}{\text{MWh}}$$

or

$$\mathrm{VOM}_t = \frac{\left\{\left(1+\frac{r}{100}\right)^{t-1} \times \mathrm{OM}_V\right\} \times \left\{8760 \times E \times \frac{\mathrm{LF}_t}{100}\right\}}{10^6} = \frac{8760 \times \left(1+\frac{r}{100}\right)^{t-1} \times \mathrm{OM}_V \times E \times \frac{\mathrm{LF}_t}{100}}{1000000}.$$

(5)

ANNUAL FUEL COST

E: Installed capacity (in MWe)

LF_t: Annual Load Factor or Annual Capacity Factor (in %)

F_s: Specific Fuel cost (in €/t)

η: Average value of efficiency of the candidate technology (in %)

CV : The calorific value of the fuel (in GJ/t or MJ/kg)

The Annual Fuel cost (in million €) is given by Eq. (6)

$$F_t = \frac{F_s \left\{\dfrac{3{,}1536 \times 10^7 \times E \times \frac{\mathrm{LF}_t}{100} \times 10^{-3}}{\frac{\eta}{100} \times CV}\right\}}{10^6} = 3{,}1536 \frac{E \times \frac{\mathrm{LF}_t}{100} \times F_s}{\eta \times CV}. \qquad (6)$$

5.4. Marginal abatement cost curves

Marginal abatement cost curves might adopt various shapes and forms as a result of the scope differences among countries/regions, sector differences, time differences or other differences (Kesicki, 2010). The abatement options of a MAC are evaluated and classified with respect to their cost effectiveness and the level of pollution mitigation. Specifically, the measures that are responsible for the marginal changes in emissions are placed in order of cost effectiveness from left to right and the result is a stepwise curve. The most cost effective options appear on the far left of the MAC curve. Each step of this stepwise curve represents solely one technological option (Halkos, 1992, 1995a, 2010).

The cost curve not only includes positive costs but also negative costs. The abatement options with negative cost may be defined in the literature as no regrets mitigation options. The existence of negative costs means that the society benefits from the specified mitigation actions. A number of authors argued about the validity of negative costs in MAC analysis.

According to Ekins et al. (2011) negative costs might appear due to a number of reasons such as the insufficiently definition of cost, the implementation of non-financial barriers or inconsistent discount rates. Furthermore, Brown (2001) presets a rage of market failures and institutional barriers such as market imperfections, irrationality of the agents, imperfect information and transaction costs that could also cause various problems. The above indicate that although we must be cautious about the interpretation of negative costs, they are desirable and society gains both in terms of cost and pollution mitigation.

Marginal abatement cost curves have been widely used across the literature. Halkos (1993) investigated acid rain and sulphur dioxide emissions and applied a MAC in order to evaluate and classify the abatement options for sulphur dioxide reductions. In addition, the author examined whether economic instruments work better than regulations. The results indicated significant differences in favor of economic instruments. Also, the author marked the significance of international cooperation towards the joint reduction of emissions. Halkos (1994) examined the abatement technologies for sulphur emissions regarding the minimization of abatement cost under different policy scenarios. The results indicated significant emissions reduction if the countries are to cooperate. Halkos (1995b) categorized the available sulphur abatement technologies into pre-combustion, during combustion and post combustion. The author used MAC curves in order to study these abatement technologies and found that a significant mitigation can be achieved with a relatively low cost, however additional reductions require a significant investment.

Ellerman and Decaux (1998) defined and examined the robustness of MACs. According to the authors a MAC curve is robust if the results are unchanged regardless the reductions that take place in other countries. Robustness of MAC curves have also been examined by Klepper and Peterson (2006), however the results were mixed. Morris et al. (2012) enhanced the model by investigating a number of neglected issues, such as the stability of the MAC curve over time, path dependency, measures of welfare derived from the MAC and the inclusion of non-CO2 GHGs.

Criqui et al. (1999) examined the role of a tradable emissions permit system as a mechanism for Annex B[88] countries to fulfill their Kyoto obligations. The authors used MAC curves and the POLES model for the needs of their model. Van Vuuren et al. (2004) investigated the case of a global uniform carbon tax. They used progressively increasing taxes

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[88] Annex B countries are those countries which have signed the Kyoto protocol.

in order to construct abatement cost curves. However, the difference between their method and typical MAC curves is that the authors examined how the system develops over time after the implementation of the carbon tax. Chen (2005) constructed MAC curves for the years 2010, 2020 and 2030 for China. The findings indicated that carbon abatement cost was higher in case the emissions were further reduced beyond the baseline scenario while the carbon abatement potential was limiting. Kesicki and Strachan (2011) marked the significant help which MAC curves offer to the decision maker if they are combined with other tools. In addition the authors provided useful insights about a number of shortcomings in MAC curve methodology.

Recently McKinsey brought MAC curves back into the attention of policy makers by publishing MAC curves for a number of countries and McKinsey (2009) published a global MAC curve regarding Energy, Industry, Transport, Residential, Agricultural, Wastes and Forestry sectors. McKinsey (2012) published a MAC curve for Greece regarding three sectors in detail (energy, residential and transport) and two more sectors (industry and agriculture). The report indicated that energy sector is the primary source of possible emissions reductions by accounting for 40% of possible emissions reduction while industry sector accounts only for 10%. In 2020, the average abatement cost for energy sector will be 31 euro/tCO2 eq. and the contribution of the sector into the overall abatement potential will be 55%. On the other hand industry's average abatement cost will be -38 euro/tCO2 eq. and the contribution of the sector into the overall abatement potential will be 13%.

5.4.1. Negative abatement cost

According to Ekins et al. (2011) the McKinsey abatement cost curve shows a significant amount of negative costs. In this study, they mention that as the project costs are correctly estimated, the explanation of these negative costs based on the insufficiently definition of the extensive cost, the implementation of non-financial barriers or inconsistent discount rates. Further, they note that markets are not perfect and suffer from various imperfections. So, the cost curve cannot assume rational agents, perfect information and no transaction costs.

Ackerman and Bueno (2011) present an overview of the McKinsey results and discuss the controversy about the meaning of the negative abatement cost. They mention that for this phenomenon McKinsey is not alone as there are bottom-up studies for energy savings and emission reductions which have negative cost options. In order to avoid the academic controversy about the interpretation of negative cost investment opportunities they offer a new method. Their method obtains estimates which are in some respects comparable to other bottom-up analysis of energy costs. Finally, they note that, according to Brown (2001), there are a range of market failures and institutional barriers, which are presented in Table 4.1, that explain the existence of the efficiency gap. This gap is the difference between the actual level of investment in energy efficiency and the higher level that would be cost-beneficial from the consumer's point of view.

5.4.2 Cost analysis

We used an optimization process in order to determine the least cost option for each sector and to rank the available abatement technology options which we presented thoroughly in a previous section. In order to determine the least cost option we considered a number of variables such as capital cost, variable costs, total installed capacity, annual load factor and other factors. Next we present in Tables 5.18-5.21 the least cost option and the abatement potential for each abatement technology option. We used the abatement potential from McKinsey (2009). Table 5.18 shows the least costs for energy sectors.

Table 5.19 shows that energy efficiency from behavioural changes is the least cost option with abatement potential up to 2.75%. On the other hand Carbon capture and storage abatement technology option which is the most expensive option, however the abatement potential is up to 40%.

Table 5.20 shows that clinker replacement with slag is the least cost option with abatement potential is up to 50%.

Table 5.21 demonstrates that energy efficiency improvements is the least cost option with abatement potential up to 32%.

Table 5.18: Least cost options and abatement potentials for Energy sector

Abatement options	Least cost option (million €)	Abatement potential
Wind power	39.12	7.9%
Solar photovoltaic	49.18	10.5%
Geothermal energy	44.66	5.25%
Biomass	356.85	11.2%
Small-hydro	39.52	4.5%

Table 5.19: Least cost options and abatement potentials for petroleum downstream refining subsector sector

Abatement options	Least cost option (million €)	Abatement potential
Energy efficiency from behavioral changes	0	2.75%
Energy efficiency from improved maintenance and process control	319.49	4.25%
Energy efficiency requiring Capital expenses at process unit level	831.229	4.2%
Carbon capture and storage	43.451	40%

Table 5.20: Least cost options and abatement potentials for cement subsector

Abatement options	Least cost option (million €)	Abatement potential
Clinker replacement with fly ash	241.29	50%[89]
Clinker replacement with slag	223.02	50%[43]
Increased share of waste as kiln fuel	765.60	27%[90]
Increased share of biomass as kiln fuel	710.17	27%[44]

Table 5.21: Least cost options and abatement potentials for iron and Steel subsector

Abatement options	Least cost option (million €)	Abatement potential
Energy efficiency improvements	1.91	32%
Co-generation	34.40	21%
Direct casting	4.49	3%
Smelt reduction	10.45	12%

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[89] The abatement potential for clinker replacement with fly ash and slag is the average value.

[90] The abatement potential for increased share of waste and biomass as kiln fuel is the average value.

Next, we will focus our analysis at a plant level. Table 5.22 presents a brief overview for energy sector of existing thermal plants in Greece. Specifically we present the number of unites for each plant, the fuel produced, installed capacity and pollutants (ypeka, 2013). Tables 5.23 and 5.24 present the cost of converting existing thermal plants to renewable energy sources plants. Specifically, Table 5.23 presents the capital and fixed operation and maintenance cost for the conversion and Table 5.23 presents the cost effectiveness of the conversion.

Table 5.22: Existing thermal power plants in Greece

Power plant	**Number of units**	**Fuel produced**	**Installed Capacity (MW)**	**Region**	**Pollutants million mt CO2 Eq.**
Agios Georgios	2	NG	360	Attica	2.55
Agios Dimitrios	5	Lignite	1595	W. Macedonia	7.10
Aliveri	4	Mazut	380	C. Greece	0.60
Amynteo	2	Lignite	600	W. Macedonia	2.70
Kardia	4	Lignite	1250	W. Macedonia	5.50
Lavrio	5	NG-Mazut	1572	Attica	2.40
Liptol	2	Lignite	43	W. Macedonia	0.20
Megalopoli	4	Lignite	850	Peloponnese	3.80
Ptolemaida	4	Lignite	620	W. Macedonia	2.80
Linoperamata	12	Diesel-Mazut	192.87	Crete	0.30
Florina	1	Lignite	330	W. Macedonia	1.50
Komotini	1	NG	485	Thrace	3.45
Rhodes	10	Diesel-Mazut	206.11	Dodekanisa	0.30

Table 5.23: Capital and fixed operation and maintenance costs for thermal power plants

	Capital cost (million €)					Fixed operation and maintenance cost (million €)				
Power Plant	**Wind**	**Solar Photovoltaic**	**Geothermal**	**Biomass**	**Small-hydro**	**Wind**	**Solar Photovoltaic**	**Geothermal**	**Biomass**	**Small-hydro**
Agios Georgios	9000.00	1620.00	936.00	720.00	1080.00	32.40	10.80	39.60	18.00	18.00
Agios Dimitrios	39875.00	7177.50	4147.00	3190.00	4785.00	143.55	47.85	175.45	79.75	79.75
Aliveri	9500.00	1710.00	988.00	760.00	1140.00	34.20	11.40	41.80	19.00	19.00
Amynteo	15000.00	2700.00	1560.00	1200.00	1800.00	54.00	18.00	66.00	30.00	30.00
Kardia	31250.00	5625.00	3250.00	2500.00	3750.00	112.50	37.50	137.50	62.50	62.50
Lavrio	39300.00	7074.00	4087.20	3144.00	4716.00	141.48	47.16	172.92	78.60	78.60
Liptol	1075.00	193.50	111.80	86.00	129.00	3.87	1.29	4.73	2.15	2.15
Megalopoli	21250.00	3825.00	2210.00	1700.00	2550.00	76.50	25.50	93.50	42.50	42.50
Ptolemaida	15500.00	2790.00	1612.00	1240.00	1860.00	55.80	18.60	68.20	31.00	31.00
Linoperamata	4821.75	867.92	501.46	385.74	578.61	17.36	5.79	21.22	9.64	9.64
Florina	8250.00	1485.00	858.00	660.00	990.00	29.70	9.90	36.30	16.50	16.50
Komotini	12125.00	2182.50	1261.00	970.00	1455.00	43.65	14.55	53.35	14.25	14.25
Rhodes	5152.75	927.50	535.89	412.22	618.33	18.55	6.18	22.67	10.31	10.31

Table 5.24: Cost effectiveness for thermal power plants

	Cost effectiveness (€/tCO2 eq)				
Power plant	**Small-hydro**	**Solar Photovoltaic**	**Geothermal**	**Biomass**	**Wind**
Agios Georgios	650.96	818.40	657.60	5938.16	743.15
Agios Dimitrios	1035.85	1302.28	1046.41	9449.14	1182.55
Aliveri	2920.30	3671.43	2950.07	26639.27	3333.87
Amynteo	1024.67	1288.22	1035.11	9347.11	1169.78
Kardia	1047.95	1317.50	1058.64	9559.55	1196.36
Lavrio	3020.21	3797.04	3050.99	27550.61	3447.92
Liptol	991.37	1246.36	1001.47	9043.33	1131.76
Megalopoli	1031.41	1296.70	1041.92	9408.61	1177.47
Ptolemaida	1021.01	1283.62	1031.41	9313.73	1165.60
Linoperamata	2964.41	3726.89	2994.63	27041.66	3384.23
Florina	1014.42	1275.34	1024.76	9253.64	1158.08
Komotini	648.21	814.94	654.82	5913.06	740.01
Rhodes	3167.91	3982.73	3200.20	28898.00	3616.54

Next, we present similar tables for petroleum refineries, cement plants and iron and steel plants respectively.

Table 5.25: Installed capacity and pollutants for petroleum refineries

Company	Refinery	Installed Capacity (MW)	Region	Pollutants thousand mt CO2 Eq.
Hellenic Petroleum	Aspropyrgos	239.38	Attica	57.04
	Thessaloniki	132.96	C. Macedonia	31.68
	Elefsina	177.31	Attica	42.24
Motor Oil Hellas	Agioi Theodoroi	177.31	Peloponnese	42.24

Table 5.26: Installed capacity and pollutants for cement plants

Company	Plant	Region	Installed Capacity (thousands tons of cement)	Pollutants thousand mt CO2 Eq.
Heracles GCC (Lafarge Group)	Volos	Magnesia	4500	547.08
	Milaki (Evia)	C. Greece	2200	267.46
TITAN	Elefsina	Attica	140	17.02
	Thessaloniki	C. Macedonia	2000	243.15
	Drepano (Ahaia)	Peloponnese	2000	243.15
	Kamari	C. Greece	2900	352.56
Halyps Cement (Italcementi Group)	Aspropyrgos	Attica	1000	121.57

Table 5.27: Installed capacity and pollutants for iron and steel plants

Company	Plant	Region	Installed Capacity (thousands tons of cement)	Pollutants thousand mt CO2 Eq.
Hellenic Halyvourgia	Velestinos	Magnesia	700	23.34
	Volos	Magnesia	600	20.00
Sidenor S.A.	Thessaloniki	C. Macedonia	800	26.67
	Almyros	Magnesia	1200	40.01
Hellenic Steel	Thessaloniki	C. Macedonia	1145	38.18

Table 5.28: Capital and fixed operation and maintenance costs for petroleum refineries

	Capital cost (thousand €)				**Fixed operation and maintenance cost (thousand €)**			
Refinery	Energy efficiency from behavioral changes	Energy efficiency from improved maintenance and process control	Energy efficiency requiring Capital expenses at process unit level	Carbon capture and storage	Energy efficiency from behavioral changes	Energy efficiency from improved maintenance and process control	Energy efficiency requiring Capital expenses at process unit level	Carbon capture and storage
Aspropyrgos	0	394.99	19752.07	756.47	0	59.85	988.68	32.80
Thessaloniki	0	219.38	10970.53	420.15	0	33.24	549.12	18.22
Elefsina	0	292.56	14629.85	560.30	0	44.33	732.29	24.29
Agioi Theodoroi	0	292.56	14629.85	560.30	0	44.33	732.29	24.29

Table 5.29: Capital and fixed operation and maintenance costs for cement plants

	Capital cost (thousand €)				**Fixed operation and maintenance cost (thousand €)**			
Plant	Replacement of clinker with fly ash	Replacement of clinker with slag	Increased share of waste as fuel	Increased share of biomass as fuel	Replacement of clinker with fly ash	Replacement of clinker with slag	Increased share of waste as fuel	Increased share of biomass as fuel
Volos	22.50	652.50	900.00	900.00	78.75	96.75	54.00	121.50
Milaki (Evia)	11.00	319.00	440.00	440.00	38.50	47.30	26.40	59.40
Elefsina	0.70	20.30	28.00	28.00	2.45	3.01	1.68	3.78
Thessaloniki	10.00	290.00	400.00	400.00	35.00	43.00	24.00	54.00
Drepano (Ahaia)	10.00	290.00	400.00	400.00	35.00	43.00	24.00	54.00
Kamari	14.50	420.50	580.00	580.00	50.75	62.35	34.80	78.30
Aspropyrgos	5.00	145.00	200.00	200.00	17.50	21.50	12.00	27.00

Table 5.30: Capital and fixed operation and maintenance costs for iron and steel plants

	Capital cost (thousand €)				Fixed operation and maintenance cost (thousand €)			
Plant	Improvements in energy efficiency	Co-generation	Direct casting	Smelt reduction	Improvements in energy efficiency	Co-generation	Direct casting	Smelt reduction
Velestinos	24.50	49.00	56.00	70.00	0	0	0	0
Volos	21.00	42.00	48.00	60.00	0	0	0	0
Thessaloniki	28.00	56.00	64.00	80.00	0	0	0	0
Almyros	42.00	84.00	96.00	120.00	0	0	0	0
Thessaloniki	40.08	80.15	91.60	114.50	0	0	0	0

Table 5.31: Abatement costs for petroleum refineries

	Abatement cost (thousand €)			
Refinery	Energy efficiency from behavioral changes	Energy efficiency from improved maintenance and process control	Energy efficiency requiring Capital expenses at process unit level	Carbon capture and storage
Aspropyrgos	0	10521.19	273726.19	14308.82
Thessaloniki	0	5843.59	152030.72	7947.29
Elefsina	0	7792.77	202741.93	10598.17
Agioi Theodoroi	0	7792.77	202741.93	10598.17

Table 5.32: Abatement costs for cement plants

	Abatement cost (thousand €)			
Plant	Replacement of clinker with fly ash	Replacement of clinker with slag	Increased share of waste as fuel	Increased share of biomass as fuel
Volos	73.67	68.09	233.73	216.81
Milaki (Evia)	36.01	33.29	114.27	106.00
Elefsina	2.29	21.18	7.27	6.75
Thessaloniki	32.74	30.26	103.88	96.36
Drepano (Ahaia)	32.74	30.26	103.88	96.36
Kamari	47.47	43.88	150.63	139.72
Aspropyrgos	16.37	15.13	51.94	48.18

Table 5.33: Abatement costs for iron and steel plants

	Abatement cost (thousand €)			
Plant	Improvements in energy efficiency	Co-generation	Direct casting	Smelt reduction
Velestinos	0.30	5.42	0.71	1.65
Volos	0.26	4.64	0.61	1.41
Thessaloniki	0.34	6.19	0.81	1.88
Almyros	0.52	9.29	1.21	2.82
Thessaloniki	0.49	8.86	1.16	2.69

5.4.3. Extraction of MAC curves

In this section we present the abatement cost curves for energy and industry sectors. In the X axis is the pollution abated measured in thousands of CO2 eq. while in the Y axis is the cost effectiveness measured in euro/tCO2 eq. In Figure 4.1, small-hydro abatement option lies in negative costs, so the cost of implementing this technology is lower than the cost of the baseline technology. Thus, the society benefits from the adaption of this abatement option. This technology abates pollution up to 1500 thousands tCO2 eq. For an additional 1750 thousand tCO2 eq. reduction, the policy maker should adapt geothermal energy option at a cost of 2.74 euro/tCO2 eq. If the policy maker wishes a further pollution reduction up to 5850 thousands tCO2 eq, he should adapt wind power option at a cost of 17.65 euro/tCO2. Solar photovoltaic option can achieve a further 3500 thousands tCO2 eq reduction at a cost of 31.76 euro/tCO2. Last, biomass option could abate up to 13050 thousands tCO2 for a cost of 127.73 euro/tCO2.

In Figure 5.16 a number of abatement technologies appear at negative costs, so the cost of these technologies is lower than the cost of baseline technology. Thus, behavioral changes at petroleum refineries, improvements in energy efficiency at iron and steel plants, direct casting at iron and steel plants, smelt reduction at iron and steel plants and co-generation at iron and steel plants can achieve up to 110 thousand tCO2 eq reduction. On the other hand, increased share of wastes and /or biomass as a kiln fuel at cement plants and clinker replacement with slag and/or fly ash can achieve up to 2870 thousand tCO2 eq., on significantly higher costs.

Figure 5.16: Marginal abatement cost curve for energy sector

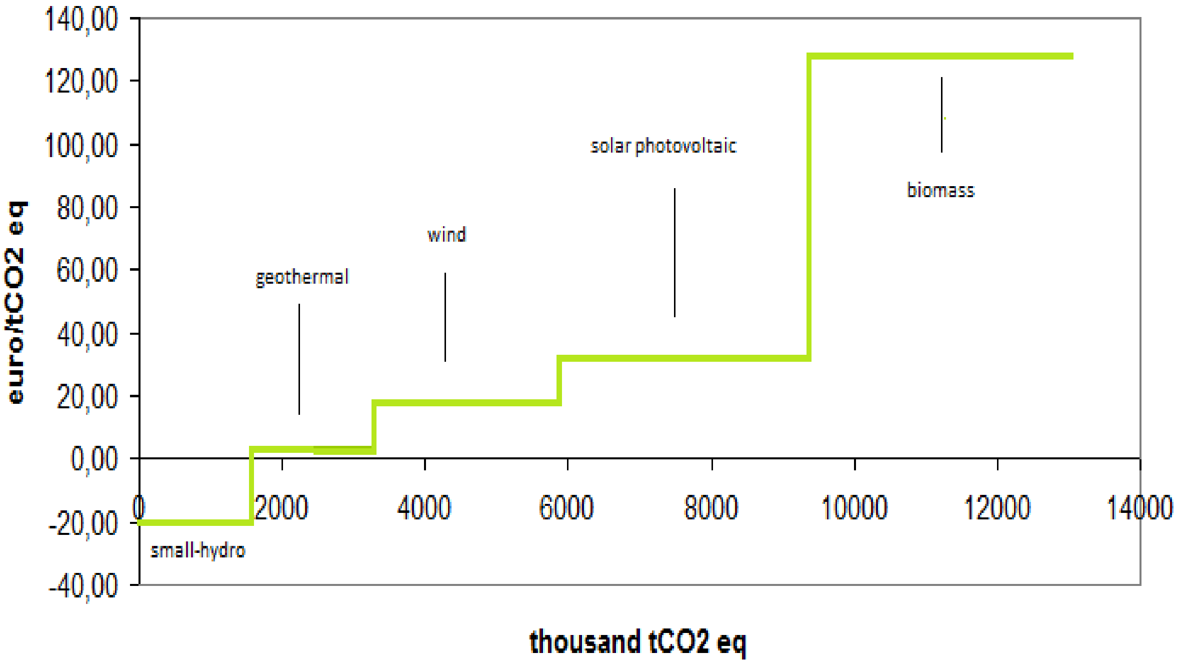
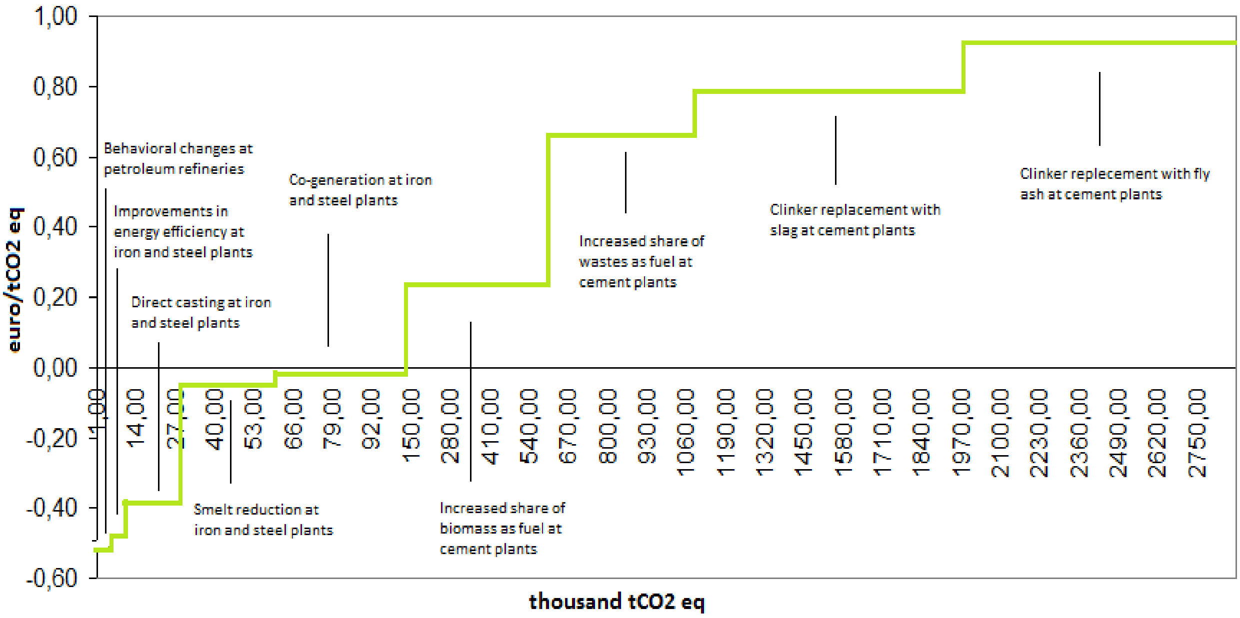
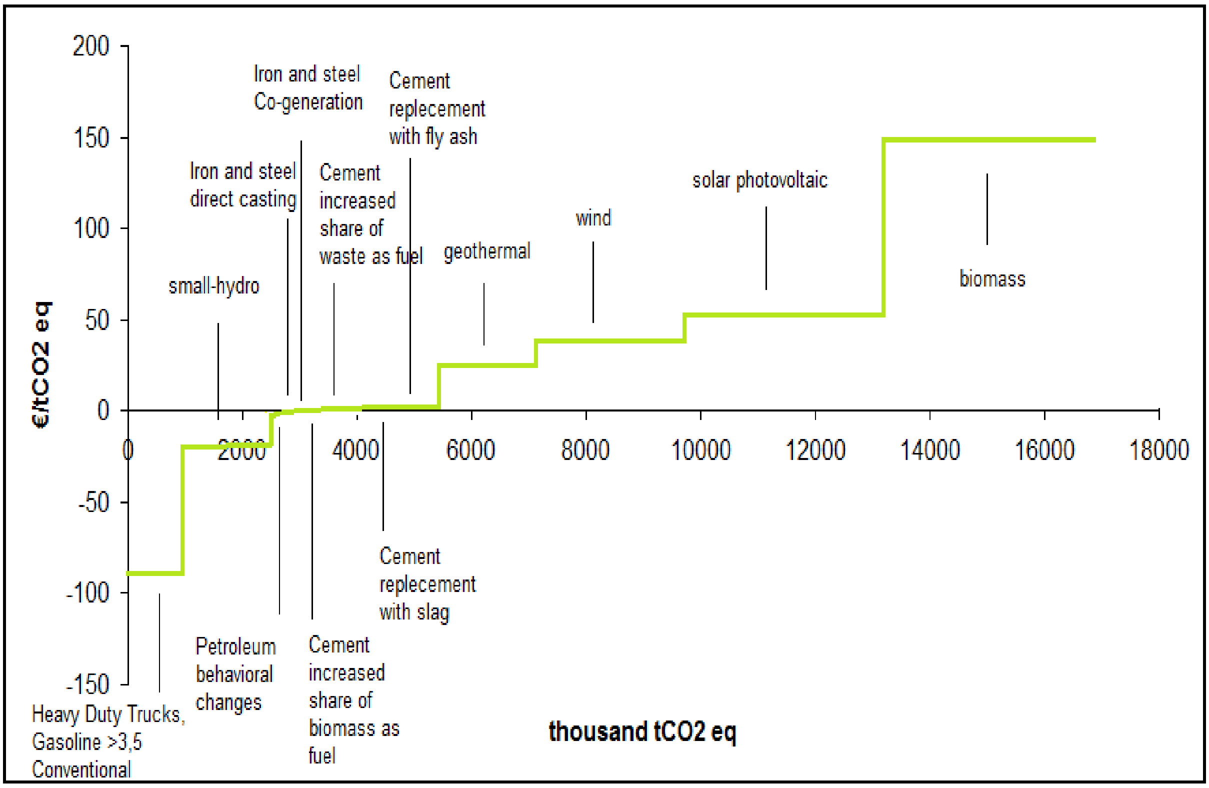


Figure 5.17: Marginal abatement cost curve for industry sector



Finally we present the overall curve for energy, industry and transport sectors. We find that only one abatement option in transport sector is cost effective and we include it in our final curve.

Figure 5.18: Marginal abatement cost curve for both sectors



Abbreviations

AAGR : Average Annual Growing Rate
AOX : Absorbable Organic Halides
AR : Atmospheric Residue
BAU : Business-as-usual
BIGCC : Biomass Integrated Gasification Combined Cycle
BOS : Basic Oxygen Steel-making
BRT : Bus Rapid Transit
CAGR : Compound Annual Growth Rate
CC : Combined Cycle
CCGT : Combined-Cycle Gas Turbines
CCS : Carbon Capture and Storage
CDU : CruDe oil distillation Units
CEE : Central and Eastern Europe
CH_4 : Methane
CHP : Combined Heat and Power
CNG : Compressed Natural Gas
CO : Monoxide
CO_2 : Carbon Dioxide
COD : Chemical Oxygen Demand
CRT : Cathode Ray Tube
DSM : Demand-Side Management
ECF : Elemental Chlorine Free
ECMS : Energy Consumption Management System
EDB : Environmental Database
EER : Energy Efficiency Ratio
ETBE : Ethyl Tertiary Butyl Ether
EV : Electric Vehicle
GDP : Gross Domestic Product
GHG : Greenhouse Gas Emissions
Ht : Heavy Truck
HVAC : Heating, Ventilation, and Air Conditioning
IEA : International Energy Agency
IGCC : Integrated Gasification-Combined Cycle
LCD : Liquid Crystal Display
LFG : Land-Fill Gas
LGO HDS : Light Gas Oil Hydro-Desulfurization Unit
LPG : Liquid Petroleum Gas
Lt : Light Trucks
MC : Motor Cycle
MCF : Maximum Capacity Factor
MEPS : Minimum Energy Performance Measures
MRT : Mass Rapid Transit
mtoe : Million tons of oil equivalent
NG : Natural Gas
NGV : Natural Gas Vehicle
NH_4-N : Ammonia Nitrogen
NMT : Non-Motorized Transportation
NMVOC : Non-Methane Volatile Organic Compounds

NO_x : Nitrogen Oxides
NPP : Nuclear Power Plant
Pb : Lead
PC : Passenger Car
PFBC : Pressurized Fluidized Bed Combustion
PJ : Petajoules (petajoule is equal to one quadrillion (10^{15}) joules)
RES : Renewable Energy Sources
ROK : Republic of Korea
SLF : System Load Factor
SO_2 : Sulfur Dioxide
SUV : Sport-Utility Vehicle
TCF : Total Chlorine
TJ : Terajoule
TSP : Total Suspended Particulates
U.S. EPA : United States Environmental Protection Agency
UEC : Unit Energy Consumption
VDU : Vacuum Distillation Unit
VR HDS : Vacuum Residue Hydro-Desulfurization

Section 6

Greenhouse gas emissions and marginal abatement cost (MAC) curves for the transport sector

6.1 Introduction

The transport sector in Greece is composed of the road, air, maritime and rail transport. According to the report by the Ministry of Environment, Energy and Climate Change (2013), the share of greenhouse gases emitted (expressed in CO_2 equivalent) by inland shipping for the period 1990-2011 ranges from 9% to 15%, with this share to reach 11% in 2011. The corresponding share for air transport ranges between 1.7% and 3.5%, with the minimum value to appear in 2011. For the rail transport this share for the same period reaches very low levels, from 1.6% in 1990 to less than 0.3% in 2011.

It is evident, therefore, that for the transport sector the largest share of greenhouse gas emissions for the period 1990-2011 is attributed to road transport. According to that report this share had increased from 82% in 1990 to 87% in 2011. This increase was the result of two conflicting factors: (a) the large increase in the number of vehicles in Greece, and (b) the significant progress achieved in engine technologies for vehicle pollution control. These trends constitute the main reason for the current work to focus the analysis on road transport modes including passenger cars, light commercial vehicles, heavy duty trucks, urban buses, coaches, motorcycles and mopeds.

More specifically, in this report, we forecast greenhouse gas emissions expressed in CO_2 equivalents for the period 2014-2030 by vehicle category distinguished according to technology (Euro 1, 2, 3, etc..), fuel type (petrol, diesel, LPG), displacement for cars, motorcycles and mopeds, and weight for trucks and buses. The predictions are obtained based on data available for number of vehicles, annual average distance driven (in kilometers), emission factors and average fuel consumption (grams per kilometer) for each combination of vehicle technology/fuel type/displacement-weight. The data for the period 2000-2013 is available from EMISSIA SA[91].

Most importantly, to make these predictions we take into account the economic crisis in Greece, which had as a result the dramatic reduction of vehicle new registrations for the period 2010-2013. To remove the effect of the crisis, first we develop for the period 1985-2013 bivariate linear econometric models that relates the number of vehicles (passenger cars, trucks, buses, motorcycles and mopeds), or the annual changes in the number of vehicles, which were in circulation at the end of each year, to the corresponding size or changes in the gross domestic product (GDP) at current prices. Using the GDP forecasts for the period 2014-2030 according to the Organization of Economic Co-operation and Development (OECD) conservative scenario from Halkos et al. (2014), through the estimated regression models we proceed to forecast the total number of vehicles in circulation at the end of each year for the specific period. Finally, the existing forecasts for the number of vehicles in each combination of technology/fuel type/displacement-weight are adjusted for each prediction year by using their weights and the predicted total number of vehicles obtained through the estimated regression model.

Particularly important is also the part which refers to cost policies of emissions control for the period 2014-2030. These policies are related to the penetration rate of the emerging standards Euro 4 (or IV) and Euro 5 (or V) to the fleet of various vehicle categories which will be in circulation at the end of each year for the period 2014-2030. So, different vehicle technology scenarios are defined according to the share of Euro 4 (or IV) and Euro 5 (or V) vehicles in combination with the corresponding shares of older standards. These shares are the

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[91] EMISSIA SA is an innovative company of the Aristotle University/Laboratory of Thermodynamics, which was founded in 2008 and specializes in emissions inventories and forecasts, emissions models, and studies for the impact of environmental policies. http://www.emisia.com

result of the continuation of 2000-2013 trends regarding the number of vehicles in various categories, adjusted according to «OECD conservative scenario of GDP growth» presented by Halkos et al. (2014).

Finally, for the first time we give for the Greek road transport estimates for the total cost related to each vehicle technology scenario at 2013 prices first for the period 2000-2012 and then for the period 2013-2030. Finding out that in each year of the period 2000-2012 the share of new-technology vehicles is relatively small, while this share becomes high for each year between 2013 and 2030, the difference of the total cost between the two periods constitute an abatement cost. This is also justified by the fact that for the majority of vehicle technology scenarios we observe decreases in greenhouse gas emissions between 2000-2012 and 2013-2030. This report closes by presenting two marginal abatement cost (MAC) curves, one for the various vehicle technology scenarios and one for the general vehicle categories.

6.2 Statistics for passenger cars

The Hellenic Statistical Authority (EL.STAT)[92] defines as **vehicle,** independently of the number of wheels, that one which is moved by a motor and is intended to transport persons or goods, or both of them either by the same single vehicle or by a trailer carried by the main motor vehicle. The survey conducted by EL.STAT is exhaustive and uses the Registry of the Ministry of Infrastructure, Transport and Networks. This registry includes all the monthly changes in vehicle registration licenses in Greece. The corresponding data for Greece are reported by vehicle category (Passenger cars, Buses, Trucks, Motorcycles) and refer to the number of vehicles which are released for the first time in Greece (a) by make and (b) according to whether the vehicle is new or used. From the census of EL.STAT, vehicles that move on rails, trolley – buses, agricultural tractors and machinery are excluded. Also all

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[92] http://www.statistics.gr/portal/page/portal/ESYE/PAGE-themes?p_param=A1106

vehicles of Armed Forces, Police, Fire Brigade, State Services, Diplomatic Body, Foreign Missions, and Invalids of War as well as motorcycles having engine capacity below 50 cc are not included in the exhaustive survey.

The following definitions are given for road-vehicles categories:

New vehicle: Vehicle which is registered for the first time in Greece and has not been released in any other country

Used vehicle: Vehicle which is registered for the first time in countries other than Greece and has been imported from them

Passenger Car: Vehicle having maximum 9 seats including the driver's seat which is used to move people

Truck: Vehicle which is used for the carriage of goods

Bus: Vehicles having nine seats or more including the driver's seat which is used to move people

Motorcycle: Two-wheel powered vehicle with or without a side-car which has engine cylinder capacity exceeding 50 cm^3 and maximum design speed exceeding 45 km/h.

In Tables 6.1 and 6.2 we present respectively for Passenger Cars, Trucks, Buses, and Motorcycles the data of EL.STAT concerning the number of vehicles in circulation in Greece at the end of each year from 1985 until 2013 and the number of vehicles (new plus used) which were first released in Greece (new entries) from 2000 until 2013. In Table 6.2 we also give for each year the number of erased-withdrawn vehicles and their share in the total number of vehicles in circulation at the end of each year. The number of erased-withdrawn vehicles in year t was calculated as the number of new registrations in year t minus the difference in the number of cars in circulation between years $t+1$ and t. The following remarks are drawn from the data of the four Tables.

Passenger Cars: In the period 2007-2012 we observe a continuous decrease in the annual rates of change. This has as a result, after 2010 to have continuous reductions in the total number of cars in circulation at the end of each year. Regarding new registrations, between 2007 and 2012, they decreased by 80%, while in 2013 this reduction appears slightly to recover. Finally, throughout the period 2000-2012 the share of the withdrawn- erased cars ranges between 1,00% and 3,74% with an average of 2,24%.

Trucks: In the period 2007-2012 we observe a continuous decrease in the annual rates of change. This has as a result, after 2011 to have continuous reductions in the total number of trucks in circulation at the end of each year. Regarding new registrations, between 2007 and 2012, they decreased by 77%, while in 2013 this reduction appears slightly to recover. Finally, throughout the period 2000-2012 the share of the withdrawn- erased trucks ranges between 1.21% and 2.91% with an average of 1.86%.

Buses: In the period 2009-2012 we observe a continuous decrease in the annual rates of change. This has as a result, after 2009 to have continuous reductions in the total number of buses in circulation at the end of each year. Regarding new registrations, between 2009 and 2011, they decreased by 76%. Finally, throughout the period 2000-2012 the share of the withdrawn- erased buses ranges between 1.93% and 10.11% with an average of 5.09%.

Motorcycles: Although between 2007 and 2012 we observe a continuous decrease in the annual rates of change, we find out that for the period 1985-2012 the total number of motorcycles in circulation at the end of each year appears a continuous increase. Despite of that, new registrations decreased by 68% between 2007 and 2012. Finally, throughout the period 2000-2012 the share of withdrawn- erased motorcycles ranges between -0.73% and 3.06%. Taking only the positive shares their average is 9,90%.

Table 6.1: Time series for the number of Vehicles in circulation in Greece at the end of each year for the period 1985-2013

	Passenger Cars		**Trucks**		**Buses**		**Motorcycles**	
Year	**Number**	**Rate of Change**	**Number**	**Rate of Change**	**Number**	**Rate of Change**	**Number**	**Rate of Change**
1985	1.259.335		595.761		19.234		162.295	
1986	1.355.142	7,61%	622.037	4,41%	19.482	1,29%	173.694	7,02%
1987	1.428.546	5,42%	650.950	4,65%	19.745	1,35%	183.253	5,50%
1988	1.503.921	5,28%	683.700	5,03%	20.074	1,67%	197.995	8,04%
1989	1.605.181	6,73%	724.203	5,92%	20.653	2,88%	219.547	10,89%
1990	1.735.523	8,12%	766.429	5,83%	21.430	3,76%	256.594	16,87%
1991	1.777.484	2,42%	792.770	3,44%	22.080	3,03%	295.675	15,23%
1992	1.829.100	2,90%	797.788	0,63%	22.674	2,69%	339.774	14,91%
1993	1.958.544	7,08%	825.697	3,50%	23.206	2,35%	387.877	14,16%
1994	2.074.081	5,90%	849.033	2,83%	23.540	1,44%	428.953	10,59%
1995	2.204.761	6,30%	883.823	4,10%	24.600	4,50%	475.668	10,89%
1996	2.339.421	6,11%	914.827	3,51%	25.096	2,02%	517.890	8,88%
1997	2.500.099	6,87%	951.785	4,04%	25.622	2,10%	570.965	10,25%
1998	2.675.676	7,02%	987.357	3,74%	26.320	2,72%	633.765	11,00%
1999	2.928.881	9,46%	1.023.987	3,71%	26.769	1,71%	710.775	12,15%
2000	3.195.065	9,09%	1.057.422	3,27%	27.037	1,00%	781.361	9,93%
2001	3.423.704	7,16%	1.085.811	2,68%	27.115	0,29%	853.366	9,22%
2002	3.646.069	6,49%	1.109.137	2,15%	27.247	0,49%	910.555	6,70%
2003	3.839.549	5,31%	1.131.027	1,97%	27.139	-0,40%	969.895	6,52%
2004	4.073.511	6,09%	1.159.137	2,49%	26.780	-1,32%	1.042.605	7,50%
2005	4.303.129	5,64%	1.186.483	2,36%	26.829	0,18%	1.124.172	7,82%
2006	4.543.016	5,57%	1.219.889	2,82%	26.938	0,41%	1.205.816	7,26%
2007	4.798.530	5,62%	1.255.945	2,96%	27.102	0,61%	1.298.688	7,70%
2008	5.023.944	4,70%	1.289.525	2,67%	27.186	0,31%	1.388.607	6,92%
2009	5.131.960	2,15%	1.302.430	1,00%	27.324	0,51%	1.448.851	4,34%
2010	5.216.873	1,65%	1.318.768	1,25%	27.311	-0,05%	1.499.133	3,47%
2011	5.203.591	-0,25%	1.321.296	0,19%	27.121	-0,70%	1.534.902	2,39%
2012	5.167.557	-0,69%	1.318.918	-0,18%	26.962	-0,59%	1.556.435	1,40%
2013	5.124.208	-0,84%	1.315.836	-0,23%	26.783	-0,66%	1.568.596	0,78%

Source: EL.STAT

Table 6.2: Time series for the number of vehicles (new plus used) which were first released in Greece from 2000 until 2013

YEAR	PASSENGER CARS			TRUCKS		
	New Registrations	**Withdrawn-erased**		**New Registrations**	**Withdrawn-erased**	
		Number	*% in the total number of vehicles in circulation at the end of each year*		*Number*	*% in the total number of vehicles in circulation at the end of each year*
2000	302.620	73.981	2,32%	46.421	18.032	1,71%
2001	289.943	67.578	1,97%	47.047	23.721	2,18%
2002	277.567	84.087	2,31%	46.466	24.576	2,22%
2003	272.515	38.553	1,00%	48.925	20.815	1,84%
2004	317.508	87.890	2,16%	54.201	26.855	2,32%
2005	302.613	62.726	1,46%	51.991	18.585	1,57%
2006	304.700	49.186	1,08%	53.422	17.366	1,42%
2007	317.879	92.465	1,93%	53.828	20.248	1,61%
2008	295.853	187.837	3,74%	50.391	37.486	2,91%
2009	244.539	159.626	3,11%	37.338	21.000	1,61%
2010	153.847	167.129	3,20%	29.213	26.685	2,02%
2011	107.737	143.771	2,76%	18.270	20.648	1,56%
2012	64.301	107.650	2,08%	12.917	15.999	1,21%
2013	64.932			13.312		

Source: EL.STAT for New Registrations

YEAR	BUSES			MOTORCYCLES		
	New Registrations	**Withdrawn-erased**		**New Registrations**	**Withdrawn-erased**	
		Number	*% in the total number of vehicles in circulation at the end of each year*		*Number*	*% in the total number of vehicles in circulation at the end of each year*
2000	1.480	1.402	5,19%	72.800	795	0,10%
2001	1.909	1.777	6,55%	76.155	18.966	2,22%
2002	1.780	1.888	6,93%	61.666	2.326	0,26%
2003	2.386	2.745	10,11%	65.599	-7.111	-0,73%
2004	2.347	2.298	8,58%	79.635	-1.932	-0,19%
2005	1.255	1.146	4,27%	90.126	8.482	0,75%
2006	1.026	862	3,20%	92.183	-689	-0,06%
2007	1.185	1.101	4,06%	103.879	13.960	1,07%
2008	1.110	972	3,58%	102.774	42.530	3,06%
2009	1.536	1.549	5,67%	73.115	22.833	1,58%
2010	817	1.007	3,69%	61.763	25.994	1,73%
2011	365	524	1,93%	47.754	26.221	1,71%
2012	457	636	2,36%	33.687	21.526	1,38%
2013	386	275		30.742		

Source: EL.STAT for New Registrations

To determine using the Tier 2 method the total amount of Greenhouse Gases (Carbon dioxide, CO_2; Methane, CH_4; Nitrus oxide, N_2O), expressed in CO_2 equivalents, which are emitted by all vehicle categories of road transport in Greece, it was necessary the availability of data, which refer to the number of vehicles and the annual average mileage (but expressed in kilometers), classified by (a) special characteristics of vehicles such as engine capacity (displacement) for passenger cars and motorcycles, and maximum weight for trucks and buses, (b) type of fuel (gasoline, diesel, liquefied petroleum gas), and (c) technology. Unfortunately neither EL.STAT nor EUROSTAT offer such data for Greece. But as mentioned in the introductory section of this report, this kind of data for the period 2000-2013 are available from EMISSIA SA. In particular, for the period 2000-2013, the data for the number of vehicles and the annual average mileage are provided and classified according to:

PASSENGER CARS (PCs)

- Gasoline 0,8 – 1,4 l
- Gasoline 1,4 – 2,0 l
- Gasoline > 2.0 l
- Diesel 1,4 – 2,0 l
- Diesel > 2.0 l
- Liquefied Petroleum Gas (LPG)

TRUCKS

- Gasoline Light Commercial Vehicles (LCVs) with maximum weight ≤ 3,5 t
- Diesel LCVs ≤ 3,5 t
- Heavy Duty Trucks (HDTs) with maximum weight > 3,5 t
    - Gasoline HDTs
    - Diesel Rigid HDTs ≤ 7,5 t
    - Diesel Rigid HDTs 7,5 – 12 t

- Diesel Rigid HDTs 12 – 14 t
- Diesel Rigid HDTs 14 – 20 t
- Diesel Rigid HDTs 20 – 26 t
- Diesel Rigid HDTs 26 – 28 t
- Diesel Rigid HDTs 28 – 32 t
- Diesel Rigid HDTs > 32 t
- Diesel Articulated HDTs 14 – 20 t
- Diesel Articulated HDTs 20 – 28 t
- Diesel Articulated HDTs 28 – 34 t
- Diesel Articulated HDTs 34 – 40 t
- Diesel Articulated HDTs 40 – 50 t
- Diesel Articulated HDTs 50 – 60 t

BUSES

- ➢ Diesel Urban Buses, midi ≤ 15 t
- ➢ Diesel Urban Buses, Standard 15 – 18 t
- ➢ Diesel Urban Buses, Articulated > 18 t
- ➢ Diesel Coaches, Standard ≤ 18 t
- ➢ Diesel Coaches, Articulated > 18 t

MOTORCYCLES (Moto)

- ➢ Gasoline motorcycles, 4-stroke ≤ 250 cm^3
- ➢ Gasoline motorcycles, 4-stroke 250 – 750 cm^3
- ➢ Gasoline motorcycles, 4-stroke > 250 cm^3

Apart from the above four vehicle categories, for Greece, EMISSIA SA offers data for the number of 2-stroke MOPEDS, and their annual average mileage. Mopeds are light two-wheel powered vehicles with an engine cylinder capacity not exceeding 50 cm^3, a maximum design speed not exceeding 45 km/h, a maximum continuous or net power ≤ 4000 W, and mass in running order ≤ 270 kg.

Regarding technology of vehicles, this is related to engine technologies offering various emission control systems. Since 1970, such systems have been introduced by relevant European Community Directives and regulations which vehicle manufacturers should comply with. Below, for the vehicle categories being in circulation in Greece between 2000 and 2013, we give the list of emission control technologies expressed in terms of the corresponding emission legislation. Further details for the specifications of these technologies can be found in the report «***EMEP / EEA emission inventory guidebook 2013 update September 2014***».

GASOLINE PASSENGER CARS

- Pre ECE vehicles up to 1971[93],
- ECE-15.00 and ECE 15.01 from 1972 until 1977,
- ECE-15.02 from 1978 until 1980,
- ECE-15.03 from 1981 until 1985, and
- ECE-15.04 from 1985 until 1992,
- Euro 1 standard introduced by Directive 91/441/EEC,
- Euro 2 standard introduced by Directive 94/12/EC,
- Euro 3 standard introduced in January 2000 by Directive 98/69/EC – Stage 2000,
- Euro 4 standard introduced in January 2005 by Directive 98/69/EC – Stage 2005,
- Euro 5 standard introduced in May 2007 by Directive EC 715/2007 (this standard came into effect in January 2010 and for new type approvals in September 2009), and
- Euro 6 and 6c standards introduced in May 2007 by Directive EC 715/2007.

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[93] Approximate implementation dates to all European Community (EC) Member states of the United Nations Economic Commission for Europe (UNECE) Regulation 15 amendments as regards the emissions of pollutants from vehicles lighter than 3,5 gross vehicle weight (GVW)

DIESEL PASSENGER CARS

- Conventional class including (a) non-regulated cars launched prior to 1985 and (b) cars of pre-1992 production complying with Directive ECE 15/04
- Euro 1 standard introduced by Directive 91/441/EEC
- Euro 2 standard introduced by Directive 94/12/EC
- Euro 3 standard introduced in January 2000 by Directive 98/69/EC – Stage 2000
- Euro 4 standard introduced in January 2005 by Directive 98/69/EC – Stage 2005
- Euro 5 standard introduced by Directive EC 715/2007 and was put in place in 2010
- Euro 6 standard introduced by Directive EC 715/2007 (this standard will become effective for new types of cars in September 2014, with full implementation for all type approvals starting from January 2015)
- Euro 6c standard introduced by Directive EC 715/2007

LPG PASSENGER CARS

- Conventional class including all LPG cars complied with legislations prior to Directive 91/441/EEC
- Euro 1 standard introduced by Directive 91/441/EEC
- Euro 2 standard introduced by Directive 94/12/EC
- Euro 3 standard introduced in January 2000 by Directive 98/69/EC – Stage 2000
- Euro 4 standard introduced in January 2005 by Directive 98/69/EC – Stage 2005
- Euro 5 standard introduced by Directive EC 715/2007
- Euro 6 standard introduced by Directive EC 715/2007

GASOLINE-HYBRID CARS

- Euro 4 class introduced by Directive 98/69/EC – Stage 2005

LIGHT COMMERCIAL VEHICLES (Gasoline and Diesel)

- Conventional Class including those vehicles covered by the various ECE steps up to 1993

- Light Duty (LD) Euro 1 standard introduced by Directive 93/59/EEC
- LD Euro 2 standard introduced by Directive 96/69/EEC
- LD Euro 3 standard introduced by Directive 96/69/EEC – Stage 2000
- LD Euro 4 standard introduced by Directive 96/69/EEC – Stage 2005
- LD Euro 5, 6, 6c standards introduced by Directive EC 715/2007

GASOLINE HEAVY-DUTY TRUCKS

- Conventional class

DIESEL HEAVY DUTY (HD) TRUCKS, BUSES, AND COACHES

- Conventional including vehicles with engines complying with ECE 49 and earlier
- HD Euro I standard introduced by Directive 91/542/EEC – Stage I
- HD Euro II standard introduced by Directive 91/542/EEC – Stage II
- HD Euro III standard introduced by Directive 1999/96/EC – Stage I
- HD Euro IV standard introduced by Directive 1999/96/EC Step 2 – Stage II
- HD Euro V standard introduced by Directive 1999/96/EC final step – Stage III
- HD Euro VI standard introduced by Regulation EC 595/2009

FOUR-STROKE MOTORCYCLES

- Conventional class including all motorcycles complied with legislations prior to Directive 97/24/EC
- Mot – Euro I standard introduced by Directive 97/24/EC
- Mot – Euro II standard introduced by Directive 2002/51/EC stage I
- Mot – Euro III standard introduced by Directive 2002/51/EC stage II
- Mot – Euro IV and V standards introduced by Regulation 168/2013

TWO-STROKE MOPEDS

- Conventional class including all motorcycles complied with legislations prior to Directive 97/24/EC

- Mop – Euro I standard introduced by Directive 97/24/EC Stage I
- Mop – Euro I standard introduced by Directive 97/24/EC Stage II
- Mop – Euro III standard introduced by Directive 2002/51/EC
- Mop – Euro IV and V standards introduced by Regulation 168/2013

For the four vehicle categories, namely, Passenger Cars, Trucks, Buses, and Motorcycles, Table 6.3 displays the differences between the data reported by EL.STAT and EMISSIA SA concerning the total number of vehicles in circulation at the end of each year of the period 2000-2013. At first observe that these differences are relatively small. Then, for each vehicle category using the weights of each combination of technology/fuel type/displacement-weight calculated from EMISSIA SA data, the number of vehicles in each combination was adjusted such that the sum in each year gives the total number of vehicle reported by EL.STAT. These numbers will be used in the analysis which follows to estimate Greenhouse Gas emissions for the period 2014-2030. Finally, as it was mentioned above, for each combination of technology/fuel type/displacement-weight, data from EMISSIA SA are available concerning annual average distance (in kilometers) driven by vehicles in each combination of technology/fuel type/displacement-weight.

Table 6.3: Comparisons between total numbers of vehicles in circulation at the end of each year reported by EL.STAT and EMISSIA SA

	PASSENGER CARS			**TRUCKS**		
Year	**EMISSIA SA**	**EL.STAT**	**Difference**	**EMISSIA SA**	**EL.STAT**	**Difference**
2000	3.312.486	3.195.065	117.421	905.544	1.057.422	151.878
2001	3.522.178	3.423.704	98.474	925.929	1.085.811	159.882
2002	3.718.059	3.646.069	71.990	932.635	1.109.137	176.502
2003	3.883.417	3.839.549	43.868	938.752	1.131.027	192.275
2004	4.097.866	4.073.511	24.355	954.109	1.159.137	205.028
2005	4.303.129	4.303.129	0	967.881	1.186.483	218.602
2006	4.543.016	4.543.016	0	976.141	1.219.889	243.748
2007	4.798.530	4.798.530	0	989.416	1.255.945	266.529
2008	5.023.944	5.023.944	0	997.998	1.289.525	291.527
2009	5.131.960	5.131.960	0	1.018.943	1.302.430	283.487
2010	5.216.873	5.216.873	0	1.026.362	1.318.768	292.406
2011	5.203.599	5.203.591	8	1.027.126	1.321.296	294.170
2012	5.324.556	5.167.557	156.999	1.027.890	1.318.918	291.028
2013	5.226.859	5.124.208	102.651	1.028.654	1.315.836	287.182

	BUSES			MOTORCYCLES		
Year	**EMISSIA SA**	**EL.STAT**	**Differences**	**EMISSIA SA**	**EL.STAT**	**Differences**
2000	23.131	27.037	3.906	668.354	781.361	113.007
2001	24.524	27.115	2.591	679.817	853.366	173.549
2002	25.087	27.247	2.160	703.682	910.555	206.873
2003	25.456	27.139	1.683	707.369	969.895	262.526
2004	26.245	26.780	535	714.549	1.042.605	328.056
2005	26.829	26.829	0	720.352	1.124.172	403.820
2006	26.938	26.938	0	838.922	1.205.816	366.894
2007	27.102	27.102	0	931.527	1.298.688	367.161
2008	27.186	27.186	0	1.023.619	1.388.607	364.988
2009	27.324	27.324	0	1.448.851	1.448.851	0
2010	27.311	27.311	0	1.499.133	1.499.133	0
2011	27.388	27.121	-267	1.509.654	1.534.902	25.248
2012	27.465	26.962	-503	1.520.175	1.556.435	36.260
2013	27.542	26.783	-759	1.530.711	1.568.596	37.885

6.3 Forecasting the number of vehicles in circulation at the end of each year for 2014-2030

In each vehicle category and for each combination of technology/fuel type/ displacement-weight, we made forecasts for the number of vehicles in circulation at the end of each year for the period 2013-2030 using trend and double exponential smoothing models (Makridakis et al., 1998). The models were fitted to the available series of the period 2000-2013. The selected models which were eventually used to produce the forecasts are given for all the combinations of vehicle technology/fuel type/displacement-weight in Table 6.4 for passenger cars, Table 6.5 for heavy duty trucks, Table 6.6 for light commercial vehicles, Table 6.7 for urban buses, Table 6.8 for coaches and Table 6.9 for motorcycles and mopeds. For each combination, the selection of the most appropriate model between alternative trend (e.g. linear, quadratic, s-curve) and double exponential smoothing models was made by comparing the values of the statistical accuracy measures MAPE (Mean Absolute Percentage Error), MAD (Mean Absolute Deviation) and MSD (Mean Squared Deviation), in combination, however, with the reasonableness of the produced forecasts according to the time evolution of the number of vehicles between 2000 and 2013. In Appendix A, for each vehicle category and for each combination of technology/fuel type/displacement-weight we give for each selected forecasting model the graph with the actual and fitted values concerning the number of vehicles and the values of the statistical accuracy measures as they were produced by the statistical package MINITAB.

Regarding the number of hybrid cars, EMISSIA SA do not have data available for the period 2000-2013 with the explanation that this number has been very small. For our part, we proceeded to produce estimates having available the number of TOYOTA PRIUS that has been released since 2002 in Greece (this number is available from EL.STAT), the market information that in 2010 the share of TOYOTA PRIUS sales was 70% of the total hybrid sales, and the assumption that in the period from 2002 to 2013, no hybrid car had been erased/withdrawn. Our estimates showed that at the end of the years 2011, 2012 and 2013, the hybrid share in the total number of cars in circulation had been stabilized at the very low level of 0.07%. Based on this finding, to predict the number of hybrid cars for the period 2014-2030, we assumed that in each year the hybrids will constitute 0.07% of the total estimated number of passenger cars in circulation.

Table 6.4: Forecasting models for the number of passenger cars in circulation at the end of each year between 2014 and 2030 for each combination of technology/fuel type/displacement

Fuel type	Technology	Displacement	Model	Used period
Gasoline	PRE ECE	< 1.4 l	We don't make forecasts because from 2002 and later there are not cars in Greece with this combination of technology/fuel type/displacement	
		1.4 - 2 l		
		> 2 l		
Gasoline	ECE 15/00-01	< 1.4 l	We don't make forecasts because from 2008 and later there are not cars in Greece with this combination of technology/fuel type/displacement	
		1.4 - 2 l		
		> 2 l		
Gasoline	ECE 15/02	< 1.4 l	We don't make forecasts because from 2011 and later there are not cars in Greece with this combination of technology/fuel type/displacement	
		1.4 - 2 l		
		> 2 l		
Gasoline	ECE 15/03	< 1.4 l	S-Curve Trend Model	2000-2013
		1.4 - 2 l	S-Curve Trend Model	2000-2013
		> 2 l	Double Exponential Method	2000-2013
Gasoline	ECE 15/04	< 1.4 l	S-Curve Trend Model	2000-2013
		1.4 - 2 l	S-Curve Trend Model	2000-2013
		> 2 l	Double Exponential Method	2000-2013

Gasoline	PC Euro 1 - 91/441/EEC	< 1.4 l	S-Curve Trend Model	2000-2013
		1.4 - 2 l	S-Curve Trend Model	2000-2013
		> 2 l	Double Exponential Method	2000-2013
Gasoline	PC Euro 2 - 94/12/EEC	< 1.4 l	Linear Trend Model	2009-2013
		1.4 - 2 l	S-Curve Trend Model	2005-2013
		> 2 l	S-Curve Trend Model	2005-2013
Gasoline	PC Euro 3 - 98/69/EC Stage2000	< 1.4 l	Linear Trend Model	2009-2013
		1.4 - 2 l	Linear Trend Model	2009-2013
		> 2 l	Linear Trend Model	2009-2013
Gasoline	PC Euro 4 - 98/69/EC Stage2005	< 1.4 l	Quadratic Trend Model	2006-2013
		1.4 - 2 l	Quadratic Trend Model	2006-2013
		> 2 l	Quadratic Trend Model	2009-2013
Gasoline	PC Euro 5 - EC 715/2007	< 1.4 l	Linear Trend Model	2010-2013
		1.4 - 2 l	Linear Trend Model	2010-2013
		> 2 l	Linear Trend Model	2010-2013
Diesel	Conventional	1.4 - 2 l	S-Curve Trend Model	2000-2013
		> 2 l	We don’t make forecasts because from 2013 and later there are not cars in Grrece with this combination of technology/fuel type/displacement	
Diesel	PC Euro 1 - 91/441/EEC	1.4 - 2 l	S-Curve Trend Model	2008-2013
		> 2 l	S-Curve Trend Model	2007-2013
Diesel	PC Euro 2 - 94/12/EEC	1.4 - 2 l	S-Curve Trend Model	2008-2013
		> 2 l	S-Curve Trend Model	2007-2013
Diesel	PC Euro 3 - 98/69/EC Stage 2000	1.4 - 2 l	Quadratic Trend Model	2000-2013
		> 2 l	Double Exponential Method	2000-2013
Diesel	PC Euro 4 - 98/69/EC Stage2005	< 2l	Linear Trend Model	2006-2013
		> 2 l	Linear Trend Model	2006-2013
Diesel	PC Euro 5 - EC 715/2007	< 2l	Linear Trend Model	2010-2013
		> 2 l	Linear Trend Model	2010-2013

LPG	Conventional	We don’t make forecasts because from 2009 and later there are not cars in Grrece with this combination of technology/fuel type/displacement	
LPG	PC Euro 1 - 91/441/EEC	We don’t make forecasts because from 2011 and later there are not cars in Grrece with this combination of technology/fuel type/displacement	
LPG	PC Euro 2 -94/12/EEC	S-Curve Trend Model	2007-2013
LPG	PC Euro 3 - 98/69/EC Stage2000	S-Curve Trend Model	2009-2013
LPG	PC Euro 4 - 98/69/EC Stage2005	Linear Trend Model	2006-2013
LPG	PC Euro 5 - EC 715/2007	Linear Trend Model	2010-2013

Table 6.5: Forecasting models for the number of Heavy Duty Trucks in circulation at the end of each year between 2014 and 2030 for each combination of technology/fuel type/weight

Fuel type	Technology	Weight	Model	Used period
Gasoline	Conventional	>3.5t	Linear Trend Model	2008-2013
Diesel	Conventional, Rigid	<=7.5t	S-Curve Trend Model	2000-2013
Diesel	Conventional, Rigid	7.5-12t	S-Curve Trend Model	2000-2013
Diesel	Conventional, Rigid	12-14t	S-Curve Trend Model	2000-2013
Diesel	Conventional, Rigid	14-20t	S-Curve Trend Model	2000-2013
Diesel	Conventional, Rigid	20-26t	S-Curve Trend Model	2000-2013
Diesel	Conventional, Rigid	26-28t	S-Curve Trend Model	2000-2013
Diesel	Conventional, Rigid	28-32t	S-Curve Trend Model	2000-2013
Diesel	Conventional, Rigid	>32t	S-Curve Trend Model	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Rigid	<=7.5t	Linear Trend Model	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Rigid	7.5-12t	Linear Trend Model	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Rigid	12-14t	Linear Trend Model	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Rigid	14-20t	Linear Trend Model	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Rigid	20-26t	Linear Trend Model	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Rigid	26-28t	Linear Trend Model	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Rigid	28-32t	Linear Trend Model	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Rigid	>32t	Linear Trend Model	2000-2013
Diesel	Euro 2-91/542/EEC Stage 2, Rigid	<=7.5t	S-Curve Trend Model	2005-2013

Diesel	Euro 2-91/542/EEC Stage 2, Rigid	7.5-12t	S-Curve Trend Model	2005-2013
Diesel	Euro 2-91/542/EEC Stage 2, Rigid	12-14t	S-Curve Trend Model	2005-2013
Diesel	Euro 2-91/542/EEC Stage 2, Rigid	14-20t	S-Curve Trend Model	2005-2013
Diesel	Euro 2-91/542/EEC Stage 2, Rigid	20-26t	S-Curve Trend Model	2005-2013
Diesel	Euro 2-91/542/EEC Stage 2, Rigid	26-28t	S-Curve Trend Model	2005-2013
Diesel	Euro 2-91/542/EEC Stage 2, Rigid	28-32t	S-Curve Trend Model	2005-2013
Diesel	Euro 2-91/542/EEC Stage 2, Rigid	>32t	S-Curve Trend Model	2005-2013
Diesel	Euro 3-2000 Standards, Rigid	<=7.5t	Double Exponential Method	2002-2013
Diesel	Euro 3-2000 Standards, Rigid	7.5-12t	Double Exponential Method	2002-2013
Diesel	Euro 3-2000 Standards, Rigid	12-14t	Double Exponential Method	2002-2013
Diesel	Euro 3-2000 Standards, Rigid	14-20t	Double Exponential Method	2002-2013
Diesel	Euro 3-2000 Standards, Rigid	20-26t	Double Exponential Method	2002-2013
Diesel	Euro 3-2000 Standards, Rigid	26-28t	Double Exponential Method	2002-2013
Diesel	Euro 3-2000 Standards, Rigid	28-32t	Double Exponential Method	2002-2013
Diesel	Euro 3-2000 Standards, Rigid	>32t	Double Exponential Method	2002-2013
Diesel	Euro 4-2005 Standards, Rigid	<=7.5t	Quadratic Trend Model	2010-2013
Diesel	Euro 4-2005 Standards, Rigid	7.5-12t	Quadratic Trend Model	2010-2013
Diesel	Euro 4-2005 Standards, Rigid	12-14t	Quadratic Trend Model	2010-2013
Diesel	Euro 4-2005 Standards, Rigid	14-20t	Quadratic Trend Model	2010-2013
Diesel	Euro 4-2005 Standards, Rigid	20-26t	Quadratic Trend Model	2010-2013
Diesel	Euro 4-2005 Standards, Rigid	26-28t	Quadratic Trend Model	2006-2013
Diesel	Euro 4-2005 Standards, Rigid	28-32t	Quadratic Trend Model	2010-2013
Diesel	Euro 4-2005 Standards, Rigid	>32t	Quadratic Trend Model	2010-2013
Diesel	Euro 5-2008 Standards, Rigid	<=7.5t	Linear Trend Model	2010-2013
Diesel	Euro 5-2008 Standards, Rigid	7.5-12t	Linear Trend Model	2009-2013
Diesel	Euro 5-2008 Standards, Rigid	12-14t	Linear Trend Model	2009-2013
Diesel	Euro 5-2008 Standards, Rigid	14-20t	Linear Trend Model	2009-2013
Diesel	Euro 5-2008 Standards, Rigid	20-26t	Linear Trend Model	2009-2013

Diesel	Euro 5-2008 Standards, Rigid	26-28t	Linear Trend Model	2009-2013
Diesel	Euro 5-2008 Standards, Rigid	28-32t	Linear Trend Model	2009-2013
Diesel	Euro 5-2008 Standards, Rigid	>32t	Linear Trend Model	2009-2013
Diesel	Conventional, Articulated	14-20t	Double Exponential Method	2000-2013
Diesel	Conventional, Articulated	20-28t	Double Exponential Method	2000-2013
Diesel	Conventional, Articulated	28-34t	Double Exponential Method	2000-2013
Diesel	Conventional, Articulated	34-40t	Double Exponential Method	2000-2013
Diesel	Conventional, Articulated	40-50t	Double Exponential Method	2000-2013
Diesel	Conventional, Articulated	50-60t	Double Exponential Method	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Articulated	14-20t	Double Exponential Method	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Articulated	20-28t	Double Exponential Method	2000-2013

Table 6.5 (Continued)

Diesel	Euro 1-91/542/EEC Stage 1, Articulated	28-34t	Double Exponential Method	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Articulated	34-40t	Double Exponential Method	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Articulated	40-50t	Double Exponential Method	2000-2013
Diesel	Euro 1-91/542/EEC Stage 1, Articulated	50-60t	Double Exponential Method	2000-2013
Diesel	Euro 2-91/542/EEC Stage 2, Articulated	14-20t	S-Curve Trend Model	2005-2013
Diesel	Euro 2-91/542/EEC Stage 2, Articulated	20-28t	S-Curve Trend Model	2005-2013
Diesel	Euro 2-91/542/EEC Stage 2, Articulated	28-34t	S-Curve Trend Model	2005-2013
Diesel	Euro 2-91/542/EEC Stage 2, Articulated	34-40t	S-Curve Trend Model	2005-2013
Diesel	Euro 2-91/542/EEC Stage 2, Articulated	40-50t	S-Curve Trend Model	2005-2013
Diesel	Euro 2-91/542/EEC Stage 2, Articulated	50-60t	S-Curve Trend Model	2005-2013
Diesel	Euro 3-2000 Standards, Articulated	14-20t	Linear Trend Model	2008-2013
Diesel	Euro 3-2000 Standards, Articulated	20-28t	Linear Trend Model	2008-2013
Diesel	Euro 3-2000 Standards, Articulated	28-34t	Linear Trend Model	2008-2013
Diesel	Euro 3-2000 Standards, Articulated	34-40t	Linear Trend Model	2008-2013
Diesel	Euro 3-2000 Standards, Articulated	40-50t	Linear Trend Model	2008-2013

Diesel	Euro 3-2000 Standards, Articulated	50-60t	Linear Trend Model	2008-2013
Diesel	Euro 4-2005 Standards, Articulated	14-20t	Quadratic Trend Model	2006-2013
Diesel	Euro 4-2005 Standards, Articulated	20-28t	Quadratic Trend Model	2006-2013
Diesel	Euro 4-2005 Standards, Articulated	28-34t	Quadratic Trend Model	2006-2013
Diesel	Euro 4-2005 Standards, Articulated	34-40t	Quadratic Trend Model	2006-2013
Diesel	Euro 4-2005 Standards, Articulated	40-50t	Quadratic Trend Model	2006-2013
Diesel	Euro 4-2005 Standards, Articulated	50-60t	Quadratic Trend Model	2006-2013
Diesel	Euro 5-2008 Standards, Articulated	14-20t	Linear Trend Model	2009-2013
Diesel	Euro 5-2008 Standards, Articulated	20-28t	Linear Trend Model	2009-2013
Diesel	Euro 5-2008 Standards, Articulated	28-34t	Linear Trend Model	2009-2013
Diesel	Euro 5-2008 Standards, Articulated	34-40t	Linear Trend Model	2009-2013
Diesel	Euro 5-2008 Standards, Articulated	40-50t	Linear Trend Model	2009-2013
Diesel	Euro 5-2008 Standards, Articulated	50-60t	Linear Trend Model	2009-2013

Table 6.6: Forecasting models for the number of Light Commercial Vehicles in circulation at the end of each year between 2014 and 2030 for each combination of technology/fuel type/weight

Fuel type	Technology	Weight	Model	Used period
Gasoline	Conventional	<3.5t	S-Curve Trend Model	2008-2013
Gasoline	LD Euro 1-93/59/EEC	<3.5t	S-Curve Trend Model	2008-2013
Gasoline	LD Euro 2-96/69/EEC	<3.5t	S-Curve Trend Model	2008-2013
Gasoline	LD Euro 3-98/69/EC Stage 2000	<3.5t	S-Curve Trend Model	2010-2013
Gasoline	LD Euro 4-98/69/EC Stage 2005	<3.5t	Quadratic Trend Model	2009-2013
Gasoline	LD Euro 5- 2008 Standards	<3.5t	Linear Trend Model	2011-2013
Diesel	Conventional	<3.5t	S-Curve Trend Model	2005-2013
Diesel	LD Euro 1-93/59/EEC	<3.5t	S-Curve Trend Model	2005-2013
Diesel	LD Euro 2-96/69/EEC	<3.5t	S-Curve Trend Model	2005-2013
Diesel	LD Euro 3-98/69/EC Stage 2000	<3.5t	Double Exponential Method	2002-2013
Diesel	LD Euro 4-98/69/EC Stage 2005	<3.5t	Quadratic Trend Model	2010-2013
Diesel	LD Euro 5- 2008 Standards	<3.5t	Linear Trend Model	2011-2013

Table 6.7: Forecasting models for the number of Urban Buses in circulation at the end of each year between 2014 and 2030 for each combination of technology/fuel type/weight

Fuel type	Technology	Weight	Model	Used period
Diesel	Conventional, Midi	<=15t	S-Curve Trend Model	2008-2013
Diesel	Euro 1-91/542/EEC Stage 1, Midi	<=15t	S-Curve Trend Model	2008-2013
Diesel	Euro 1-91/542/EEC Stage 1, Standard	15-18t	S-Curve Trend Model	2008-2013
Diesel	Euro 1-91/542/EEC Stage 1, Articulated	>18t	S-Curve Trend Model	2008-2013
Diesel	Euro 2-91/542/EEC Stage 2, Midi	<=15t	S-Curve Trend Model	2002-2013
Diesel	Euro 2-91/542/EEC Stage 2, Standard	15-18t	S-Curve Trend Model	2002-2013
Diesel	Euro 2-91/542/EEC Stage 2, Articulated	>18t	S-Curve Trend Model	2002-2013
Diesel	Euro 3-2000 Standards, Midi	<=15t	S-Curve Trend Model	2009-2013
Diesel	Euro 3-2000 Standards, Standard	15-18t	S-Curve Trend Model	2009-2013
Diesel	Euro 3-2000 Standards, Articulated	>18t	Linear Trend Model	2009-2013
Diesel	Euro 4-2005 Standards, Midi	<=15t	Quadratic Trend Model	2006-2013
Diesel	Euro 4-2005 Standards, Standard	15-18t	Quadratic Trend Model	2006-2013
Diesel	Euro 4-2005 Standards, Articulated	>18t	Quadratic Trend Model	2006-2013
Diesel	Euro 5-2008 Standards, Midi	<=15t	Linear Trend Model	2009-2013
Diesel	Euro 5-2008 Standards, Standard	15-18t	Linear Trend Model	2009-2013
Diesel	Euro 5-2008 Standards, Articulated	>18t	Linear Trend Model	2009-2013

Table 6.8: Forecasting models for the number of Coaches in circulation at the end of each year between 2013 and 2030 for each combination of technology/fuel type/weight

Fuel type	Technology	Weight	Model	Used period
Diesel	Conventional, Standard	<=18t	S-Curve Trend Model	2007-2013
Diesel	Conventional, Articulated	>18t	S-Curve Trend Model	2007-2013
Diesel	HD Euro 1-91/542/EEC Stage 1, Standard	<=18t	S-Curve Trend Model	2007-2013
Diesel	HD Euro 1-91/542/EEC Stage 1, Articulated	>18t	S-Curve Trend Model	2007-2013
Diesel	HD Euro 2-91/542/EEC Stage 2, Standard	<=18t	S-Curve Trend Model	2005-2013
Diesel	HD Euro 2-91/542/EEC Stage 2, Articulated	>18t	S-Curve Trend Model	2005-2013

Diesel	HD Euro 3-2000 Standards, Standard	<=18t	S-Curve Trend Model	2008-2013
Diesel	HD Euro 3-2000 Standards, Articulated	>18t	S-Curve Trend Model	2008-2013
Diesel	HD Euro 4-2005 Standards, Standard	<=18t	Quadratic Trend Model	2006-2013
Diesel	HD Euro 4-2005 Standards, Articulated	>18t	Quadratic Trend Model	2006-2013
Diesel	HD Euro 5-2008 Standards, Standard	<=18t	Linear Trend Model	2009-2013
Diesel	HD Euro 5-2008 Standards, Articulated	>18t	Linear Trend Model	2009-2013

Table 6.9: Forecasting models for the number of Motorcycles* and Mopeds** in circulation at the end of each year between 2013 and 2030 for each combination of technology/fuel type/displacement

Fuel type	Technology	Displacement	Model	Used period
Gasoline*	Conventional, 4 stroke	<250 cm^3	S-Curve Trend Model	2000-2013
Gasoline*	Conventional, 4 stroke	250-750 cm^3	S-Curve Trend Model	2000-2013
Gasoline*	Conventional, 4 stroke	>750 cm^3	S-Curve Trend Model	2009-2013
Gasoline*	Euro 1, 4 stroke	<250 cm^3	S-Curve Trend Model	2004-2013
Gasoline*	Euro 1, 4 stroke	250-750 cm^3	S-Curve Trend Model	2004-2013
Gasoline*	Euro 1, 4 stroke	>750 cm^3	S-Curve Trend Model	2004-2013
Gasoline*	Euro 2, 4 stroke	>50 cm^3	S-Curve Trend Model	2014-2018
Gasoline*	Euro 2, 4 stroke	250-750 cm^3	S-Curve Trend Model	2014-2018
Gasoline*	Euro 2, 4 stroke	>750 cm^3	S-Curve Trend Model	2014-2018
Gasoline*	Euro 3, 4 stroke	>50 cm^3	Linear Trend Model	2008-2013
Gasoline*	Euro 3, 4 stroke	250-750 cm^3	Linear Trend Model	2008-2013
Gasoline*	Euro 3, 4 stroke	>750 cm^3	Linear Trend Model	2009-2013
Gasoline**	Conventional	<50 cm^3	S-Curve Trend Model	2006-2013
Gasoline**	Euro 1	<50 cm^3	S-Curve Trend Model	2011-2013
Gasoline**	Euro 2	<50 cm^3	Quadratic Trend Model	2008-2013

An important problem arising in the forecasting process was the inclusion of the economic crisis impact on the numbers of vehicles for the years 2010 till 2013 and therefore on the forecasts for the period 2014-2030. As mentioned before, due to the crisis, new registrations for all vehicle categories dramatically decreased and this leaded to reductions of the number of vehicles in circulation between 2010 until 2013. In contrast, for passenger cars and trucks, in 2013 a slight increase in new registrations was observed. Especially for passenger cars, market estimates point out that car market will recover. This view is reinforced in particular by the policy of reduced selling prices due to the measure of withdrawal and by the attractive new car market financing programs which are offered. Many companies do not ask for an advance payment, while the number of monthly payments reaches 84 with a floating interest rate at 5% per annum and fixed at 8%.

To remove the effect of the crisis on the predicted number of vehicles for the period 2014-2030, for each vehicle category (Passenger Cars, Trucks, Buses, and Motorcycles) as this is given by EL.STAT, we developed a bivariate econometric model that related the number of vehicles in circulation at the end of each year to the GDP at current prices. The GDP series is available either by EL.STAT[94], or by the International Monetary Fund (IMF)[95]. Having available the forecasts of GDP for the period 2014-2030 from Halkos et al. (2014) according to the «OECD conservative scenario (The Organization for Economic Co-operation and Development, 2014)», and using the econometric model we obtained forecasts for the total number of vehicles in circulation at the end of each year of this period. Below, for each vehicle category, we present the estimation process in details.

6.3.1 Passenger Cars, Trucks, and Motorcycles

To estimate the linear econometric model, for each vehicle category we used initially as dependent variable the number of vehicles in circulation at the end of each year for the period 1985-2013 (see Table 2.1) and as explanatory the GDP at current prices for the same period. By applying augmented Dickey-Fuller tests (eg, Box et al., 2008; Halkos and Kevork, 2005;Harvey 1993) to both variables (number of vehicles and GDP), including in the test

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[94] http://www.statistics.gr/portal/page/portal/ESYE/PAGE-themes?p_param=A0702

[95] http://www.imf.org/external/data.htm

equation both a trend term and an intercept, we found out that the two series were stationary in second differences. However, applying the augmented Dickey-Fuller test to the residuals from the linear regression of the number of vehicles on GDP, including in the test equation neither a trend term nor an intercept, we found out that we did not have sufficient statistical evidence to reject the null hypothesis that the residuals are not stationary in levels. Therefore, we concluded that this initial regression was spurious and for each vehicle category the number of vehicles and GDP series were not cointegrated.

An alternative approach was to use in the linear econometric model for each vehicle category as dependent variable the annual change (namely, the first differences) in the number of vehicles in circulation at the end of each year and as explanatory variable the annual change in GDP. So, the following four variables were constructed:

(ΔPGC_t**): Annual change of number of Passenger Cars**

($\Delta TRUCK_t$**):Annual change of number of Trucks**

($\Delta MOTO_t$**): Annual change of number of Motorcycles**

(ΔGDP_t**): Annual change of GDP**

As it was expected, the application of the augmented Dickey-Fuller tests gave stationarity for these four new time series (ΔPGC_t, $\Delta TRUCK_t$, $\Delta MOTO_t$, ΔGDP_t) in first differences (see estimation output B1 of the Appendix B). Moreover, applying the corresponding augmented Dickey-Fuller test (including in the test equation neither a trend term nor an intercept) to the residuals of the linear regressions (i) ΔPGC_t on ΔGDP_t, (ii) $\Delta TRUCK_t$ on ΔGDP_t, and (iii) $\Delta MOTO_t$ on ΔGDP_t, we found that at 10% significance level there was sufficient statistical evidence to reject the null hypothesis that the residuals are not stationary in levels (see estimation output B2 of the Appendix B). This offered the necessary information to support that the pairs of variables (i) ΔPGC_t and ΔGDP_t, (ii) $\Delta TRUCK_t$ and ΔGDP_t, (iii) $\Delta MOTO_t$ and ΔGDP_t are cointegrated. Performing also residual diagnostic tests in the three estimated regressions (see estimation outputs B3 and B4 of the Appendix B), we obtained sufficient statistical evidence to support that the errors in each linear regression model are normally distributed with no ARCH effect. However, to all estimated regression models the errors were found to be serially correlated.

Following the above residual diagnostic test results, we proceeded to re-estimate the three linear regression models (see estimation output B5 of the Appendix B) with the errors to be autocorrelated. Having strong indication from the sample ACF and PACF functions that the errors follow the first order autoregressive model, AR(1), the Cochranne-Orcutt method (e.g. Halkos, 2011) was used, which gave the following updated estimated models:

$$\Delta\hat{P}GC_t = 99087{,}360 + 6213{,}104 \cdot \Delta GDP_t + \hat{\varepsilon}_t$$

$$\text{where } \hat{\varepsilon}_t = 0{,}676286 \cdot \hat{\varepsilon}_{t-1} \text{ and } \hat{\varepsilon}_{2013} = -72271{,}78. \qquad (6.1)$$

$$\Delta\hat{T}RUCK_t = 1096{,}686 + 1850{,}773 \cdot \Delta GDP_t + \hat{\varepsilon}_t$$

$$\text{where } \hat{\varepsilon}_t = 0{,}409643 \cdot \hat{\varepsilon}_{t-1} \text{ and } \hat{\varepsilon}_{2013} = -9547{,}904573. \qquad (6.2)$$

$$\Delta\hat{M}OTO_t = 47750{,}361 + 1182{,}089 \cdot \Delta GDP_t + \hat{\varepsilon}_t$$

$$\text{where } \hat{\varepsilon}_t = 0{,}820655 \cdot \hat{\varepsilon}_{t-1} \text{ and } \hat{\varepsilon}_{2013} = -22240{,}031292. \qquad (6.3)$$

Performing residual diagnostic tests in the estimated models (6.1), (6.2), (6.3) we obtained sufficient statistical evidence to support that the errors (a) are uncorrelated (b) are normally distributed and (c) do not have ARCH effect (see estimation output B6 of the Appendix B).

Substituting the forecasts of GDP changes according to the «OECD conservative scenario of GDP growth» from Halkos et al. (2014) into the estimated models (6.1), (6.2), (6.3) we take for each vehicle category the total number of vehicles at the end of each year of the period 2014-2030. For each vehicle category, this total number is given columns (2), (4), and (6) of Table 6.10 Furthermore, in the same Table we give for each year [columns (3), (5), (7)] the estimated total number of vehicles which is calculated for each vehicle category as the sum of the individual forecasts obtained from fitting the selected trend and double exponential smoothing models to all the combinations of vehicle technology/fuel type/displacement-weight. As it was explained, these forecasting models have been presented in Tables (6.1)-(6.6) and illustrated graphically in Appendix A.

From the data of Table 6.10 we confirm the negative impacts of the crisis from 2010 to 2013 on the predicted number of cars in circulation during the period 2014-2030. More specifically, the estimated total number of vehicles in columns (3), (5), (7), varies well below than the corresponding estimated number from models (6.1), (6.2) and (6.3) especially for years close to 2030, something that could be justified only by a «catastrophic scenario of negative GDP growth», which does not seem to be valid given the present conditions of the Greek economy. For this reason, as final forecasts for the number of vehicles in circulation were taken the numbers presented in columns (2), (4), and (6) of Table 6.10. Then the individual forecasts which were made with the trend and double exponential smoothing models for the number of vehicles in each combination of technology/fuel type/displacement-weight were readjusted appropriately such that their sum gives for each prediction year the total numbers given in columns (2), (4), and (6) of Table 6.10.

Table 6.10: Comparisons between forecasts for the total numbers of passenger cars, trucks and motorcycles in circulation at the end of each year

	Passenger Cars		Trucks		Motorcycles	
Year	From model (6.1)	From trend and double exponential smoothing models (3)	From model (6.2)	From trend and double exponential smoothing models (5)	From model (6.3)	From trend and double exponential smoothing models (7)

	(2)		(4)		(6)	
2014	5.155.189	5.155.189	1.327.381	1.291.769	1.594.436	1.594.811
2015	5.229.007	5.160.988	1.346.004	1.263.989	1.628.690	1.605.873
2016	5.317.197	5.160.412	1.366.221	1.234.621	1.666.328	1.610.527
2017	5.415.059	5.155.710	1.387.255	1.209.128	1.706.634	1.608.470
2018	5.516.952	5.164.232	1.408.295	1.190.650	1.748.585	1.599.430
2019	5.623.377	5.186.007	1.429.617	1.181.265	1.792.254	1.581.753
2020	5.731.271	5.219.445	1.450.829	1.180.144	1.836.994	1.554.908
2021	5.841.511	5.261.949	1.472.199	1.185.748	1.882.893	1.520.168
2022	5.952.228	5.310.533	1.493.477	1.196.343	1.929.508	1.480.908
2023	6.064.240	5.362.293	1.514.863	1.210.339	1.976.911	1.442.063
2024	6.176.347	5.414.640	1.536.184	1.226.434	2.024.796	1.408.900
2025	6.289.225	5.465.428	1.557.585	1.243.634	2.073.220	1.385.573
2026	6.402.068	5.512.948	1.578.943	1.261.169	2.121.970	1.374.286
2027	6.515.398	5.555.884	1.600.361	1.278.483	2.171.090	1.375.264
2028	6.628.670	5.593.238	1.621.752	1.295.164	2.220.431	1.387.338
2029	6.742.282	5.624.265	1.643.191	1.310.901	2.270.030	1.408.664
2030	6.855.845	5.648.414	1.664.613	1.325.463	2.319.780	1.437.287

6.3.2 Buses

The application of augmented Dickey-Fuller tests to the levels of variables “Number of Buses” and “GDP” (including in the test equation both a trend term and an intercept) gave sufficient statistical evidence to support at 5% level of significance that the two series are stationary in second differences (see estimation output B7 of the Appendix B). Further, from applying the augmented Dickey-Fuller test to the residuals from the estimation of the regression model

$$\mathrm{BUS}_t = \alpha + \beta \cdot \mathrm{GDP}_t + \gamma \cdot \mathrm{GDP}_t^2 + \varepsilon_t , \qquad (6.4)$$

including in the test equation neither a trend term nor an intercept, we obtained sufficient statistical evidence to conclude that this regression is not spurious (see estimation output B8 of the Appendix B). Performing also residual diagnostics tests on the residual series from the estimated regression of (6.4), we had sufficient statistical evidence to conclude that the errors are normally distributed with no ARCH effect (see estimation output B9 of the Appendix B). However, the sample ACF and PACF functions gave strong indications that the residuals are autocorrelated.

Fitting successfully an AR(2) process, $\varepsilon_t = \phi_1 \varepsilon_{t-1} + \phi_2 \varepsilon_{t-2} + u_t$, to the residuals of (6.4) (see estimation output B10 of the Appendix B), we estimated the model

$$Y_t = \alpha^* + \beta \cdot X_t + \gamma \cdot Z_t + \varepsilon_t \qquad (6.5)$$

where

$$Y_t = BUS_t - \hat{\phi}_1 BUS_{t-1} - \hat{\phi}_2 BUS_{t-2},$$

$$\alpha^* = \alpha \cdot \left(1 - \hat{\phi}_1 - \hat{\phi}_2\right),$$

$$X_t = GDP_t - \hat{\phi}_1 GDP_{t-1} - \hat{\phi}_2 GDP_{t-2},$$

$$Z_t = GDP_t^2 - \hat{\phi}_1 GDP_{t-1}^2 - \hat{\phi}_2 GDP_{t-2}^2,$$

with $\hat{\phi}_1 = 1{,}218280$ and $\hat{\phi}_2 = -0{,}660226$. Residual diagnostic tests applied to (6.5) gave sufficient statistical evidence to conclude that the errors (a) are uncorrelated (b) are normally distributed and (c) do not have ARCH effect (see estimation output B11 of the Appendix B). Therefore, the total number of Buses in circulation at the end of each year of the period 2014-2030 will be estimated from

$$\hat{BUS}_t = 17192{,}796 + 109{,}23629 \cdot GDP_t - 0{,}29384 \cdot GDP_t^2 + \hat{\varepsilon}_t,$$

where (6.6)

$$\hat{\varepsilon}_t = 1{,}218280 \cdot \hat{u}_{t-1} - 0{,}660226 \cdot \hat{u}_{t-2} \text{ with } \hat{\varepsilon}_{2012} = 366{,}6265 \text{ and } \hat{\varepsilon}_{2013} = 557{,}7319,$$

after substituting the forecasts of GDP according to the «OECD conservative scenario of GDP growth» from Halkos et al. (2014). In Table 6.11, we present the estimated total number of Buses according to model (6.6). In the same Table we also give the total number of Buses which is calculated as the sum of the individual forecasts obtained from fitting the selected trend and double exponential smoothing models to all the combinations of Buses technology/fuel type/weight. Then these individual forecasts were adjusted appropriately such that for each year of the period 2014-2030 their sum gives the estimated total number computed from (6.6).

6.3.3 Mopeds

Unfortunately, the number of MOPEDS was not available by EL.STAT. So, to develop a prediction model based on GDP, we used the total number of MOPEDS which is given by EMISSIA SA. For the period 2000-2013, we found that the annual change of the number of MOPEDS ($\Delta MOPED_t$) is stationary in first differences. Performing the augmented Dickey-Fuller test (including in the test equation neither a trend term nor an intercept) on the residuals from the regression of $\Delta MOPED_t$ on ΔGDP_t we obtained sufficient statistical evidence to support at level of significance 1% that the series $\Delta MOPED_t$ and ΔGDP_t are co-integrated. Further, diagnostic tests on the residual series from the regression of $\Delta MOPED_t$ on ΔGDP_t indicated (although the sample is very small) that the errors are uncorrelated and display no ARCH effect (see estimation output B12 of the Appendix B) . So, we decided to use the next model

$$\Delta \hat{MOPED}_t = 3968{,}0402 + 365{,}4959 \cdot \Delta GDP_t \qquad (6.7)$$

to predict the total number of Mopeds at the end of each year of the period 2014-2030, using for ΔGDP_t the annual change GDP forecasts according to the «OECD conservative scenario of GDP growth» from Halkos et al. (2014).

In Table 6.11, we present the estimated total number of Mopeds calculated from (6.7). In the same Table we also give the total number of Mopeds which is calculated as the sum of the individual forecasts obtained from fitting the selected trend and double exponential smoothing models to the combinations of Moped technology/displacement. Then these individual forecasts were adjusted appropriately such that for each year of the period 2014-2030 their sum gives the number computed from (6.7).

Table 6.11: Comparisons between forecasts for the total numbers of Buses and Mopeds in circulation at the end of each year

	Buses		Mopeds	
Year	From model (6.6)	From trend and double exponential smoothing models	From model (6.7)	From trend and double exponential smoothing models
2014	26.894	26.742	237.679	201.410
2015	27.171	26.709	242.105	192.548
2016	27.429	26.737	246.747	184.261
2017	27.560	26.845	251.532	176.542
2018	27.550	27.016	256.267	169.369
2019	27.450	27.262	261.073	162.711
2020	27.333	27.571	265.834	156.525
2021	27.253	27.431	270.644	150.768
2022	27.228	27.496	275.422	145.390
2023	27.245	27.549	280.236	140.342
2024	27.274	27.599	285.027	135.578
2025	27.290	27.636	289.846	131.047
2026	27.280	27.656	294.649	126.705
2027	27.245	27.647	299.473	122.510
2028	27.197	27.593	304.287	118.418
2029	27.146	27.497	309.118	114.393
2030	27.100	27.333	313.943	110.399

Finally, we note that forecasts for the annual average distance traveled (in km) by each vehicle category were made for each combination of technology/fuel type/displacement-weight. From the data of Emissia SA we found that the annual decreasing rate of the average distance traveled during the period 2000-2013 remained constant for each combination. So, independently of the technology/displacement-weight of vehicles, we computed that for gasoline vehicles the annual average decreasing rate for period 2000-2013 was 5.82%, for diesel vehicles 4.08% and for LPG passenger cars 2.17%. These three annual average reduction rates were used to predict the annual average distance traveled (in km) by vehicles until 2030.

6.4 Vehicle Technology Scenarios for the period 2014-2030

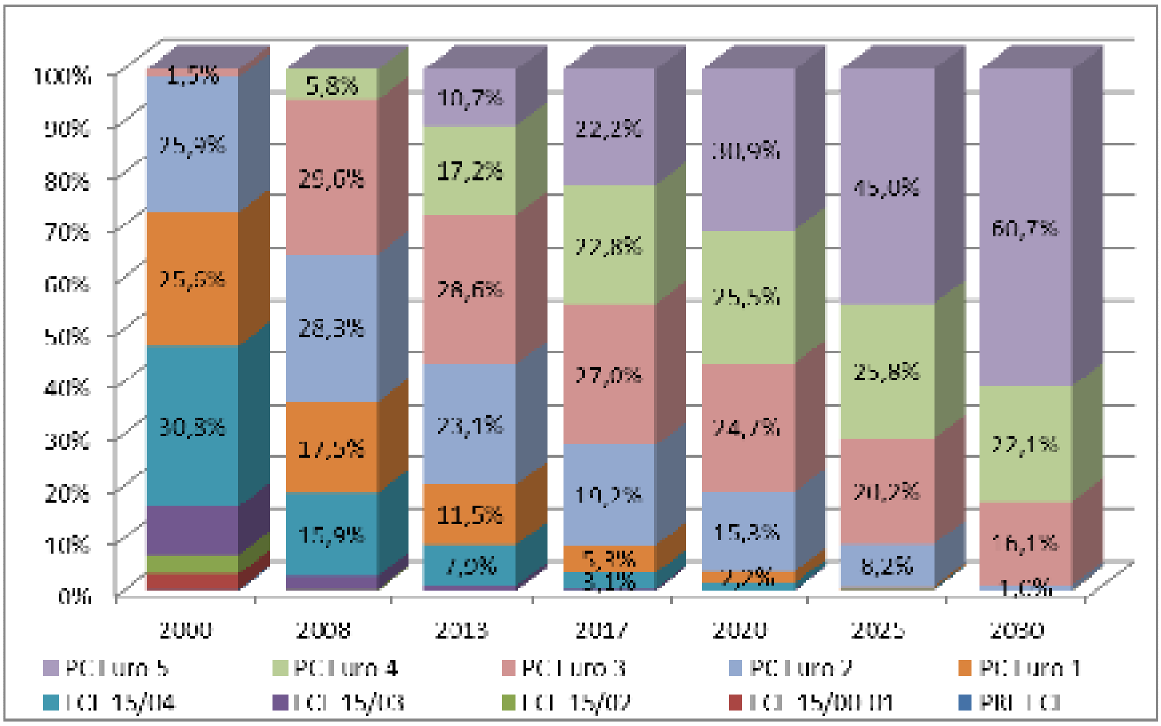
Having available for each vehicle category and for each combination of technology/fuel type/displacement-weight the number of vehicles (actual and predicted) which are in circulation at the end of each year of the period 2000-2030, we proceed to define the various vehicle technology scenarios for the period 2014-2030. To establish each scenario, we examined in each year the penetration rate of the emerging standards Euro 4 (or IV) and Euro 5 (or V) against old technologies such as conventional and Euro 1 (or I) up to Euro 3 (or III). Particularly, in each scenario, we present the time evolution of shares of Euro 4 (or IV) and Euro 5 (or V) vehicles in combination with the corresponding shares of older standards. These shares are the result of the continuation of 2000-2013 trends regarding the number of vehicles adjusted according to «OECD conservative scenario of GDP growth» presented by Halkos et al. (2014). For each vehicle technology scenario, we shall present in the next two sections estimates of the amount of Greenhouse Gasses expressed in CO_2 equivalents and the related total costs for the periods 2000-2012 and 2013-2030.

6.4.1 Passenger Cars

Gasoline Passenger Cars, 0,8 – 1,4 l

The share of Euro 4 and Euro 5 cars increases from 28% in 2013 to 56,5% in 2020, to 71% in 2025 and to 83% in 2030. Especially, in 2030 the share of Euro 5 cars will be 61% compared to the share of 11% in 2013 (see Figure 6.1)

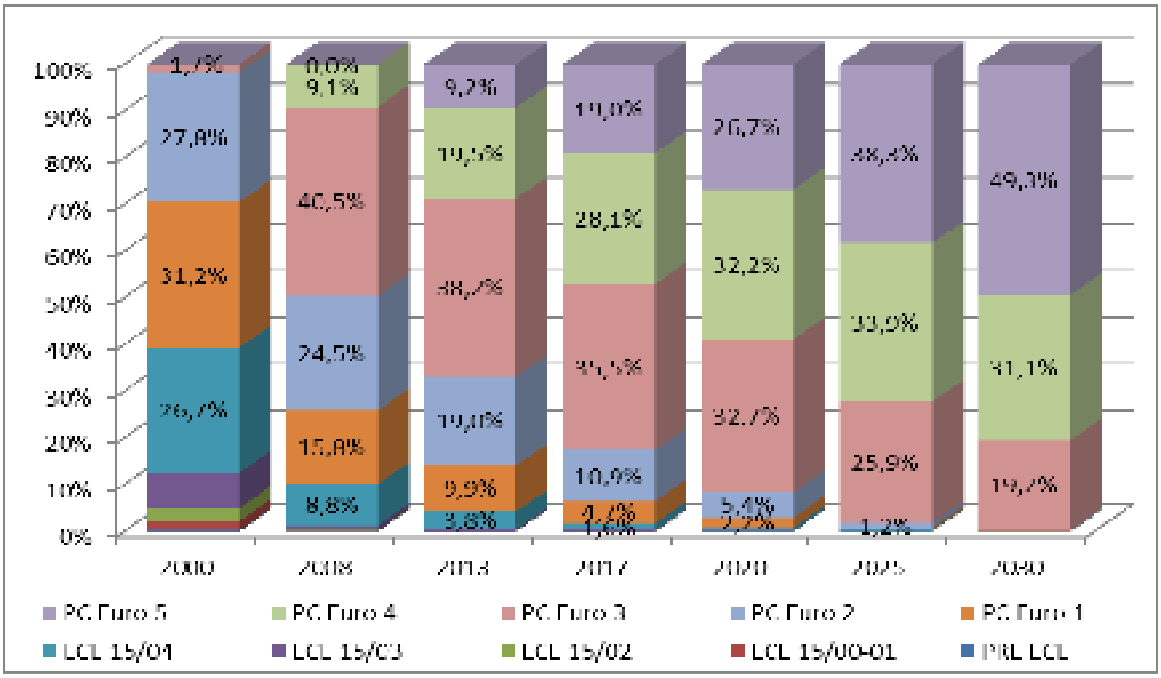
Figure 6.1: Shares of emerging technologies for Gasoline Passenger Cars, 0,8 – 1,4 l



Gasoline Passenger Cars, 1,4 – 2 l

The share of Euro 4 and Euro 5 cars increases from 29% in 2013 to 59% in 2020, to 72% in 2025 and to 80% in 2030. Especially, in 2030 the share of Euro 5 cars will be 49% compared to the share of 9% in 2013 (see Figure 6.2)

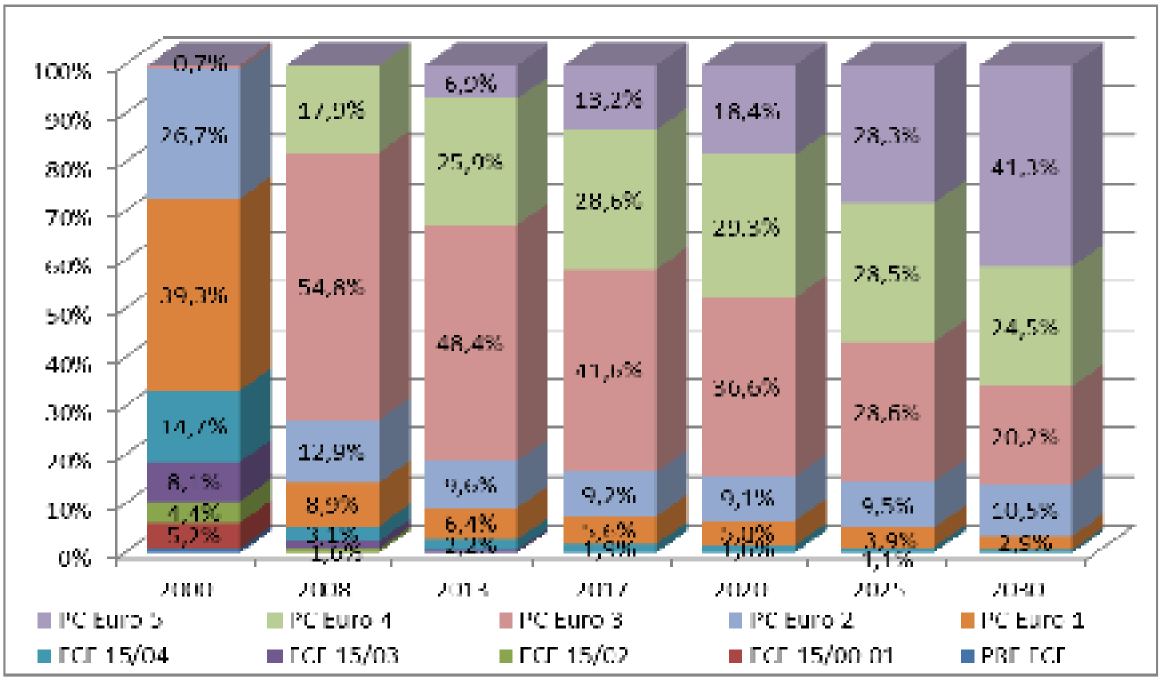
Figure 6.2: Shares of emerging technologies for Gasoline Passenger Cars, 1,4 – 2 l



Gasoline Passenger Cars, > 2 l

The share of Euro 4 and Euro 5 cars increases from 33% in 2013 to 48% in 2020, to 57% in 2025 and to 66% in 2030. Especially, in 2030 the share of Euro 5 cars will be 41% compared to the share of 7% in 2013 (see Figure 6.3)

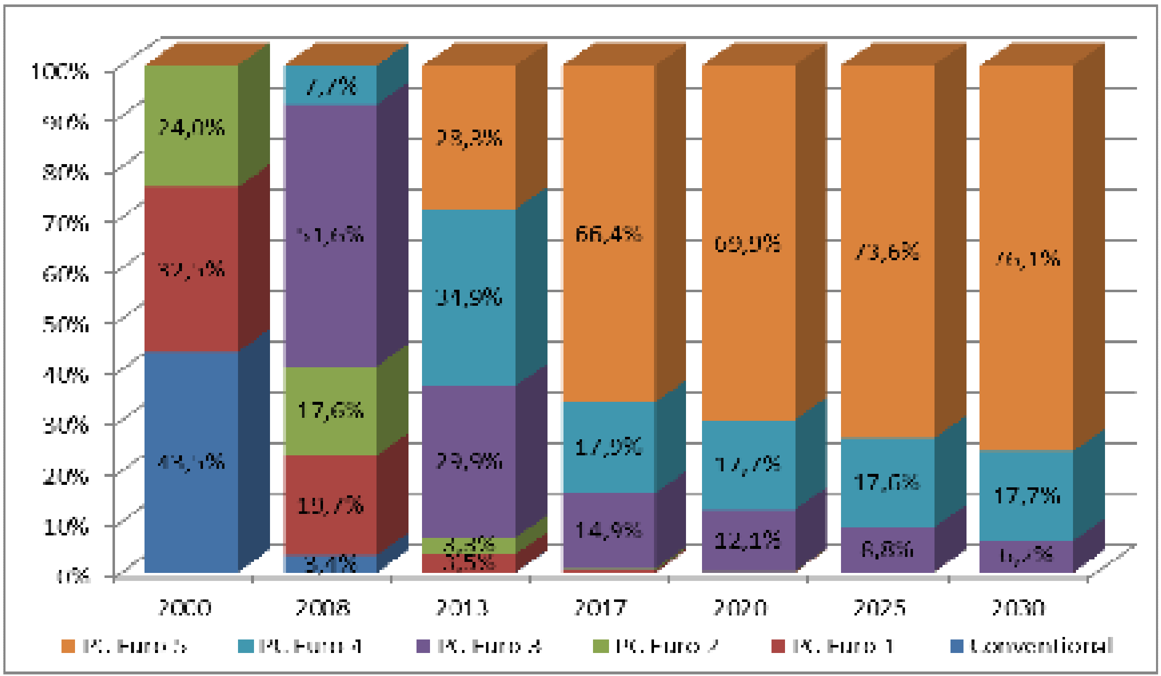
Figure 6.3: Shares of emerging technologies for Gasoline Passenger Cars > 2 l



Diesel Passenger Cars, < 2 l

The share of Euro 4 and Euro 5 cars increases from 63% in 2013 to 87% in 2020, to 91% in 2025 and to 94% in 2030. Especially, in 2030 the share of Euro 5 cars will be 76% compared to the share of 28% in 2013 (see Figure 6.4)

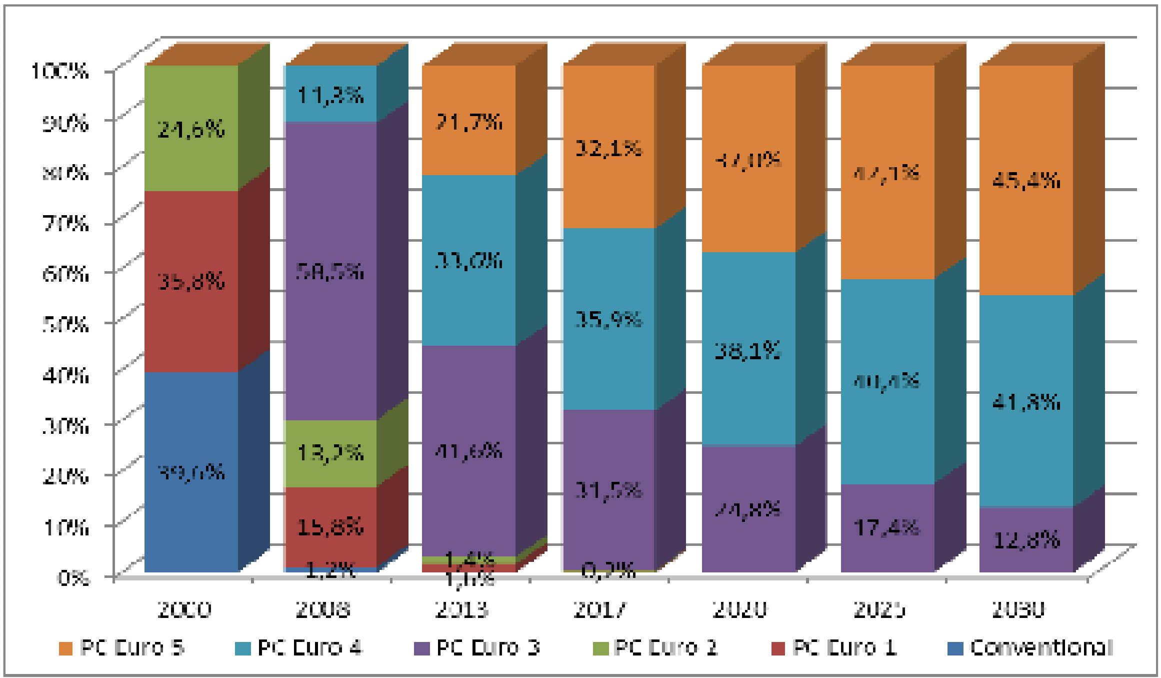
Figure 6.4: Shares of emerging technologies for Diesel Passenger Cars < 2 l



Diesel Passenger Cars, > 2 l

The share of Euro 4 and Euro 5 cars increases from 55% in 2013 to 75% in 2020, to 82% in 2025 and to 87% in 2030. Especially, in 2030 the share of Euro 5 cars will be 45% compared to the share of 22% in 2013 (see Figure 6.5)

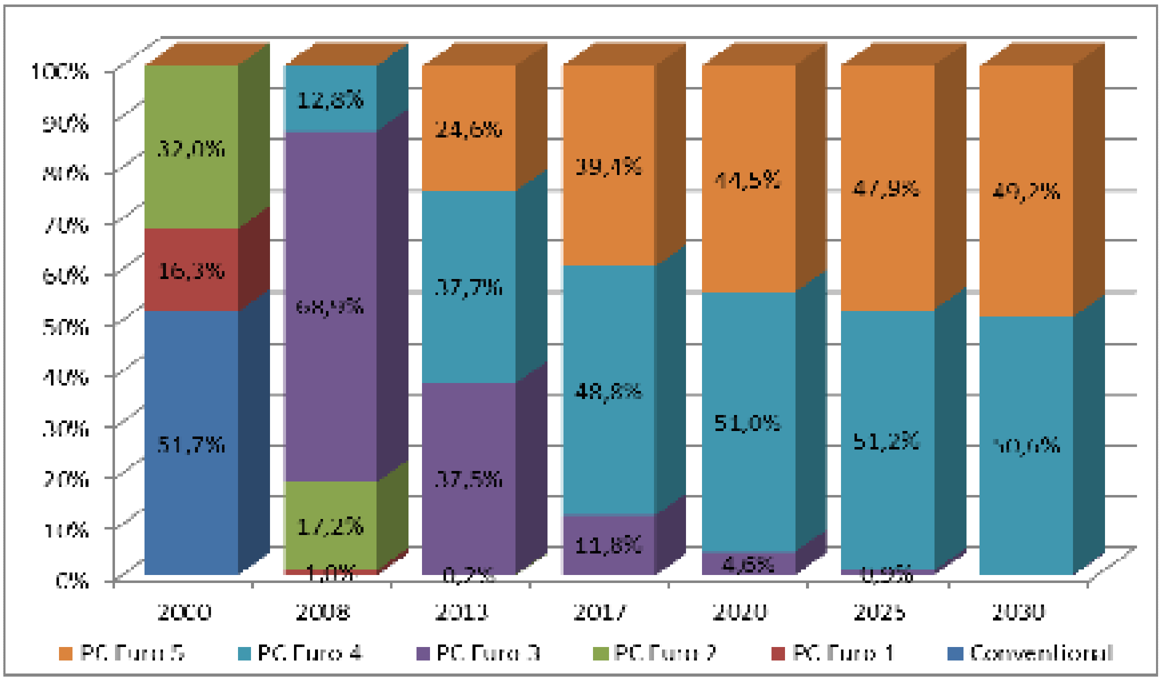
Figure 6.5: Shares of emerging technologies for Diesel Passenger Cars > 2 l



LPG Passenger Cars

The share of Euro 4 and Euro 5 cars increases from 62% in 2013 to 95% in 2020, to 99% in 2025 and to 99.8% in 2030. Especially, in 2030 the share of Euro 5 cars will be 49% compared to the share of 24% in 2013 (see Figure 6.6)

Figure 6.6: Shares of emerging technologies for LPG Cars

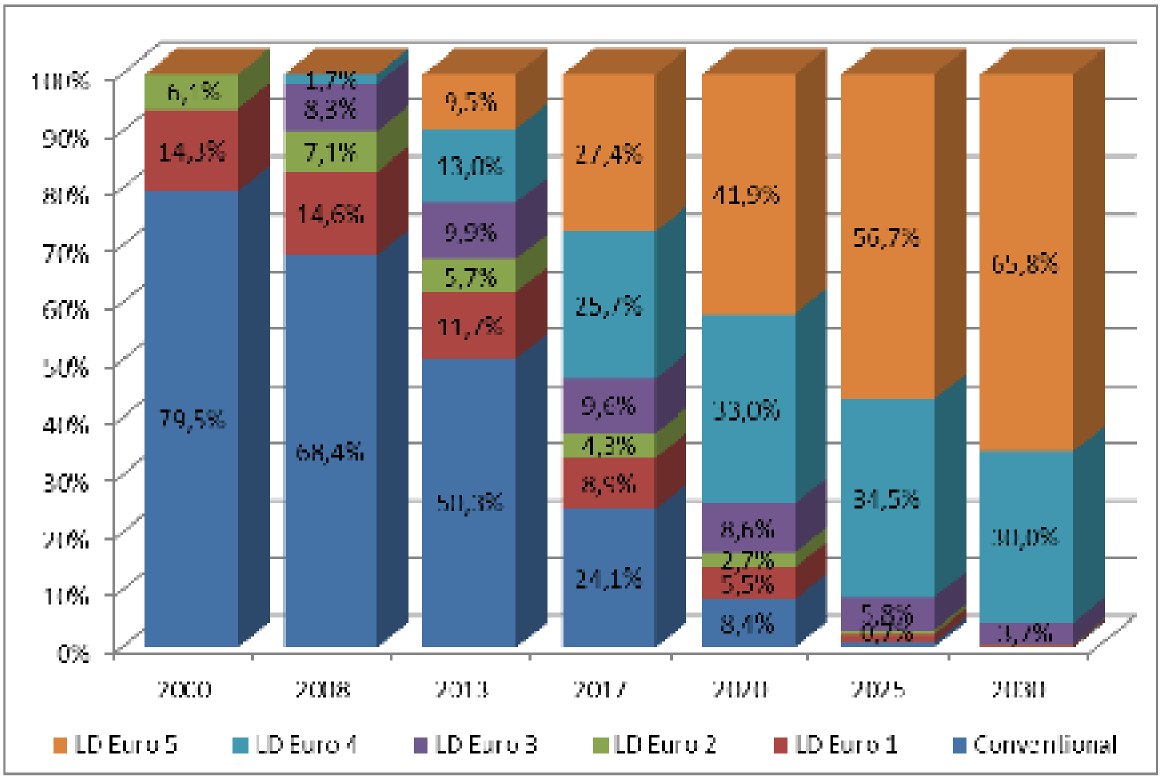


6.4.2 Trucks

Gasoline Light Commercial Vehicles < 3,5 t

The share of Euro 4 and Euro 5 trucks increases from 22% in 2013 to 75% in 2020, to 91% in 2025 and to 96% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 66% compared to the share of 9% in 2013 (see Figure 6.7)

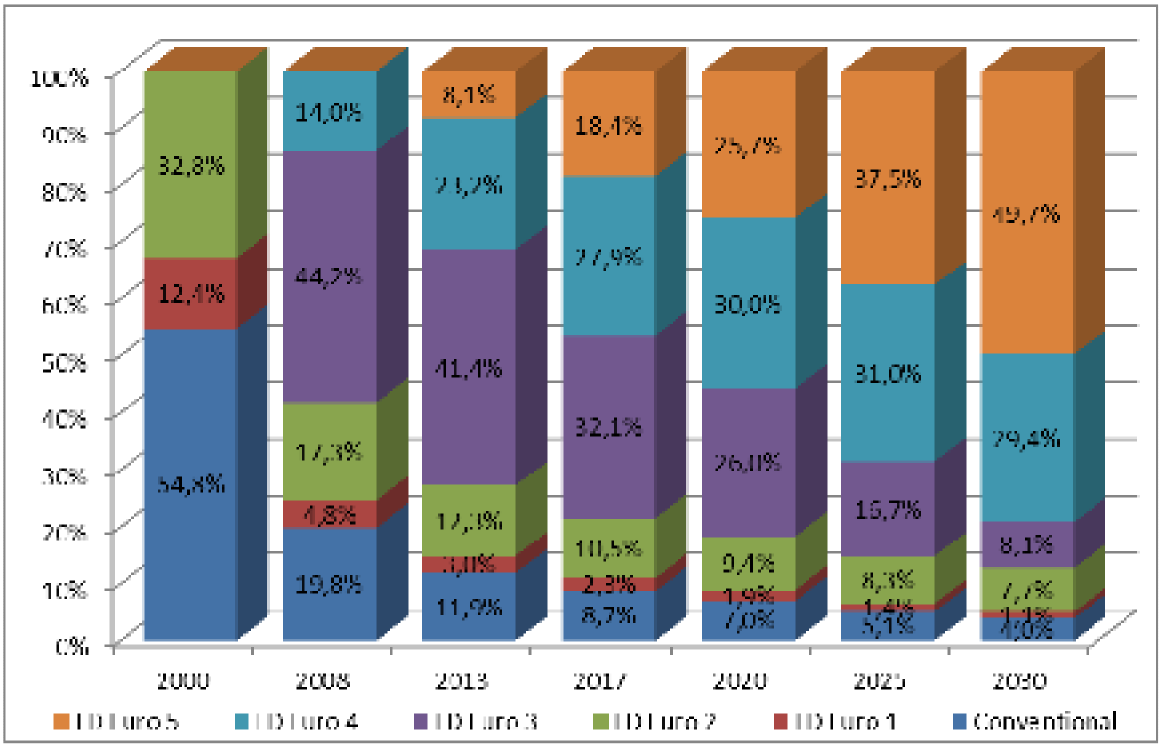
Figure 6.7: Shares of emerging technologies for Gasoline Light Commercial Vehicles < 3,5 t



Diesel Light Commercial Vehicles < 3,5 t

The share of Euro 4 and Euro 5 trucks increases from 31% in 2013 to 56% in 2020, to 68% in 2025 and to 79% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 50% compared to the share of 8% in 2013 (see Figure 6.8)

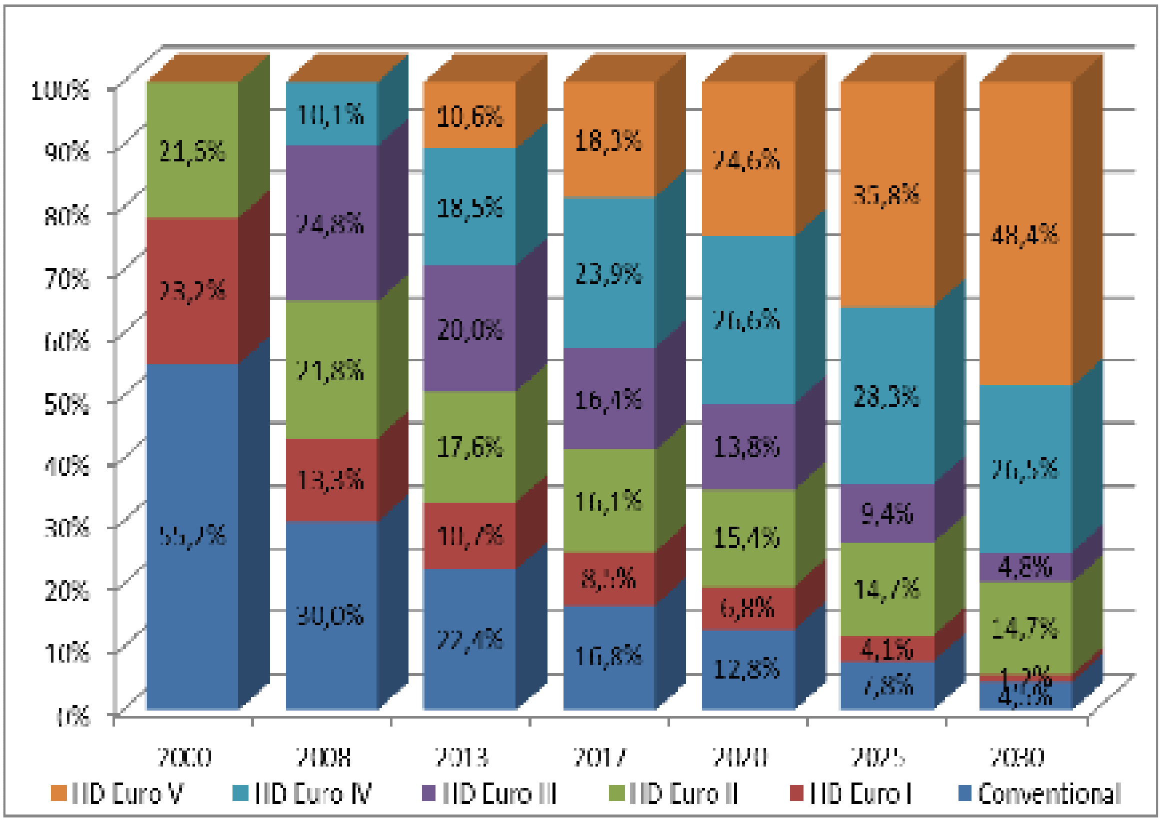
Figure 6.8: Shares of emerging technologies for Diesel Light Commercial Vehicles < 3,5 t



Heavy Duty Trucks, Rigid<= 7,5 t

The share of Euro 4 and Euro 5 trucks increases from 29% in 2013 to 51% in 2020, to 64% in 2025 and to 75% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 48% compared to the share of 11% in 2013 (see Figure 6.9)

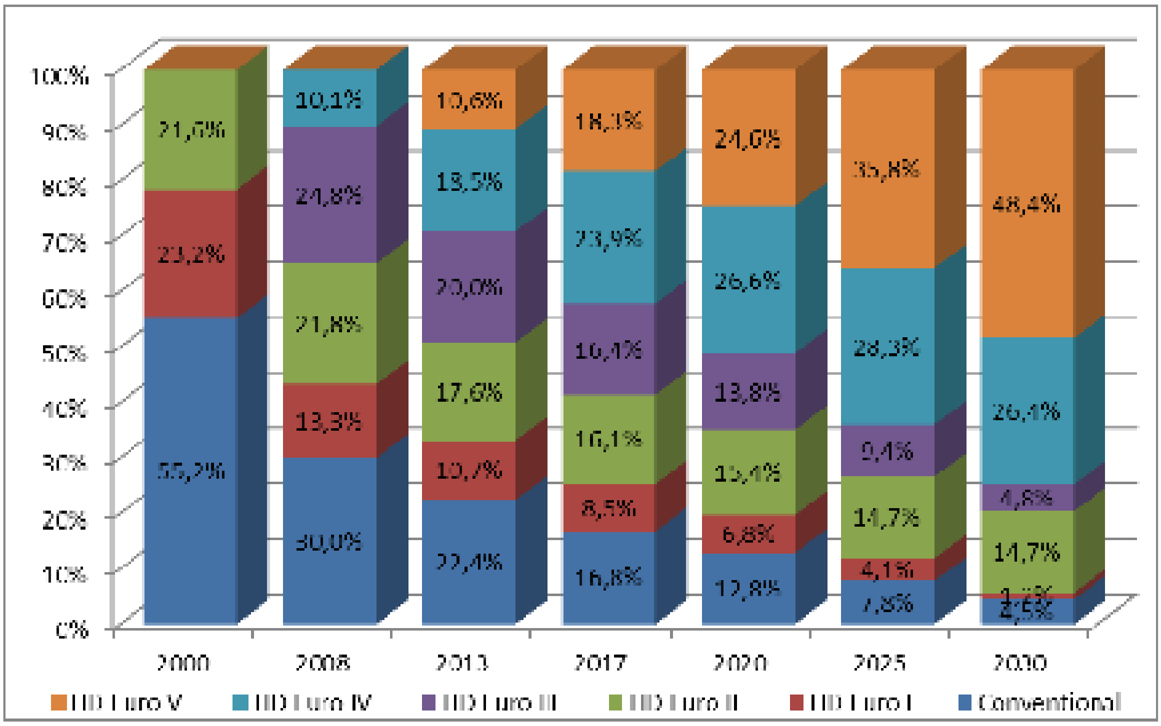
Figure 6.9: Shares of emerging technologies for Heavy Duty Trucks, Rigid <= 7,5 t



Heavy Duty Trucks, Rigid 7,5 – 12 t

The share of Euro 4 and Euro 5 trucks increases from 29% in 2013 to 51% in 2020, to 64% in 2025 and to 75% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 48% compared to the share of 11% in 2013 (see Figure 6.10)

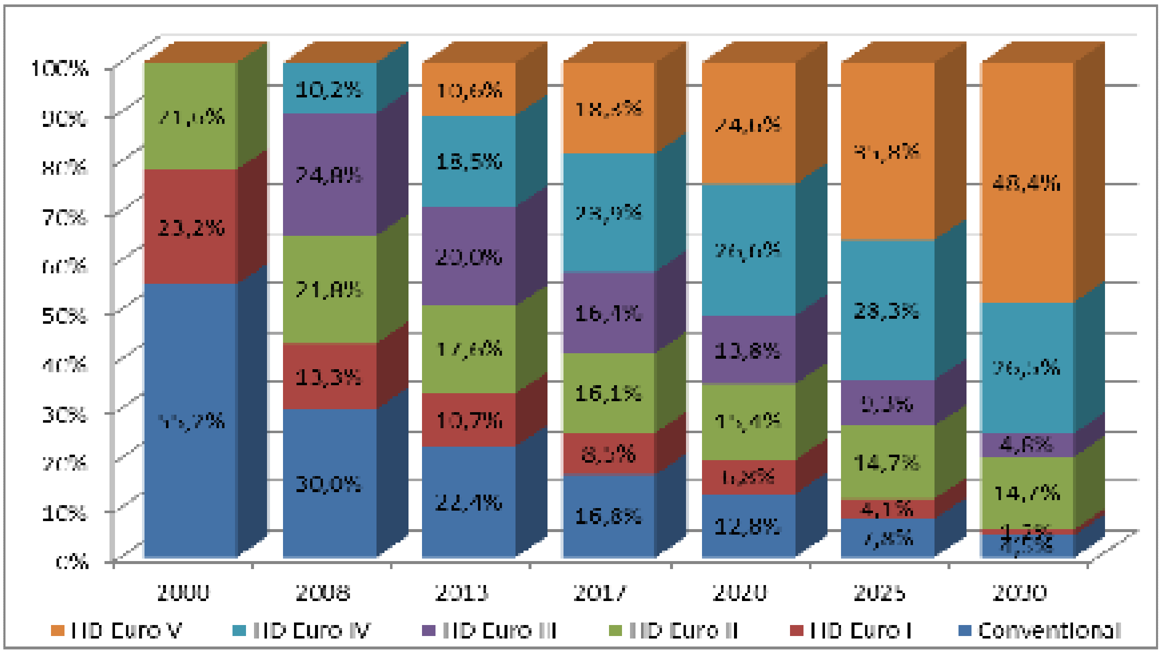
Figure 6.10: Shares of emerging technologies for Heavy Duty Trucks, Rigid 7,5 – 12 t



Heavy Duty Trucks, Rigid 12 – 14 t

The share of Euro 4 and Euro 5 trucks increases from 29% in 2013 to 51% in 2020, to 64% in 2025 and to 75% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 48% compared to the share of 11% in 2013 (see Figure 6.11)

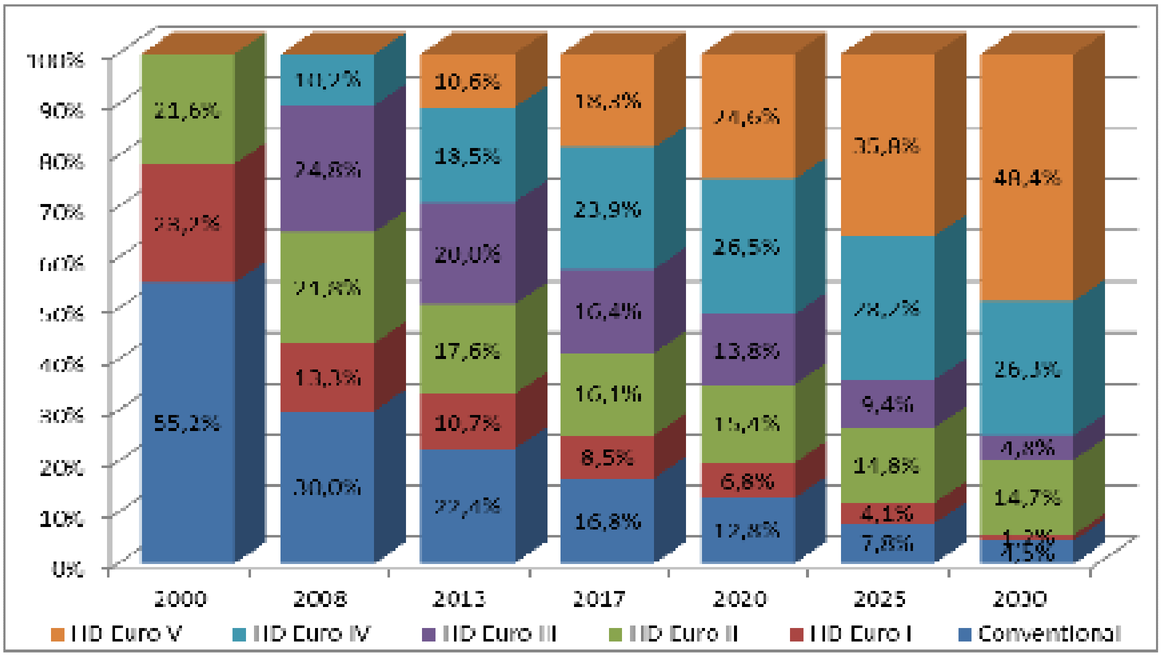
Figure 6.11: Shares of emerging technologies for Heavy Duty Trucks, Rigid 12 – 14 t



Heavy Duty Trucks, Rigid 14 – 20 t

The share of Euro 4 and Euro 5 trucks increases from 29% in 2013 to 51% in 2020, to 64% in 2025 and to 75% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 48% compared to the share of 11% in 2013 (see Figure 6.12)

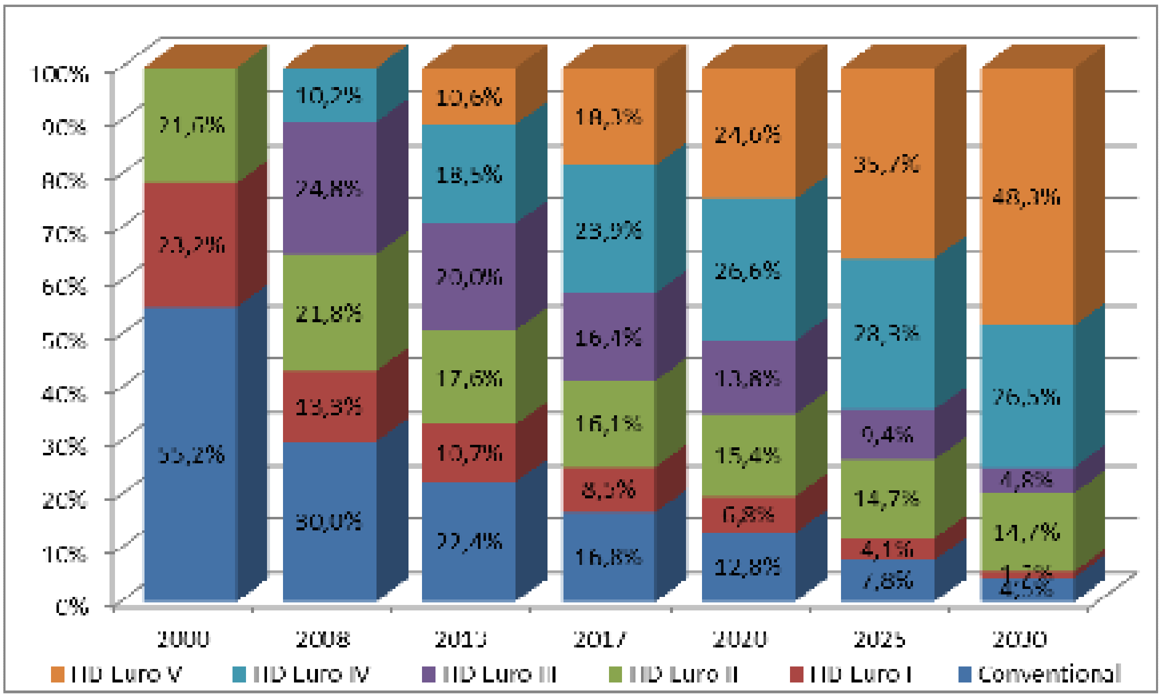
Figure 6.12: Shares of emerging technologies for Heavy Duty Trucks, Rigid 14 – 20 t



Heavy Duty Trucks, Rigid 20 – 26 t

The share of Euro 4 and Euro 5 trucks increases from 29% in 2013 to 51% in 2020, to 64% in 2025 and to 75% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 48% compared to the share of 11% in 2013 (see Figure 6.13)

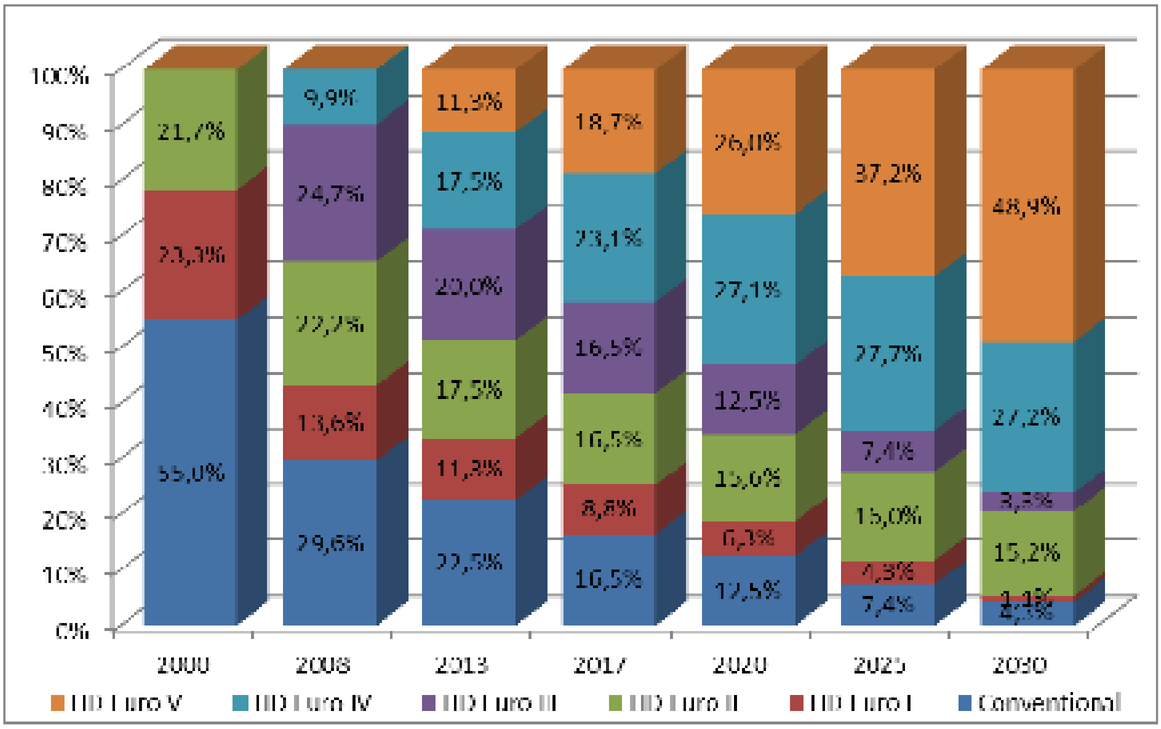
Figure 6.13: Shares of emerging technologies for Heavy Duty Trucks, Rigid 20 – 26 t



Heavy Duty Trucks, Rigid 26 – 28 t

The share of Euro 4 and Euro 5 trucks increases from 29% in 2013 to 53% in 2020, to 65% in 2025 and to 76% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 49% compared to the share of 11% in 2013 (see Figure 6.14)

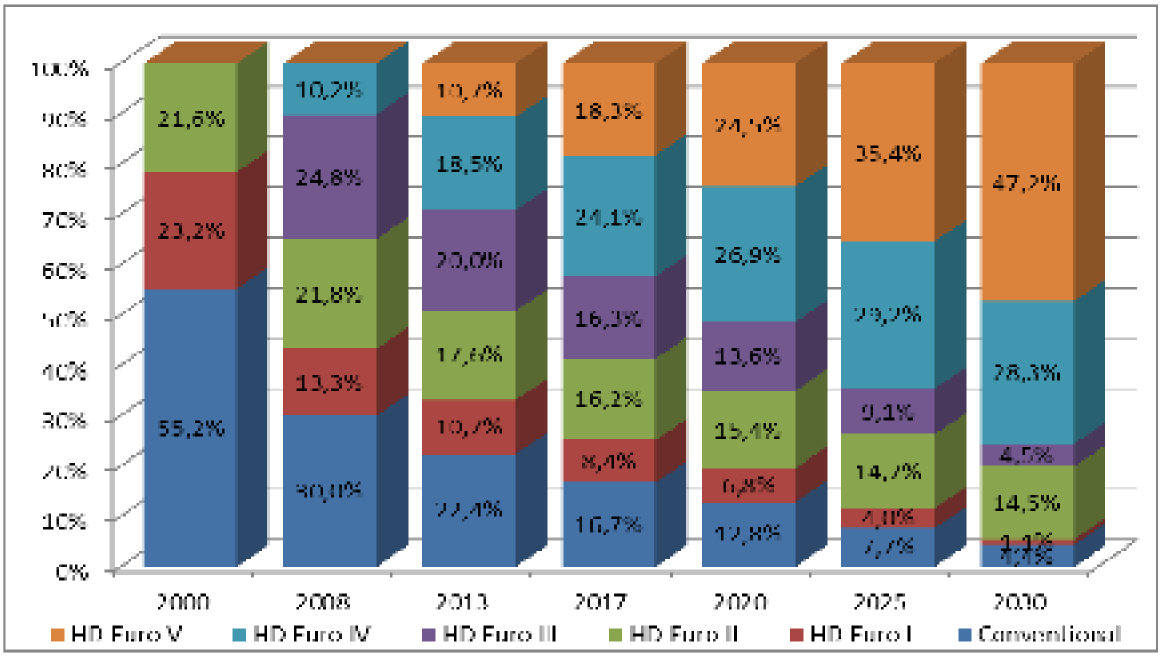
Figure 6.14: Shares of emerging technologies for Heavy Duty Trucks, Rigid 26 – 28 t



Heavy Duty Trucks, Rigid 28 – 32 t

The share of Euro 4 and Euro 5 trucks increases from 29% in 2013 to 51% in 2020, to 65% in 2025 and to 76% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 47% compared to the share of 11% in 2013 (see Figure 6.15)

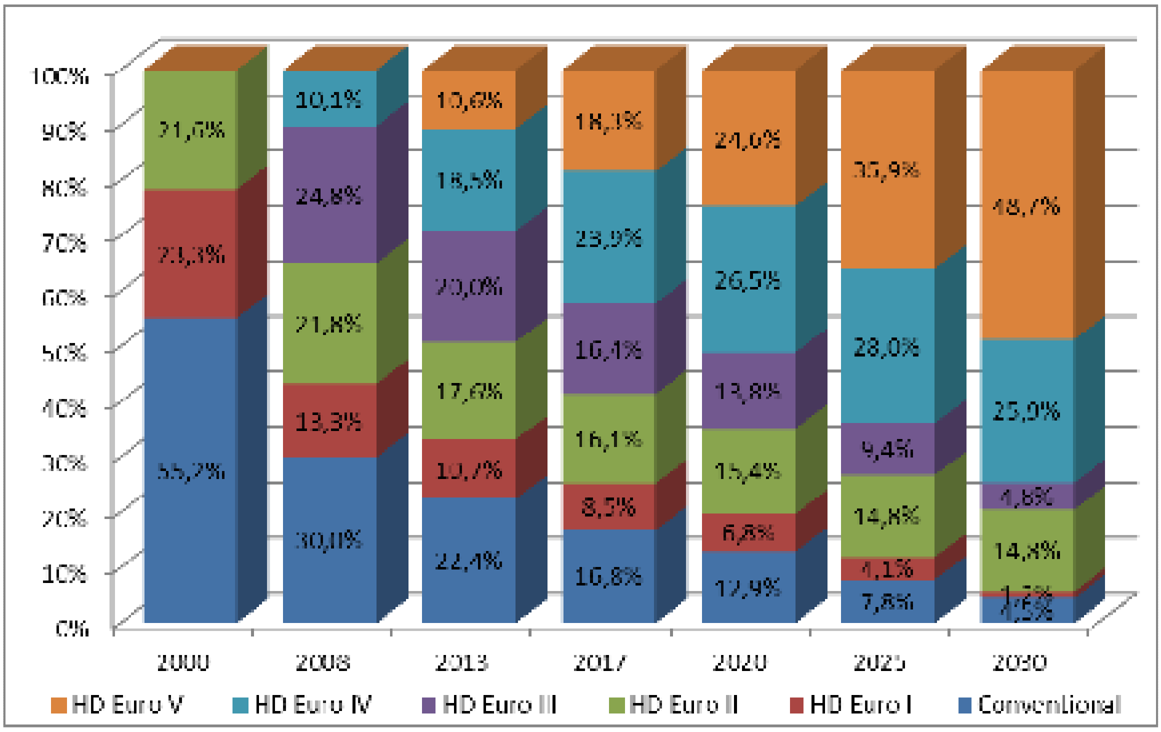
Figure 6.15: Shares of emerging technologies for Heavy Duty Trucks, Rigid 28 – 32 t



Heavy Duty Trucks, Rigid> 32 t

The share of Euro 4 and Euro 5 trucks increases from 29% in 2013 to 51% in 2020, to 64% in 2025 and to 75% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 49% compared to the share of 11% in 2013 (see Figure 6.16)

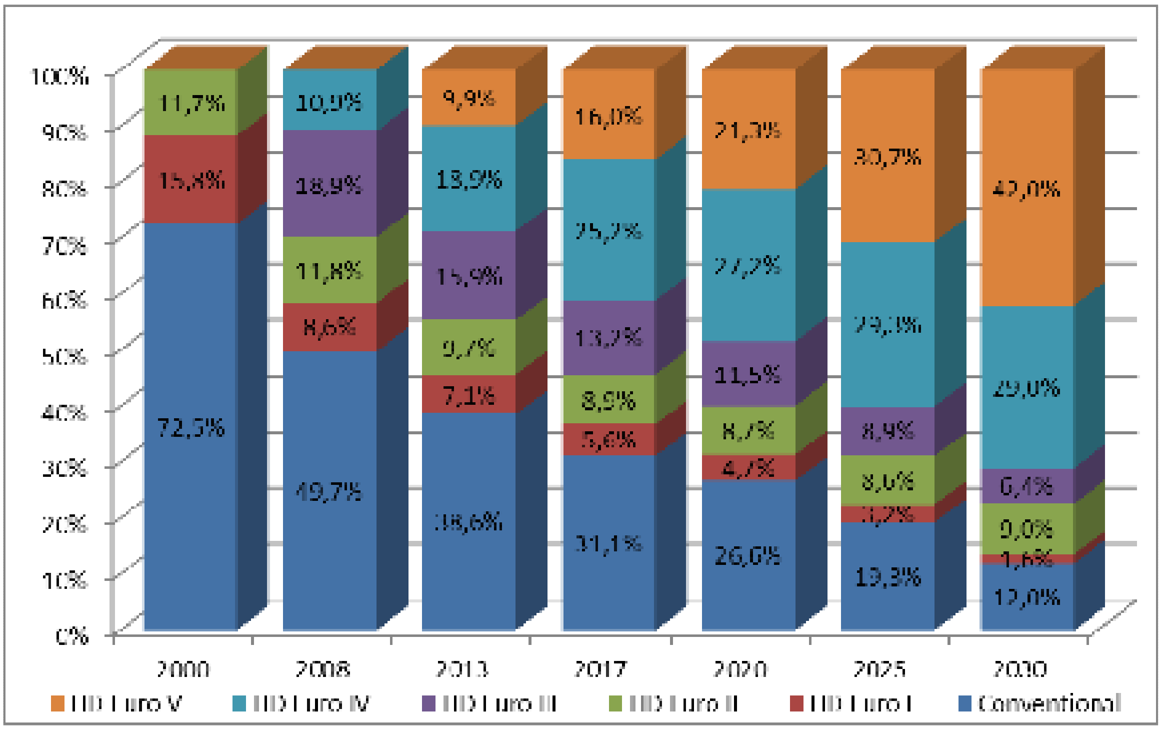
Figure 6.16: Shares of emerging technologies for Heavy Duty Trucks, Rigid > 32 t



Heavy Duty Trucks, Articulated 14 – 20 t

The share of Euro 4 and Euro 5 trucks increases from 29% in 2013 to 48% in 2020, to 60% in 2025 and to 71% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 42% compared to the share of 10% in 2013 (see Figure 6.17)

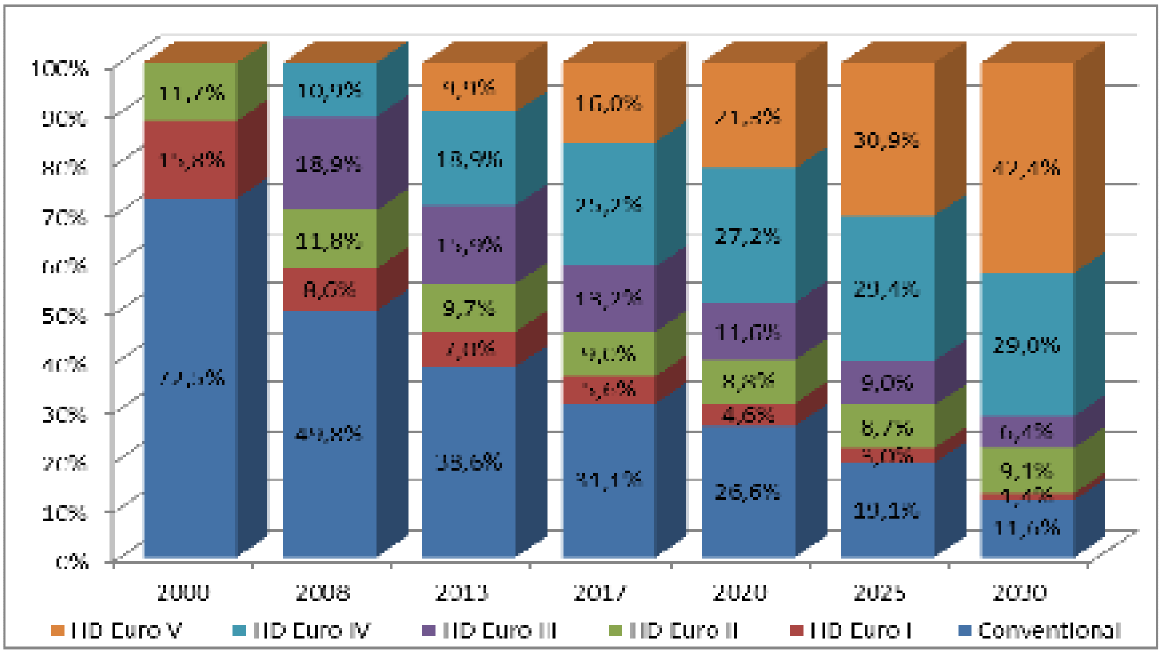
Figure 6.17: Shares of emerging technologies for Heavy Duty Trucks, Articulated 14 – 20 t



Heavy Duty Trucks, Articulated 20 – 28 t

The share of Euro 4 and Euro 5 trucks increases from 29% in 2013 to 48% in 2020, to 60% in 2025 and to 71% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 42% compared to the share of 10% in 2013 (see Figure 6.18)

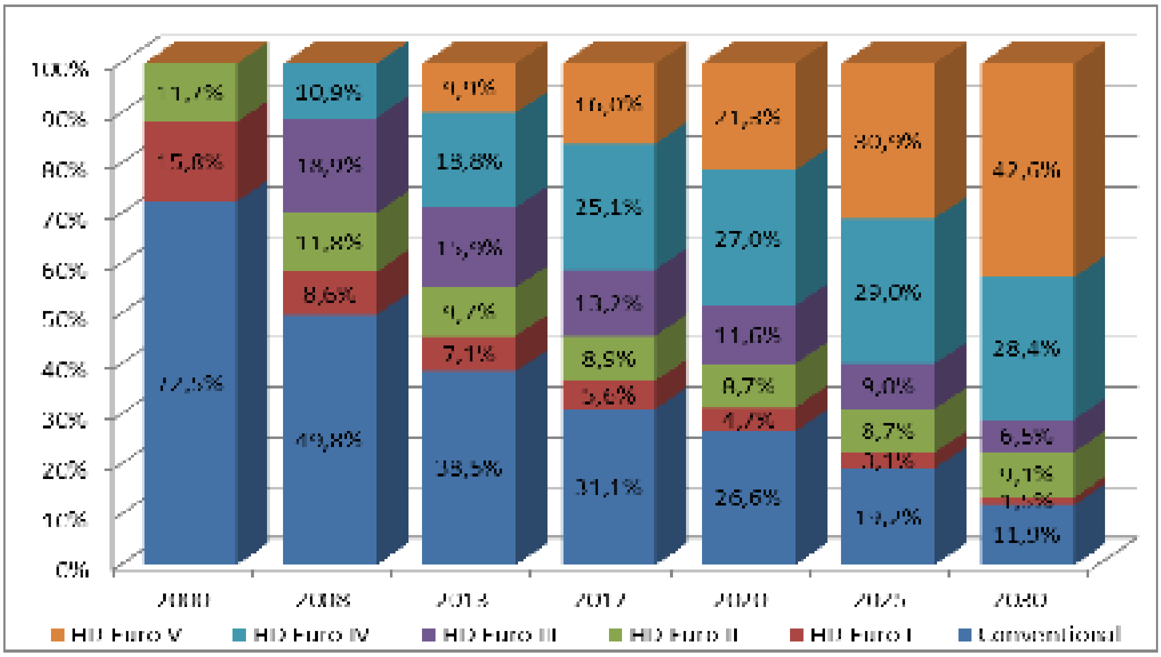
Figure 6.18: Shares of emerging technologies for Heavy Duty Trucks, Articulated 20 – 28 t



Heavy Duty Trucks, Articulated 28 – 34 t

The share of Euro 4 and Euro 5 trucks increases from 29% in 2013 to 48% in 2020, to 60% in 2025 and to 71% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 43% compared to the share of 10% in 2013 (see Figure 6.19)

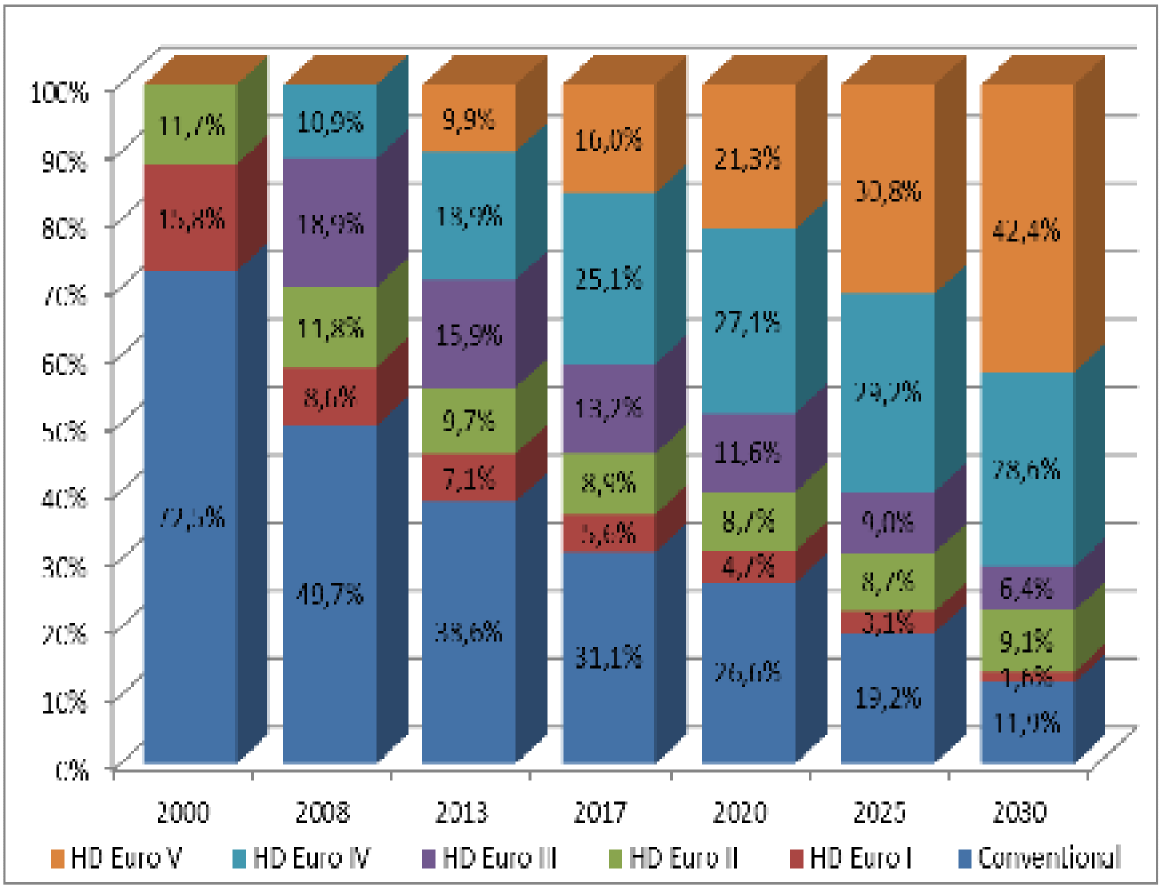
Figure 6.19: Shares of emerging technologies for Heavy Duty Trucks, Articulated 28 – 34 t



Heavy Duty Trucks, Articulated 34 – 40 t

The share of Euro 4 and Euro 5 trucks increases from 29% in 2013 to 48% in 2020, to 60% in 2025 and to 71% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 42% compared to the share of 10% in 2013 (see Figure 6.20)

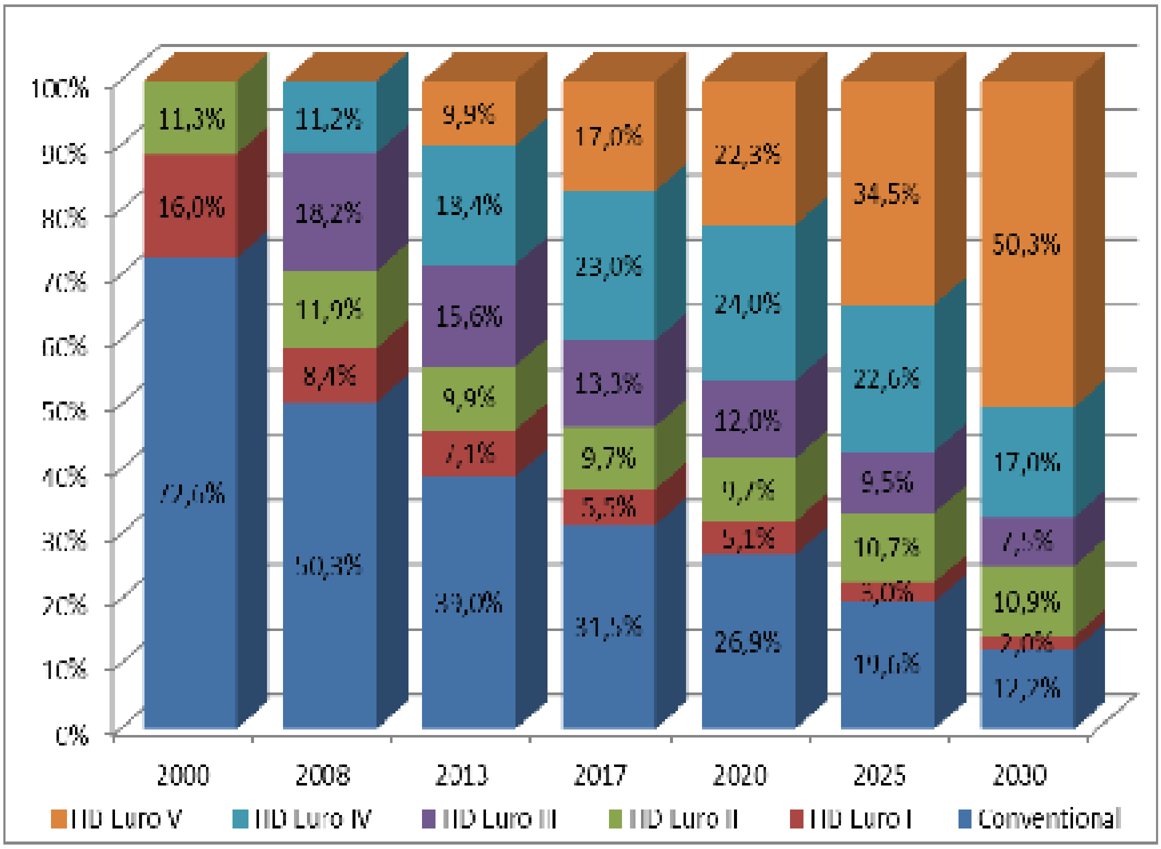
Figure 6.20: Shares of emerging technologies for Heavy Duty Trucks, Articulated 34 – 40 t



Heavy Duty Trucks, Articulated 40 – 50 t

The share of Euro 4 and Euro 5 trucks increases from 28% in 2013 to 46% in 2020, to 57% in 2025 and to 67% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 50% compared to the share of 10% in 2013 (see Figure 6.21)

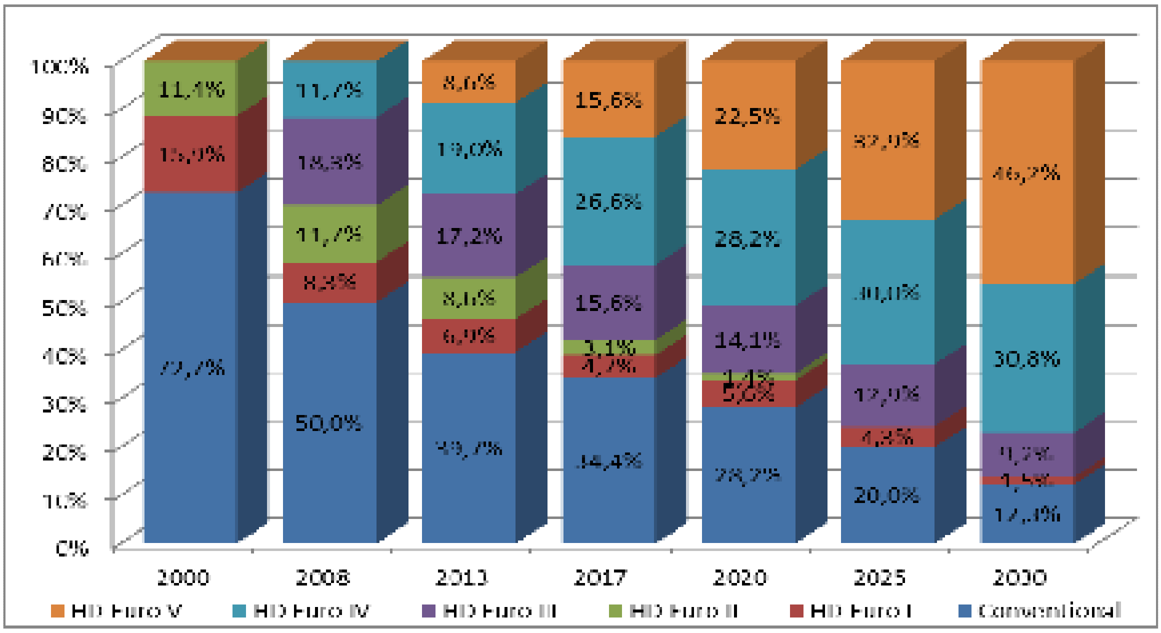
Figure 6.21: Shares of emerging technologies for Heavy Duty Trucks, Articulated 40 – 50 t



Heavy Duty Trucks, Articulated 50 – 60 t

The share of Euro 4 and Euro 5 trucks increases from 28% in 2013 to 51% in 2020, to 63% in 2025 and to 77% in 2030. Especially, in 2030 the share of Euro 5 trucks will be 46% compared to the share of 9% in 2013 (see Figure 6.22)

Figure 6.22: Shares of emerging technologies for Heavy Duty Trucks, Articulated 50 – 60 t

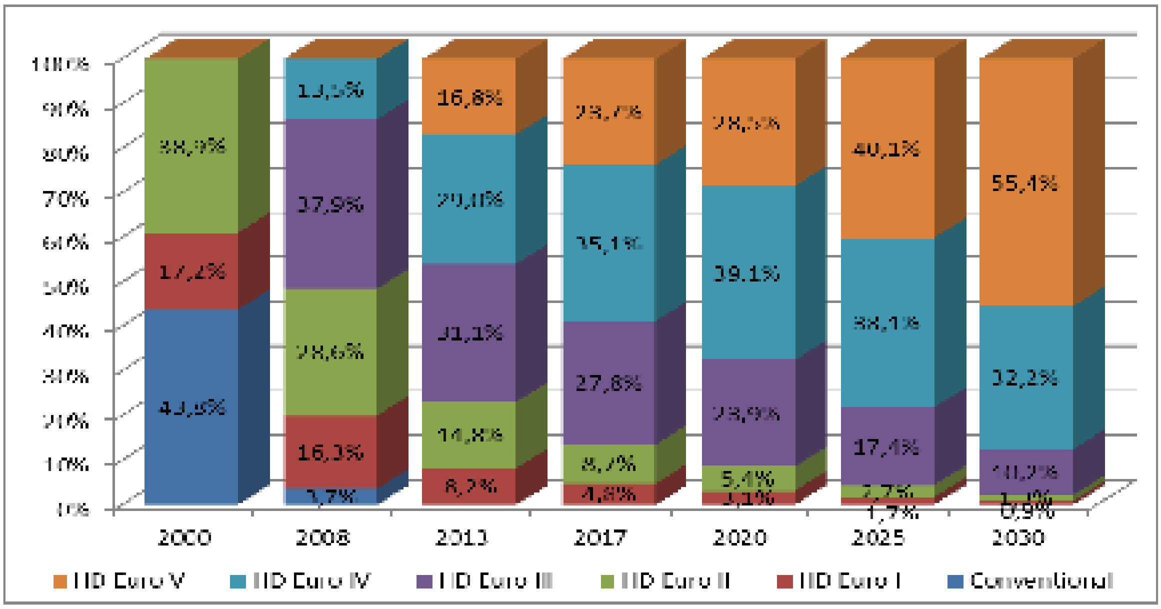


6.4.3 Buses – Coaches

Urban Buses Standard, 15 – 18 t

The share of Euro 4 and Euro 5 buses increases from 46% in 2013 to 68% in 2020, to 78% in 2025 and to 88% in 2030. Especially, in 2030 the share of Euro 5 buses will be 55% compared to the share of 17% in 2013 (see Figure 6.23)

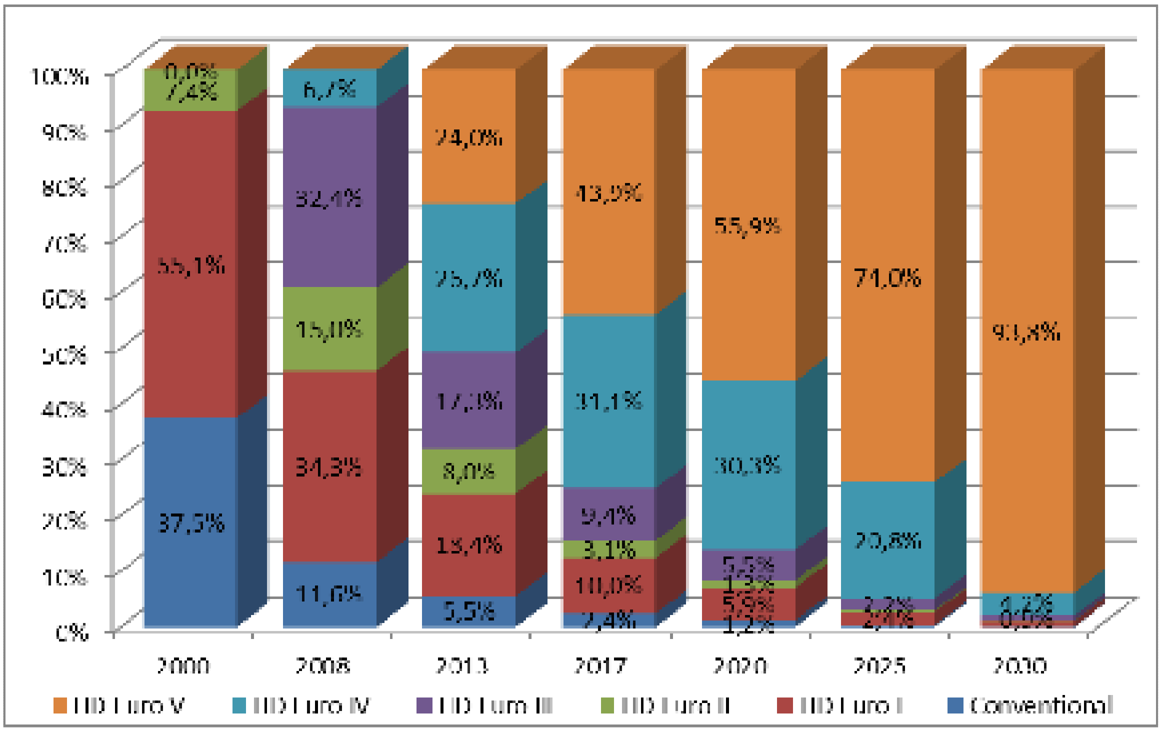
Figure 6.23: Shares of emerging technologies for Urban Buses, Standard 15 – 18 t



Coaches, Standard, <=18 t

The share of Euro 4 and Euro 5 buses increases from 51% in 2013 to 86% in 2020, to 95% in 2025 and to 98% in 2030. Especially, in 2030 the share of Euro 5 buses will be 94% compared to the share of 24% in 2013 (see Figure 6.24)

Figure 6.24: Shares of emerging technologies for Coaches, Standard, <= 18 t

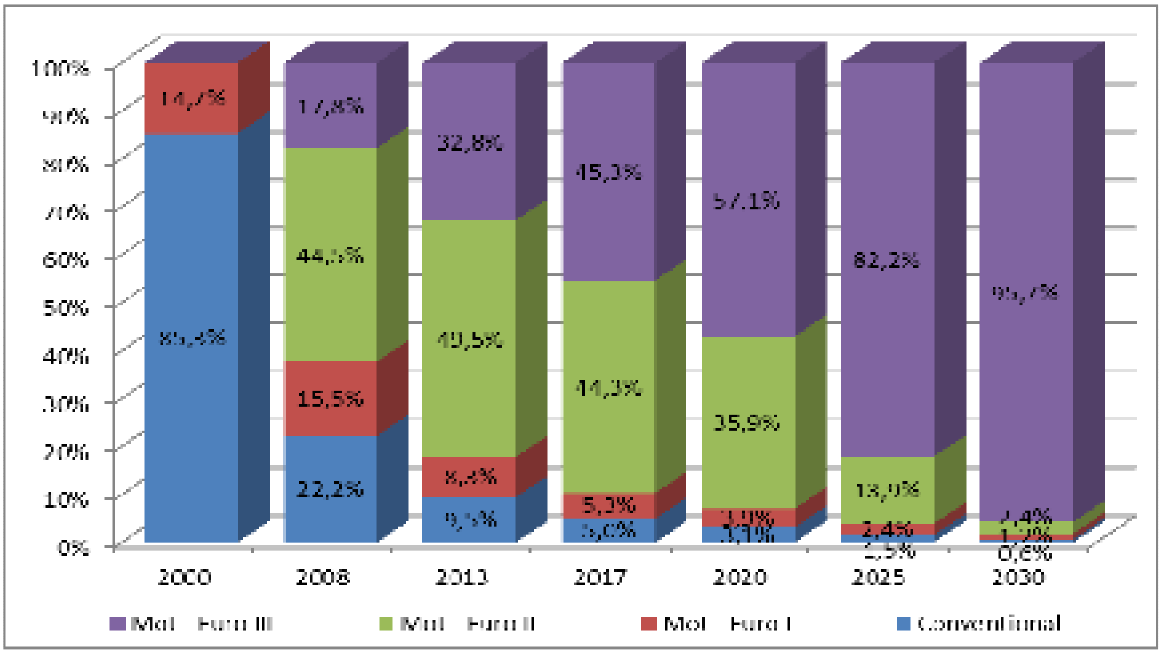


6.4.4 Motorcycles – Mopeds

Motorcycles 4-stroke < 250 cm^3

The share of Euro 2 and Euro 3 motorcycles increases from 82% in 2013 to 93% in 2020, to 96% in 2025 and to 98% in 2030. Especially, in 2030 the share of Euro 3 motorcycles will be 96% compared to the share of 33% in 2013 (see Figure 6.25)

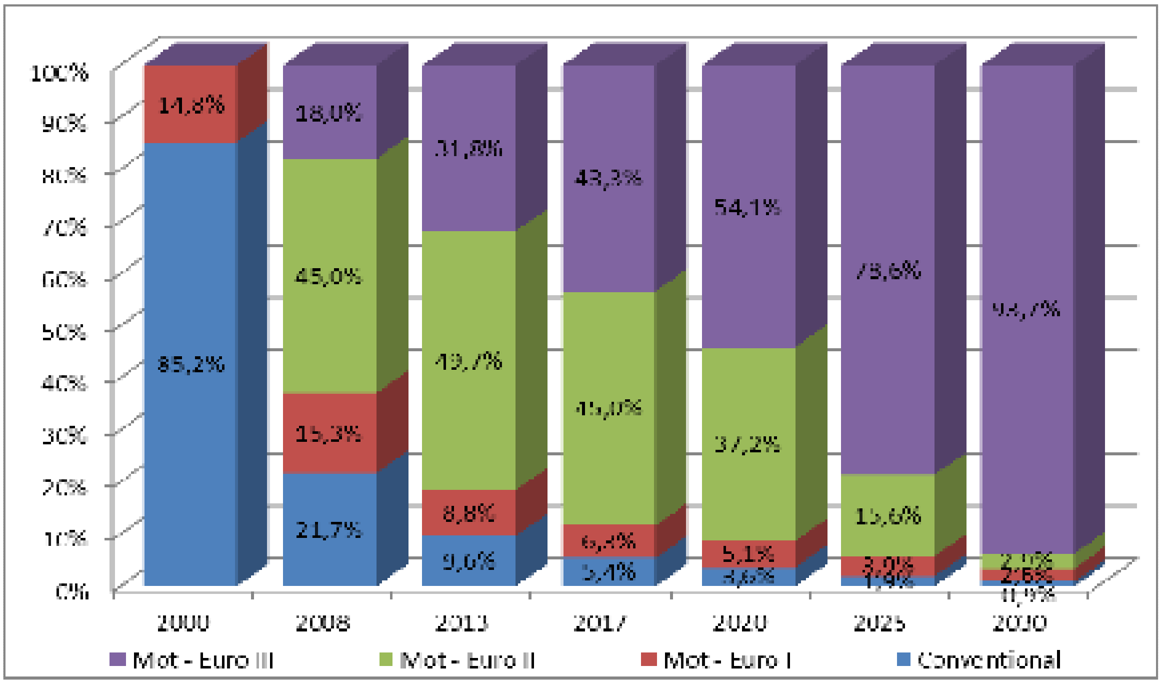
Figure 6.25: Shares of emerging technologies for Motorcycles 4-stroke < 250 cm^3



Motorcycles 4-stroke 250 – 750 cm^3

The share of Euro 2 and Euro 3 motorcycles increases from 81% in 2013 to 91% in 2020, to 94% in 2025 and to 97% in 2030. Especially, in 2030 the share of Euro 3 motorcycles will be 94% compared to the share of 32% in 2013 (see Figure 6.26)

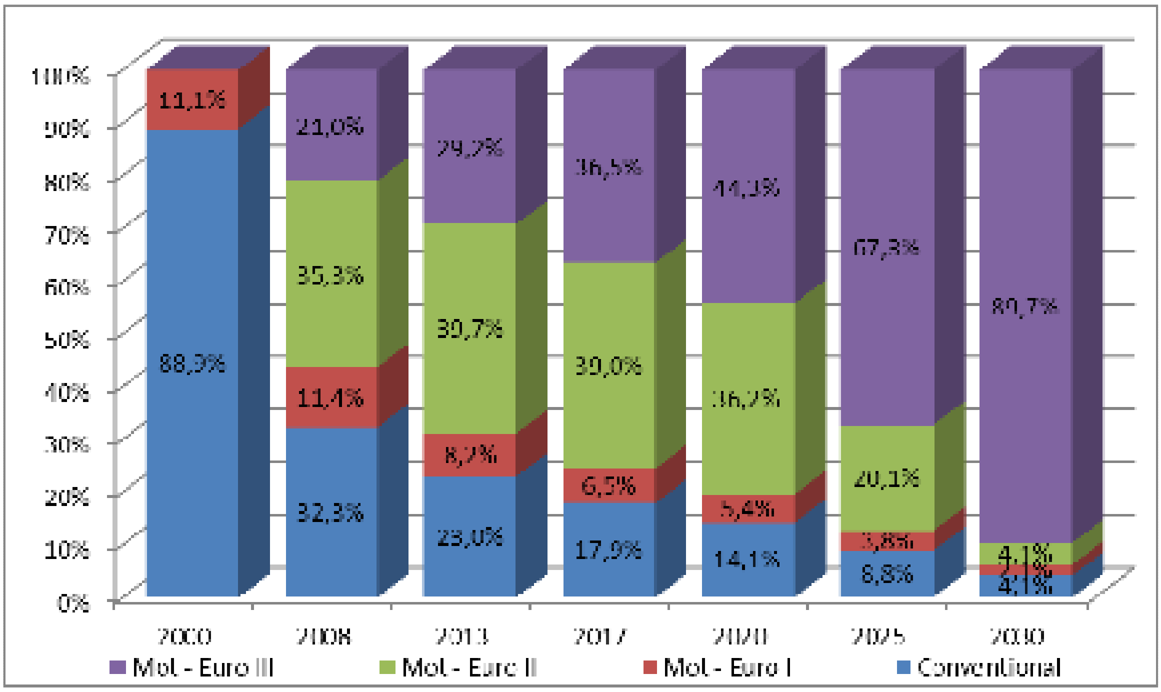
Figure 6.26: Shares of emerging technologies for Motorcycles 4-stroke 250 – 750 cm^3



Motorcycles 4-stroke > 750 cm^3

The share of Euro 2 and Euro 3 motorcycles increases from 69% in 2013 to 80% in 2020, to 87% in 2025 and to 94% in 2030. Especially, in 2030 the share of Euro 3 motorcycles will be 90% compared to the share of 29% in 2013 (see Figure 4.27)

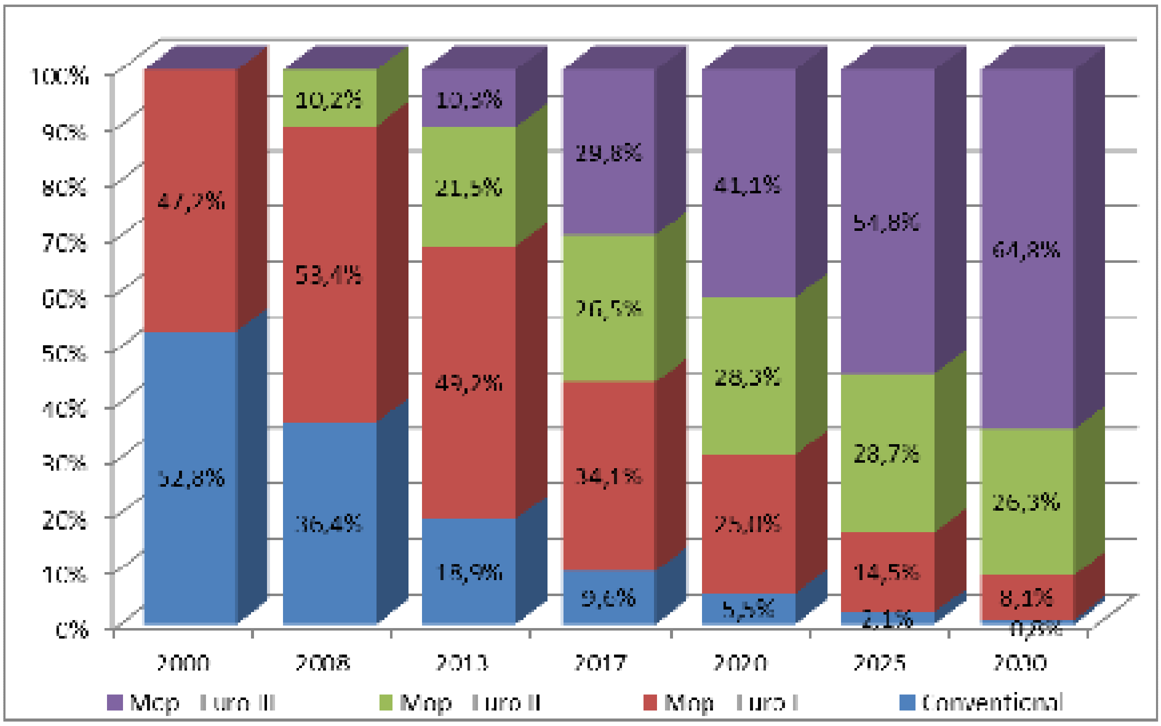
Figure 6.27: Shares of emerging technologies for Motorcycles 4-stroke > 750 cm^3



Mopeds 2-stroke < 50 cm^3

The share of Euro 2 and Euro 3 mopeds increases from 32% in 2013 to 69% in 2020, to 83% in 2025 and to 91% in 2030. Especially, in 2030 the share of Euro 3 mopeds will be 65% compared to the share of 10% in 2013 (see Figure 6.28)

Figure 6.28: Shares of emerging technologies for Mopeds 2-stroke < 50 cm^3



6.5 Greenhouse Gas emissions from road transport

In road transport, Greenhouse Gases emitted by vehicle categories include Carbon dioxide (CO_2), Methane (CH_4,) and Nitrus oxide (N_2O). To calculate the Greenhouse Gas emissions we adopt in the current study the Tier 2 method, which uses the number of vehicles, the annual mileage per vehicle and the emission factors of each pollutant.

Particularly, for year t of period 2000-2030, the quantity $E_{i,j,t}$ of pollutant i emitted by the j combination of vehicle technology/fuel type/displacement-weight is computed by

$$E_{i,j,t} = N_{j,t} \times M_{j,t} \times EF_{i,j}, \tag{6.8}$$

where $N_{j,t}$ is the number of vehicles in combination j for year t, $M_{j,t}$ is the average annual distance (km) driven by the vehicle in combination j for year t and $EF_{i,j}$ is the technology specific emission factor of pollutant i for the j combination of vehicle. The emission factors $EF_{i,j}$ in grams per kilometer for N_2O and CO_2 from combustion of lubricant oil are given in

Tables 6.16, 6.18, 6.20, 6.22 and 6.24 of the report «EMEP/EEA emission inventory guidebook 2013 update September 2014». For Methane, $\mathrm{EF}_{i,j}$ in mg/km was set equal to the Urban-Hot emission factor which is given in Table 6.72 of the same report. Finally, to transform CH_4 and N_2O emissions to CO_2 equivalent, we multiplied[96] one ton of methane by 21 and one ton of nitrus oxide by 310.

For the calculation of CO_2 emissions from the oxidation of fuel carbon, equation (6.8) is modified to

$$E_{i,j,t} = N_{j,t} \times M_{j,t} \times EF'_k \times FC_j \tag{6.9}$$

where EF'_k is the emission factor of fuel type k and FC_j is the average fuel consumption in grams per kilometer for the j combination of vehicle technology/fuel type/displacement-weight. The factor EF'_k is: 3,180 kg CO_2 per kg of Gasoline, 3,140 kg CO_2 per kg of Diesel and 3,017 kg CO_2 per kg of LPG. In Table 3.26 of the report «EMEP/EEA emission inventory guidebook 2013 update September 2014» the average fuel consumption FC_j in grams per kilometer driven by vehicles is given for the combinations of technology/fuel type/ displacement-weight under consideration. These averages have been used in our calculations.

For all the technology scenarios which were explained in Section 4, we present in Figures 6.29-6.34 the estimated total Greenhouse Gas emissions expressed in CO_2 equivalents for the period 2000-2012 and the corresponding predicted emissions for the period 2013-2030. Observe that in all scenarios the penetration of Euro 4 (or Euro IV) and Euro 5 (or Euro IV) standards to the fleet of vehicles lead to reductions in CO_2 eq. emissions. The only exception concerns the diesel, LPG and hybrid gasoline cars where the penetration of new technologies results in increased emissions between 2000-2012 and 2013-2030. The cause of this increase is the trade-off between less fuel consumption which is achieved by new

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[96] http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:CO2-eq

technologies and the longer average distance traveled in combination with lower fuel price per liter. Thus, for passenger cars, a technology that gives lower pollutants (e.g. diesel engines) loses its advantage when the distances traveled increase proportionally more, either because the technology allows economical use of fuel or because this fuel is sold at a lower price.

Figure 6.29: Greenhouse Gas emissions in Mt of CO2 equivalent emitted by passenger cars

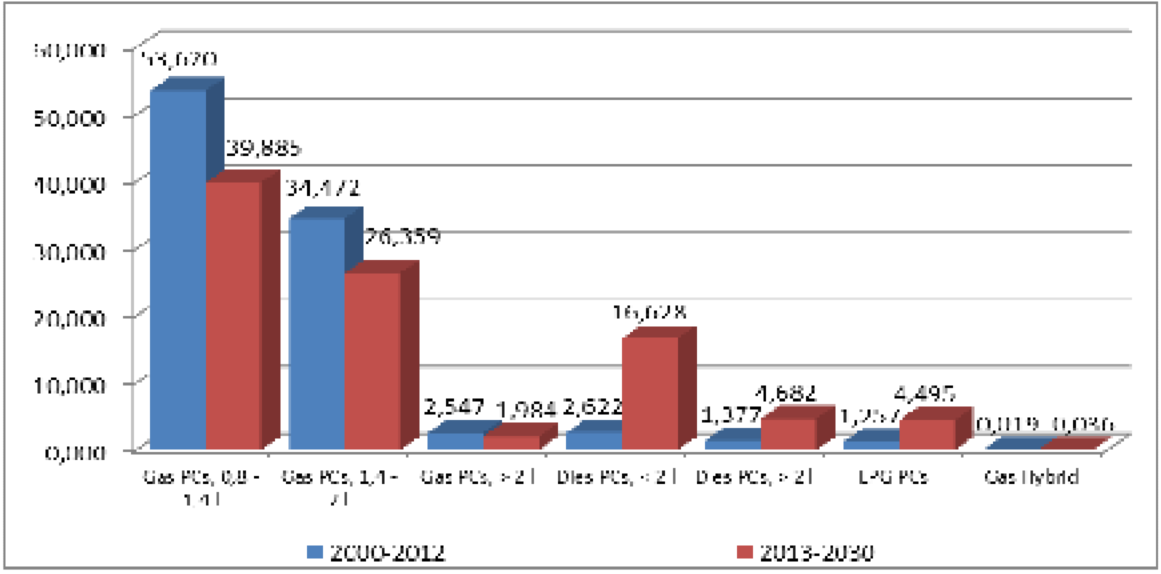


Figure 6.30: Greenhouse Gas emissions in Mt of CO2 equivalent emitted by Light Commercial Vehicles and Gasoline Heavy Duty Trucks >3,5 t conventional

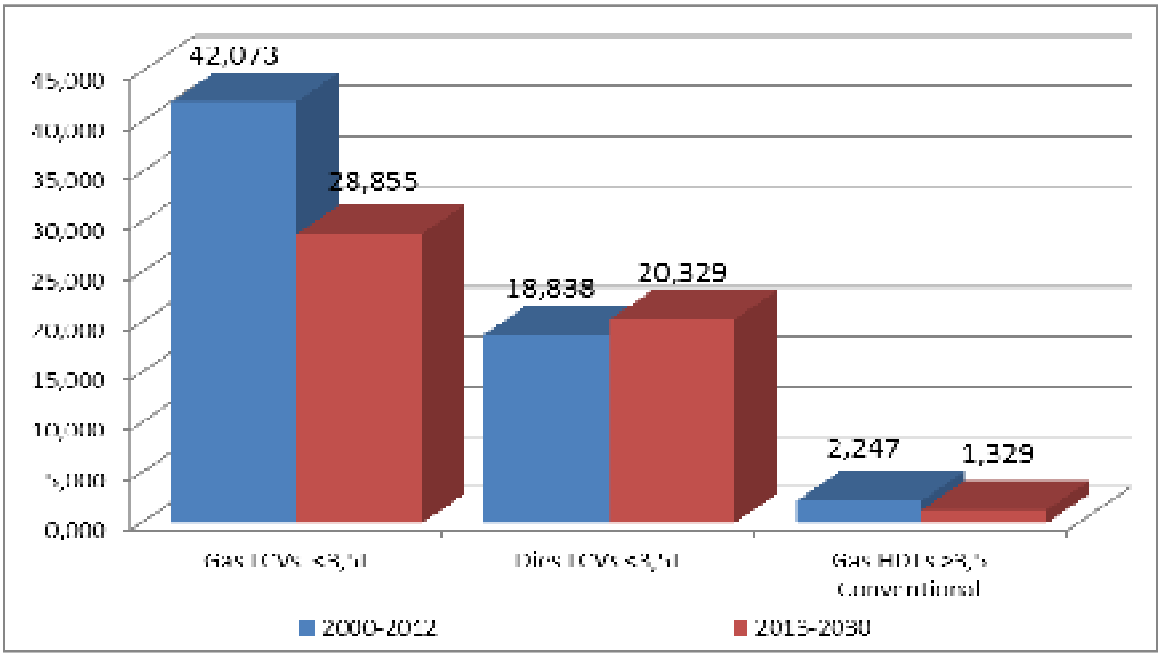


Figure 6.31: Greenhouse Gas emissions in Mt of CO2 equivalent emitted by Rigid Heavy Duty Trucks

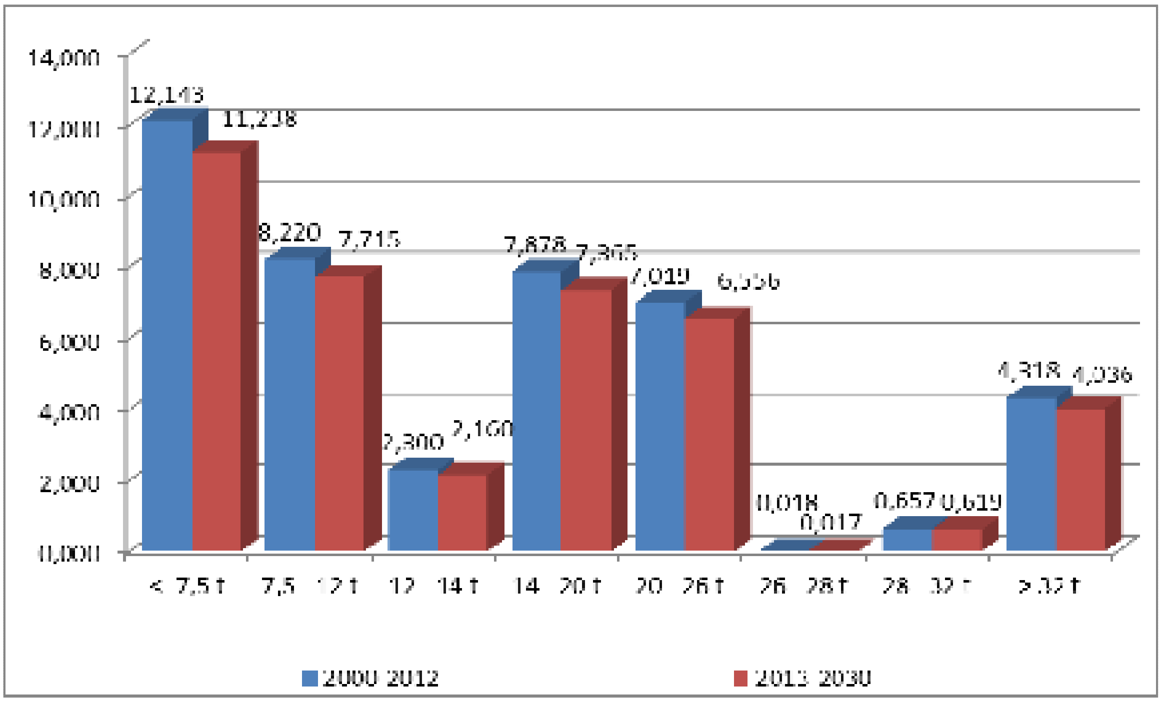


Figure 6.32: Greenhouse Gas emissions in Mt of CO2 equivalent emitted by Articulated Heavy Duty Trucks

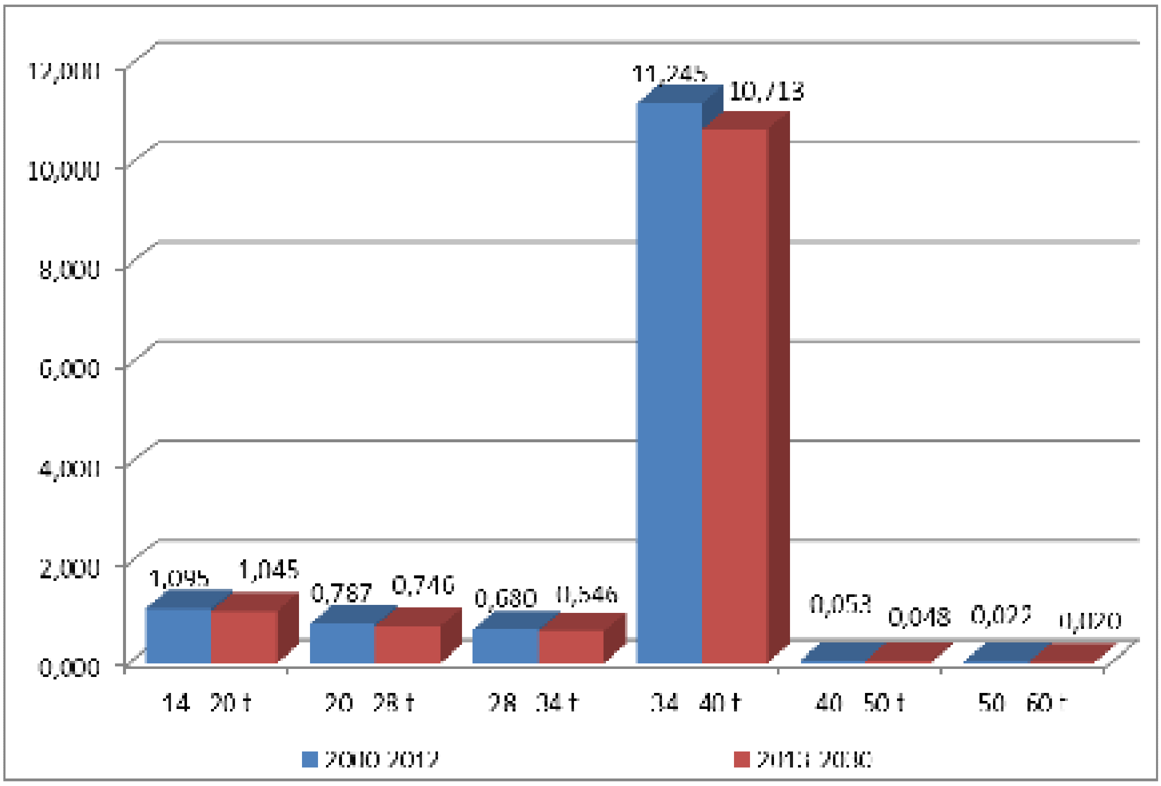


Figure 6.33: Greenhouse Gas emissions in Mt of CO2 equivalent emitted by Buses and Coaches

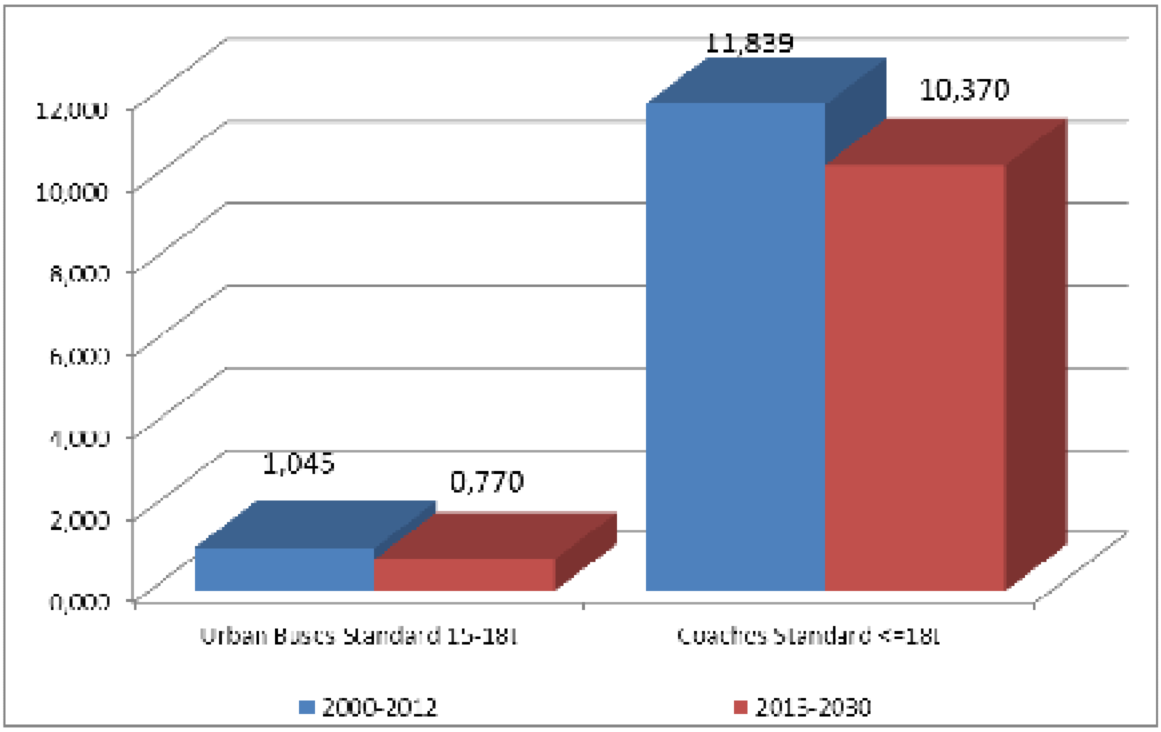
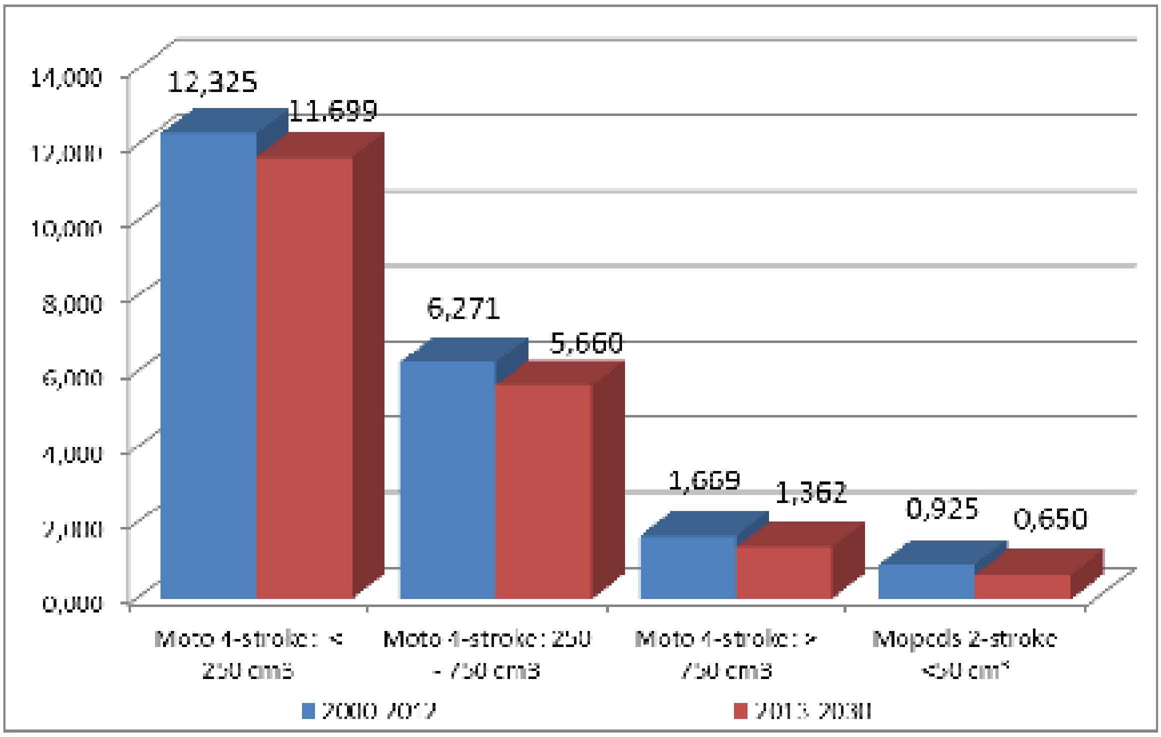


Figure 6.34: Greenhouse Gas emissions in Mt of CO2 equivalent emitted by Motorcycles and Mopeds



6.6 MAC curves for the road transport in Greece

In this section, we estimate the total cost related to each vehicle technology scenario first for the period 2000-2012 and then for the period 2013-2030. In period 2000-2012 the share of Euro 4 (or Euro IV) and Euro 5 (or Euro V) vehicles is relatively small in the fleet in circulation at the end of each year. On the other hand for the period 2013-2030 the penetration rate of the emerging new vehicle technologies is very high as this was shown in Section 5. Therefore the difference of the total cost between periods 2013-2030 and 2000-2012 is considered as abatement cost, since from Section 5, for the majority of vehicle technology scenarios we observed decreases in greenhouse gas emissions expressed in CO_2 equivalents.

For scenario i, the total cost at 2013 prices is given by

$$TC_i = C_i + FOM_i + VOM_i + F_i \qquad (6.10)$$

where C_i is the capital cost, FOM_i is the fixed operation and maintenance cost, VOM_i is the variable operation and maintenance cost and F_i is the fuel cost.

Denoting by P_k the average price of vehicle (including VAT and registration tax) which belongs to the k combination of fuel type/displacement-weight at 2013 prices, the capital cost of scenario i is calculated from

$$C_i = \sum_t \sum_k S_{i,k,t} \times P_k\,, \qquad (6.11)$$

where $S_{i,k,t}$ stands for vehicle sales of the k combination of fuel type/displacement-weight for year t according to scenario i. The indicator t takes values either from 2000 to 2012 or from 2013 to 2030. For the period 2000-2013, we take as vehicle sales for each year the numbers of new registrations as the latter ones are given by EL.STAT. For mopeds, the number of new registrations was taken from EMISSIA SA. For the period 2014-2030 and for each vehicle category, we assume that the percentage of erased/withdrawn vehicles to the total number of vehicles in circulation at the end of each year will be equal to the average percentage calculated from the data of Table 6.1. Then for each year between 2014 and 2030 and for each vehicle category, first we calculated the number of erased/withdrawn vehicles using the corresponding average percentage of erased/withdrawn vehicles. Then we estimated the number of sales by taking the sum of the number of erased/withdrawn vehicles and the difference in the number of vehicles in circulation between years $t+1$ and t. For each vehicle category, the sales were distributed across the different combinations of fuel type/displacement-weight proportionally according to the number of vehicles in each combination.

As fixed maintenance and operating costs we consider (a) the ownership tax, and (b) the vehicle insurance cost, and as variable operating and maintenance cost the average amount spent annually for vehicle service. Denoting by L_k, A_k, and M_k the annual average ownership tax, average insurance cost, and average service cost respectively for vehicles belonging to the k combination of fuel type/displacement-weight at 2013 prices, the total maintenance and operation cost is calculated from

$$FOM_i + VOM_i = \sum_t \sum_k N_{i,k,t} \times (L_k + A_k + M_k), \tag{6.12}$$

where $N_{i,k,t}$ is the number of cars in circulation belonging to the k combination fuel type/ displacement-weight at the end of year t according to scenario i. Finally if we denote by B_s the cost of fuel at 2013 prices (in kg per km) of the s fuel type (Gasoline, Diesel, LPG) and with $D_{i,s,t}$ the average total distance driven in year t by vehicles using fuel type s under scenario i, then the cost of fuel consumption is given by

$$F_i = \sum_t \sum_s B_s \times D_{i,s,t}\ . \tag{6.13}$$

Substituting (6.11)-(6.13) into (6.10), the total pollution cost of scenario i at 2013 prices is determined from

$$TC_i = \sum_t \sum_k S_{i,k,t} \times P_k + \sum_t \sum_k N_{i,k,t} \times (L_k + A_k + M_k) + \sum_t \sum_s B_s \times D_{i,s,t} \, . \qquad (6.14)$$

For the determination of P_k, L_k, A_k and M_k, we used the data of Emissia SA referring to 2009 prices. For the adjustment of the various costs at 2013 prices, we used from EL.STAT[97] appropriate price indices with base year 2009. Finally, taking the selling price of fuel from the Ministry of Development and Competitiveness for the period 04.01.2013 to 27.12.2013, averages were obtained over this period, which are displayed in Table 6.11 in euro per liter. But for the conversion of the fuel price from liters to kilograms the specific weight for each fuel type was needed. The specific weight was set equal to 0,725 for gasoline, 0.845 for diesel, and 0.545 for LPG. Multiplying these specific weights by the fuel price per liter we transformed the fuel prices to euro per kg, and these latter fuel prices were taken as values of B_s, presented also in Table 6.11. For all the scenarios, the values of P_k, L_k, A_k and M_k,are displayed in Table 6.13.

Substituting the values of Tables 6.12 and 6.13 into equation (6.10), we obtain the total cost related to each vehicle technology scenario first for the period 2000-2012, and then for the period 2013-2030. For each vehicle technology scenario, the total cost in billion € for each period is presented in figures 6.1 – 6.6. Observe that in all scenarios the total cost increases between period 2000-2012 and period 2013-2030. The only exception concerns the conventional gasoline heavy duty truck for which the total cost declines.

Combining the results of figures 6.29 – 6.34 and the results of figures 6.35 – 6.40, we present in Table 6.3 the marginal abatement costs at 2013 prices for all the scenarios for which between the periods 2000-2012 and 2013-2030 we observed reduction in the emissions and increase or decrease in the cost. We excluded the cases of Diesel, LPG and Hybrid passenger cars for which we found increases in both emissions and costs. From Table 6.3 we realize that only 4 out of the 26 scenarios have MAC below 1000 €, and also 4 out of the 26 scenarios MAC between 1000 and 2000 €. All the remaining scenarios are considered as less

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[97] http://www.statistics.gr/portal/page/portal/ESYE/PAGE-themes?p_param=A0515&r_param=DKT87&y_param=2013_12&mytabs=0

effective since their MAC exceeds 2000 €. Furthermore, Table 6.4 presents the marginal abatement costs for the general vehicle categories. Observe that the high penetration of new technologies in the fleet of rigid and articulated heavy duty trucks as well as in the fleet of motorcycles and mopeds (e.g. Euro IV, V for trucks and Euro II and III for motorcycles and Mopeds) constitutes a less effective policy since between 2000-2012 and 2013-2030 the marginal abatement cost exceeds 2500 € per ton CO_2 eq.

Table 6.12: Average fuel price (in €) for 2013

	Unleaded 95	**DIESEL**	**LPG**
€/lt	1,69	1,39	0,89
€/kg	1,2252	1,1746	0,4851

Table 6.13: ***Cost elements*** (in €) per vehicle at 2013 prices

Technology Scenario	**Average Price (including VAT and registration tax) (P_K)**	**Average ownership tax (L_K)**	**Average Insurance cost (A_K)**	**Average Service cost (M_K)**
Gasoline Passenger Cars, 0,8 - 1,4 l	12.152,98	209,87	509,52	358,58
Gasoline Passenger Cars, 1,4 - 2 l	23.229,97	439,55	724,63	505,49
Gasoline Passenger Cars, > 2 l	39.884,74	1.129,22	1.077,72	668,42
Diesel Passenger Cars, < 1,4	13.825,86	362,92	560,48	369,34
Diesel Passenger Cars, 1,4 - 2 l	25.032,60	546,02	797,09	520,66
Diesel Passenger Cars, > 2 l	42.015,69	1.129,22	1.185,49	688,47
LPG Passenger cars	26.867,61	499,17	828,15	526,81
Gasoline Hybrid cars	26.867,61	622,65	828,15	526,81
Light Commercial Vehicles Gasoline <3,5t	20.779,14	105,63	1.028,33	1.012,05
Light Commercial Vehicles Diesel <3,5t	21.569,63	105,63	1.049,32	1.032,70
Heavy Duty Trucks, Gasoline >3,5 t Conventional	27.499,24	295,29	1.248,95	1.921,70
Heavy Duty Trucks: Rigid <= 7,5 t	27.499,24	295,29	1.248,95	1.921,70
Heavy Duty Trucks: Rigid 7,5 - 12 t	35.459,26	590,59	1.421,55	2.133,09
Heavy Duty Trucks: Rigid 12 - 14 t	38.444,27	590,59	1.479,08	2.367,73
Heavy Duty Trucks: Rigid 14 - 20 t	50.384,31	590,59	1.824,29	2.628,18
Heavy Duty Trucks: Rigid 20 - 26 t	62.324,35	929,10	2.169,49	2.917,28
Heavy Duty Trucks: Rigid 26 - 28 t	70.284,38	929,10	2.399,63	3.238,18
Heavy Duty Trucks: Rigid 28 - 32 t	76.254,40	929,10	2.572,23	3.594,38
Heavy Duty Trucks: Rigid > 32 t	80.234,42	929,10	2.802,37	3.989,76
Heavy Duty Trucks: Articulated 14 - 20 t	32.395,34	885,88	1.824,29	2.628,18
Heavy Duty Trucks: Articulated 20 - 28 t	40.835,70	1.224,39	2.227,02	3.022,40
Heavy Duty Trucks: Articulated 28 - 34 t	51.687,59	1.604,91	2.629,76	3.475,76
Heavy Duty Trucks: Articulated 34 - 40 t	56.510,65	1.604,91	2.974,97	3.823,34
Heavy Duty Trucks: Articulated 40 - 50 t	66.156,78	1.774,16	3.435,24	4.205,67
Heavy Duty Trucks: Articulated 50 - 60 t	78.214,43	1.774,16	3.783,57	4.626,24
Urban Buses Standard 15 - 18 t	183.037,67	506,49	3.288,53	3.899,10
Coaches Standard <= 18 t	198.571,98	506,49	3.441,48	4.289,01
Motorcycles 4-stroke: < 250 cm^3	3.673,01	55,22	231,67	230,72
Motorcycles 4-stroke: 250 - 750 cm^3	3.673,01	55,22	231,67	230,72
Motorcycles 4-stroke: > 750 cm^3	3.673,01	55,22	231,67	230,72
Mopeds 2-stroke <50 cm^3	1.526,03	21.37	89.76	75.3

Following the above analysis, we are closing this report by presenting the MAC curves for the vehicle technology scenarios of table 6.3 and for the general vehicle categories of Table 6.4. The two MAC curves are illustrated in Figures 6.41 and 6.42.

Figure 6.35: Total cost (in billion €) related to passenger car scenarios

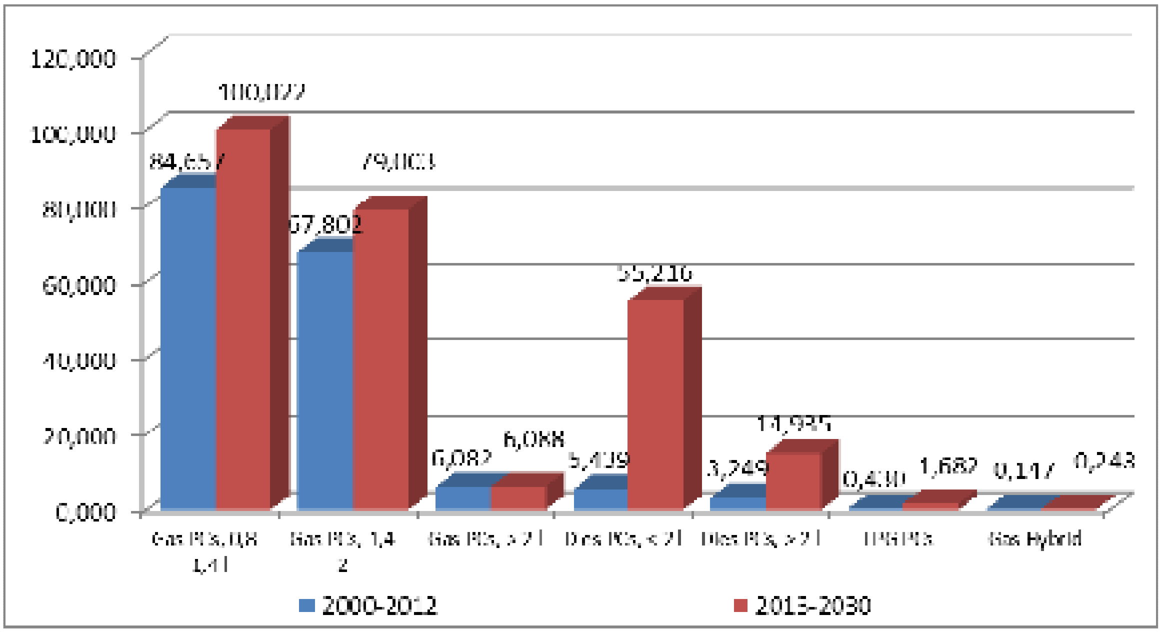


Figure 6.36: Total cost (in billion €) related to scenarios which are referred to Light Commercial Vehicles and Gasoline Heavy Duty Trucks >3,5 t conventional

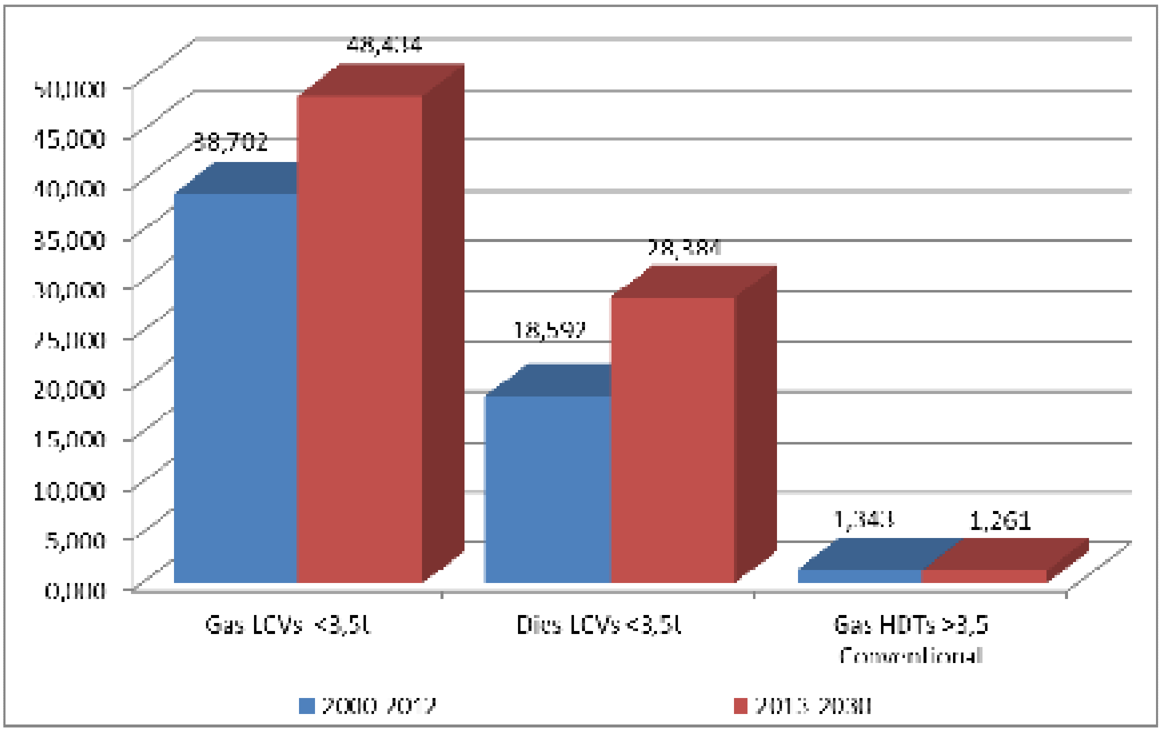


Figure 6.37: Total cost (in billion €) related to scenarios which are referred to Rigid Heavy Duty Trucks

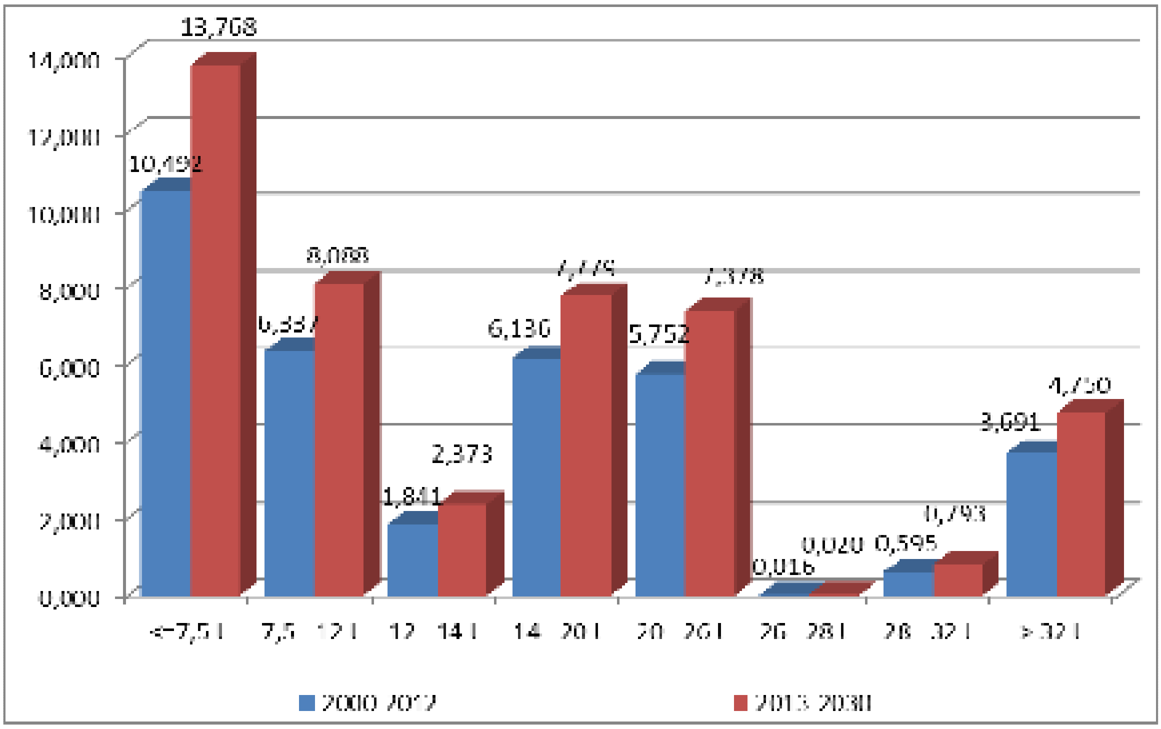


Figure 6.38: Total cost (in billion €) related to scenarios which are referred to Articulated Heavy Duty Trucks

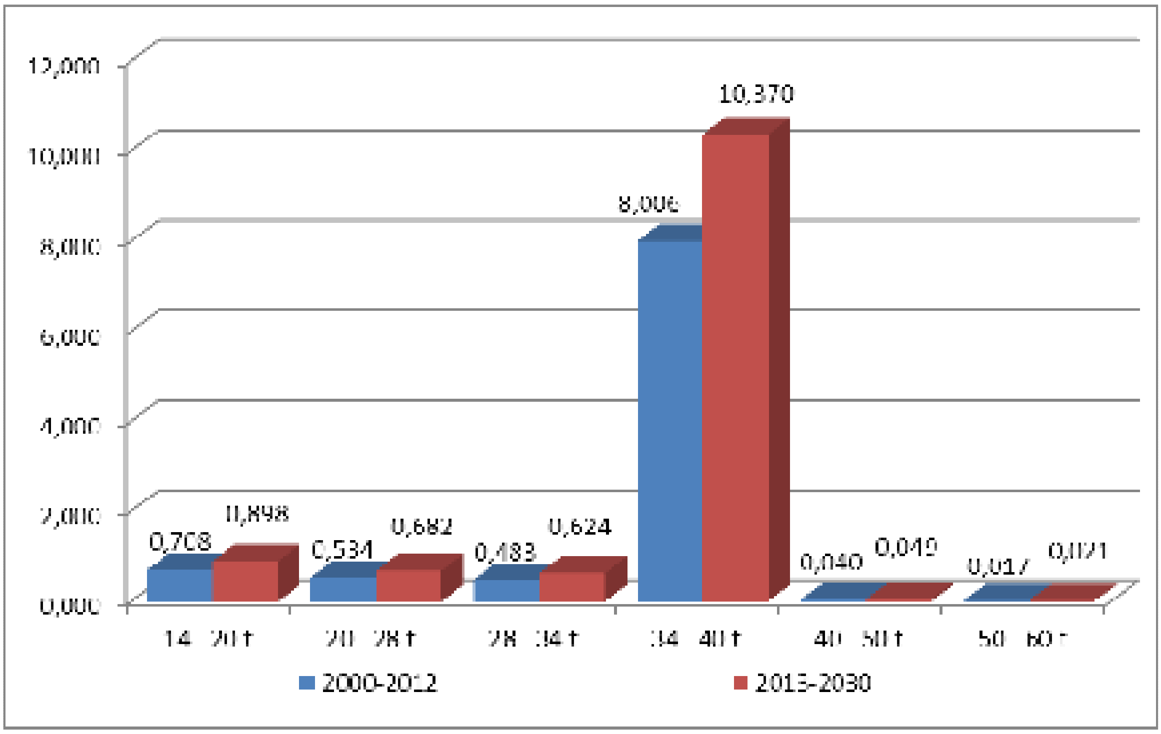


Figure 6.39: Total cost (in billion €) related to scenarios which are referred to Buses and Coaches

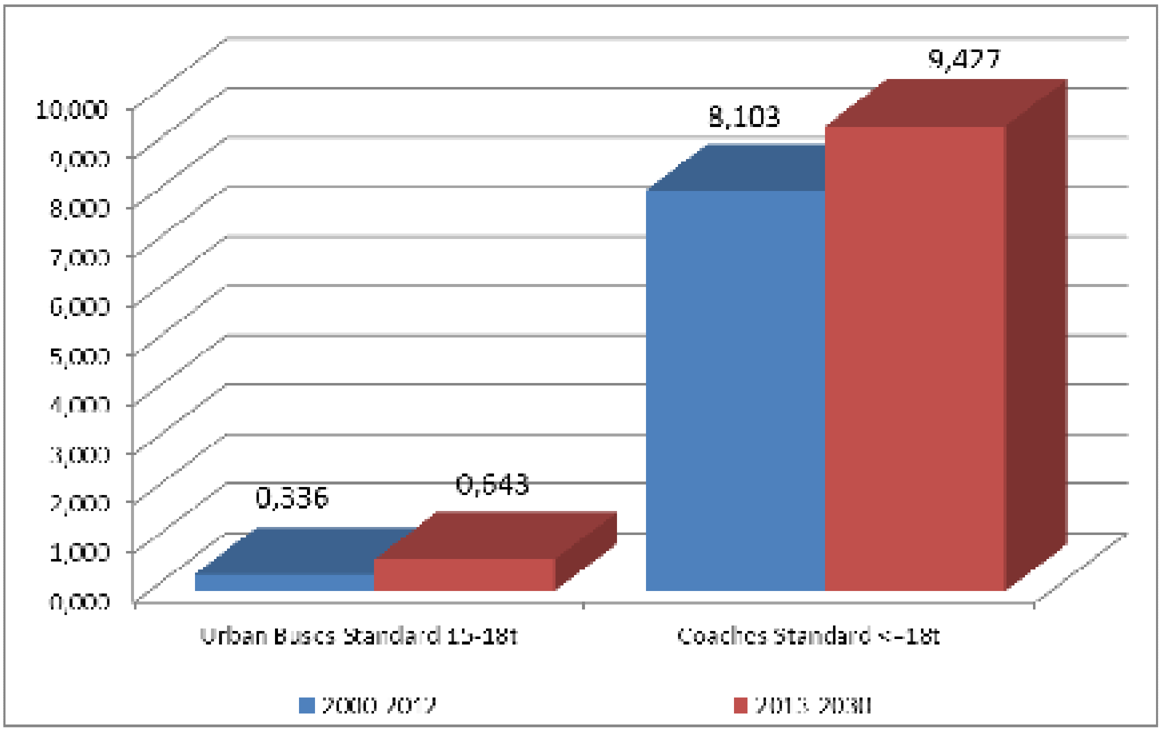


Figure 6.40: Total cost (in billion €) related to scenarios which are referred to Motorcycles and Mopeds

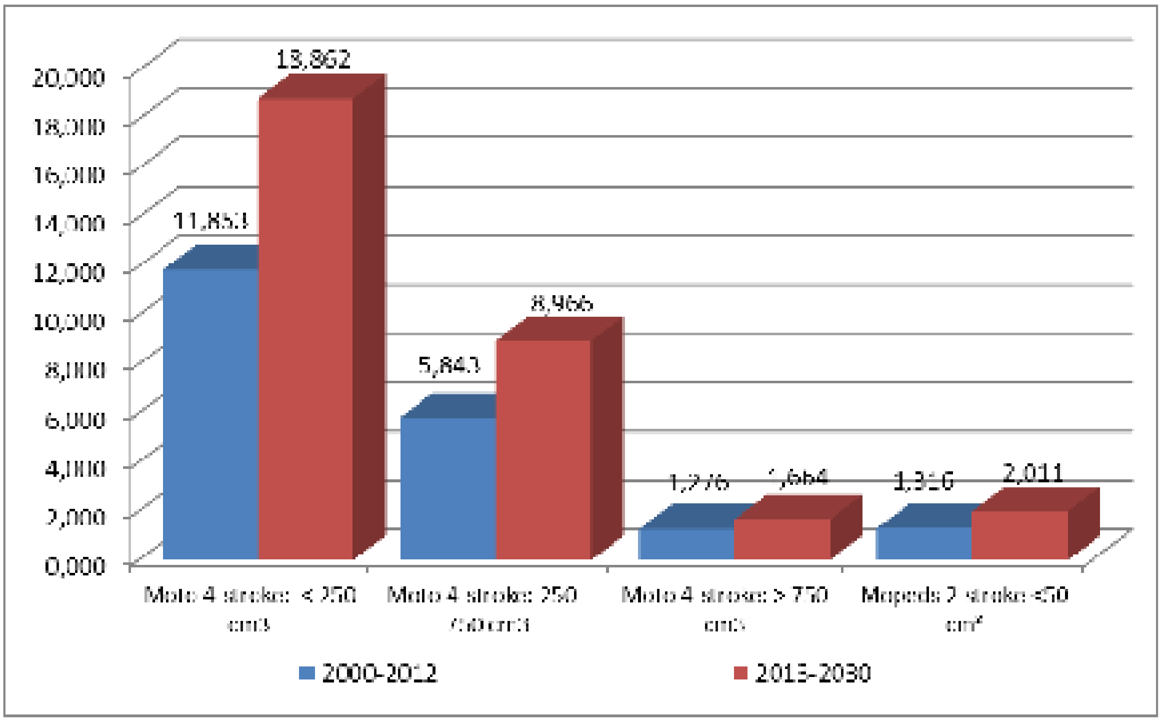


Table 6.14: Marginal abatement cost (MAC) for various scenarios

Vehicle Technology Scenarios	Between periods 2000-2012 and 2013-2030		
	Greenhouse gas emissions reduction in CO2 eq. (in tons)	Cost increase (in €)	MAC in € per ton CO2 eq.
Heavy Duty Trucks, Gasoline >3,5 Conventional	918.136,086	-81.945.750,08	-89,25
Gasoline Passenger Cars, > 2 l	562.719,584	5.903.027,78	10,49
Light Commercial Vehicles Gasoline <3,5t	13.218.817,249	9.732.953.189,86	736,30
Coaches Standard <= 18t	1.468.728,881	1.324.560.758,51	901,84
Urban Buses, Standrad 15 - 18 t	274.587,382	307.019.582,20	1.118,11
Gasoline Passenger Cars, 0,8 - 1,4 l	13.735.695,590	15.364.813.592,79	1.118,60
Motorcycles 4-stroke: > 750 cm^3	307.100,217	388.225.605,05	1.264,17
Gasoline Passenger Cars, 1,4 - 2 l	8.113.300,208	11.200.695.584,14	1.380,54
Heavy Duty Trucks: Articulated 40 - 50 t	4.123,261	9.280.866,64	2.250,86
Heavy Duty Trucks: Articulated 50 - 60 t	1.776,583	4.085.463,72	2.299,62
Mopeds 2-stroke <50 cm^3	275.070,218	695.000.277,31	2.526,63
Heavy Duty Trucks: Rigid 26 - 28 t	1.630,499	4.411.352,09	2.705,52
Heavy Duty Trucks: Rigid 14 - 20 t	513.258,405	1.643.271.008,33	3.201,64
Heavy Duty Trucks: Rigid 7,5 - 12 t	505.538,895	1.751.442.432,94	3.464,51
Heavy Duty Trucks: Rigid 20 - 26 t	463.439,818	1.625.862.182,96	3.508,25
Heavy Duty Trucks: Articulated 20 - 28 t	41.073,822	147.759.748,87	3.597,42
Heavy Duty Trucks: Rigid <= 7,5 t	905.400,557	3.275.368.149,68	3.617,59
Heavy Duty Trucks: Rigid > 32 t	282.657,403	1.059.412.643,44	3.748,04
Heavy Duty Trucks: Articulated 14 - 20 t	50.417,671	190.042.806,97	3.769,37
Heavy Duty Trucks: Rigid 12 - 14 t	139.843,178	531.975.322,51	3.804,08
Heavy Duty Trucks: Articulated 28 - 34 t	33.965,270	140.995.501,08	4.151,17
Heavy Duty Trucks: Articulated 34 - 40 t	531.775,086	2.363.848.118,52	4.445,20
Motorcycles 4-stroke: 250 - 750 cm^3	611.339,146	3.122.744.966,98	5.108,04
Heavy Duty Trucks: Rigid 28 - 32 t	38.091,003	197.249.507,67	5.178,38
Motorcycles 4-stroke: < 250 cm^3	626.156,496	7.008.977.889,28	11.193,65

Table 6.15: Marginal abatement costs for the general categories of vehicles

Vehicle Technology Scenarios	Between periods 2000-2012 and 2013-2030		
	Greenhouse gas emissions reduction in CO2 eq. (in tons)	Cost increase (in €)	MAC in € per ton CO2 eq.
Heavy Duty Trucks, Gasoline >3,5 Conventional	918.136,086	-81.945.750,08	-89,25
Light Commercial Vehicles Gasoline <3,5t	13.218.817,249	9.732.953.189,86	736,30
Coaches Standard <= 18t	1.468.728,881	1.324.560.758,51	901,84
Urban Buses, Standrad 15 - 18 t	274.587,382	307.019.582,20	1.118,11
Gasoline Passenger cars	22.411.715,381	26.571.412.204,70	1.185,60
Mopeds 2-stroke <50 cm^3	275.070,218	695.000.277,31	2.526,63
Heavy Duty Trucks, Rigid	2.849.859,758	10.088.992.599,63	3.540,17
Heavy Duty Trucks, Articulated	663.131,694	2.856.012.505,80	4.306,86
Motorcycles 4-stroke	1.544.595,860	10.519.948.461,31	6.810,81

Figure 6.41: MAC curve at 2013 prices for general vehicle categories

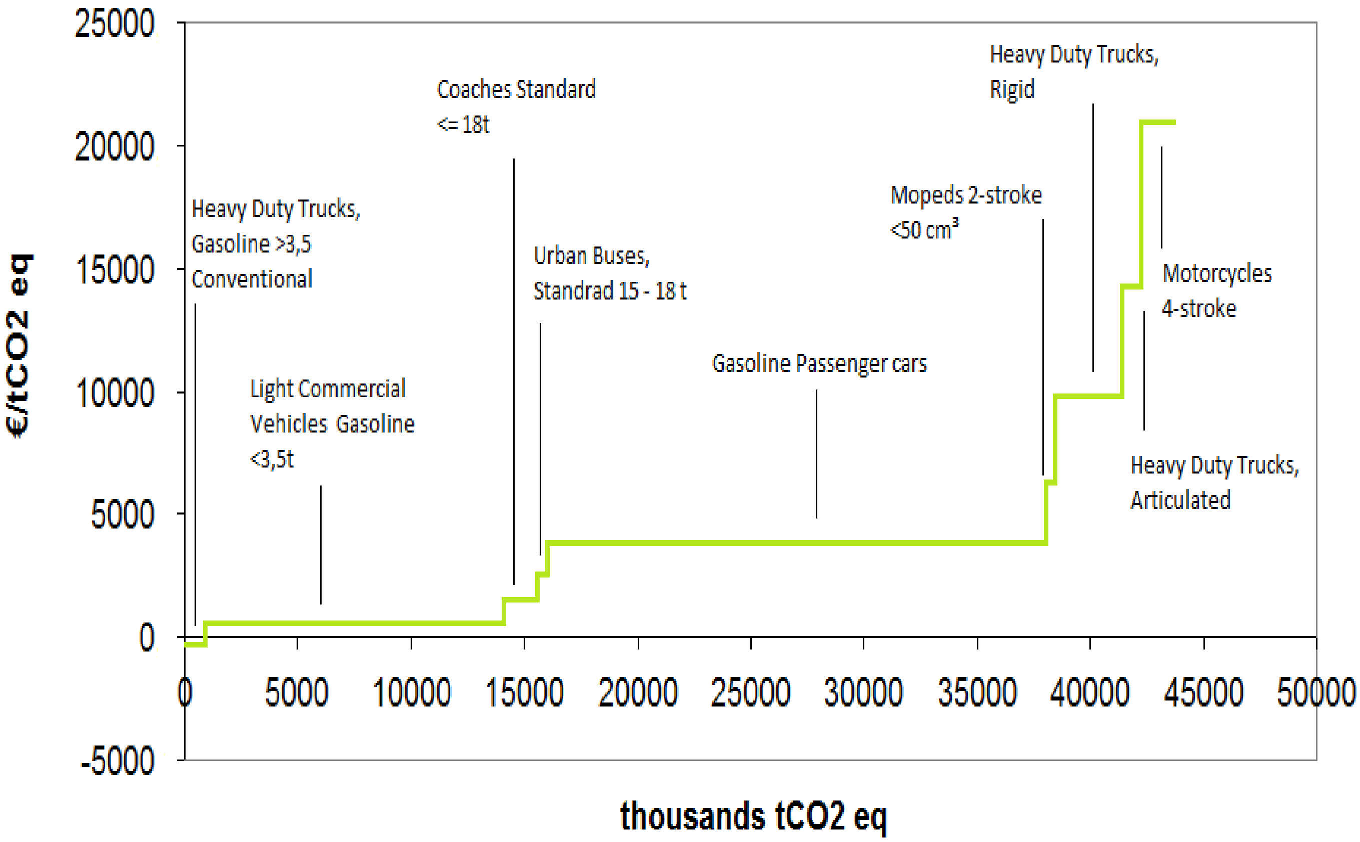
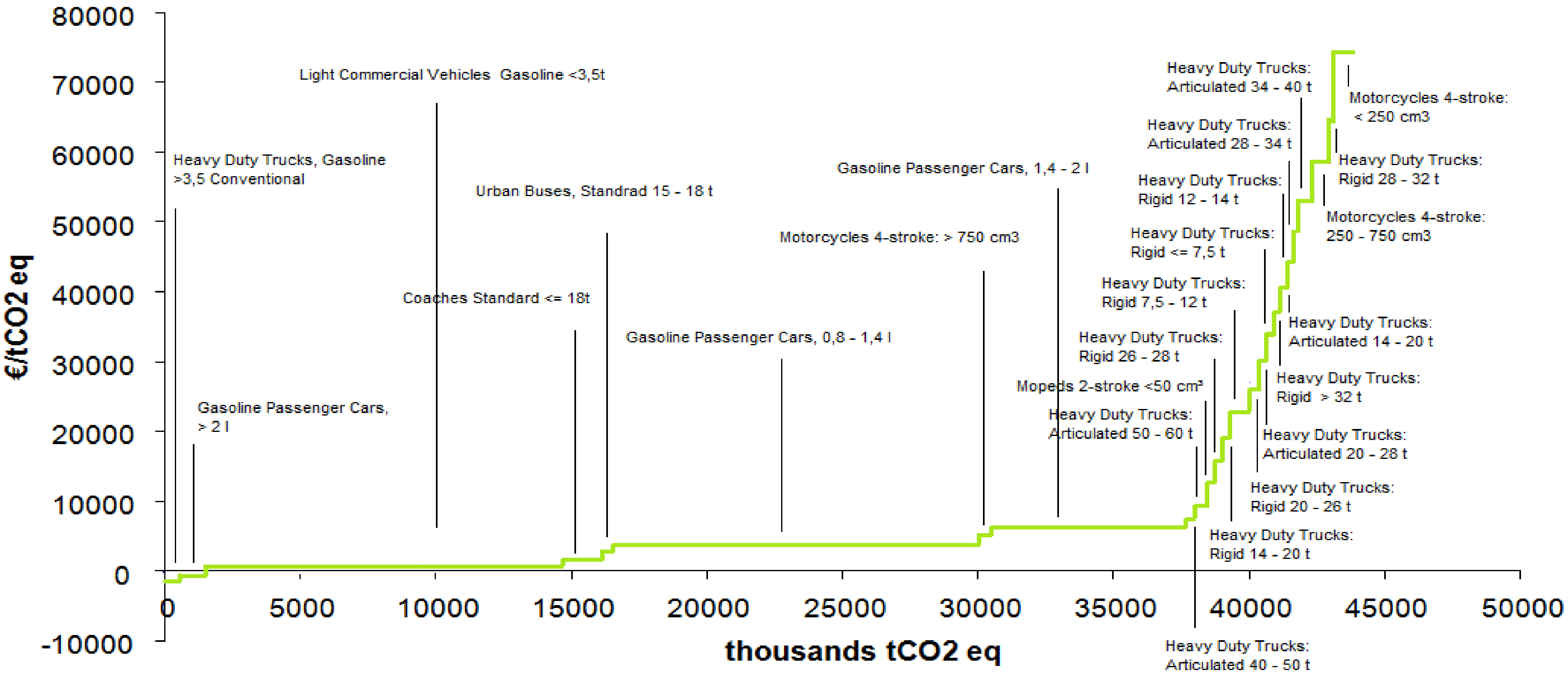


Figure 6.42: MAC curve at 2013 prices for vehicle technology scenarios

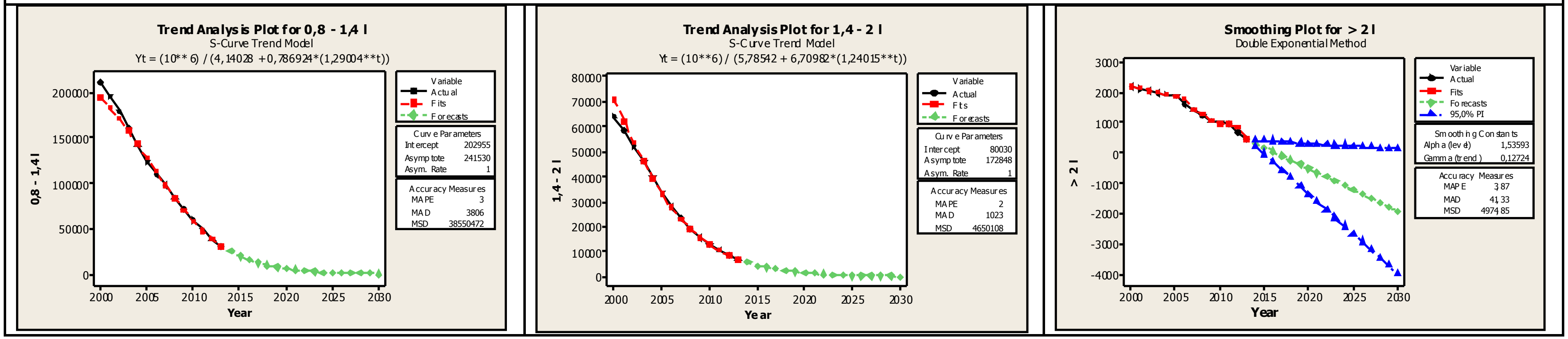


APPENDIX A

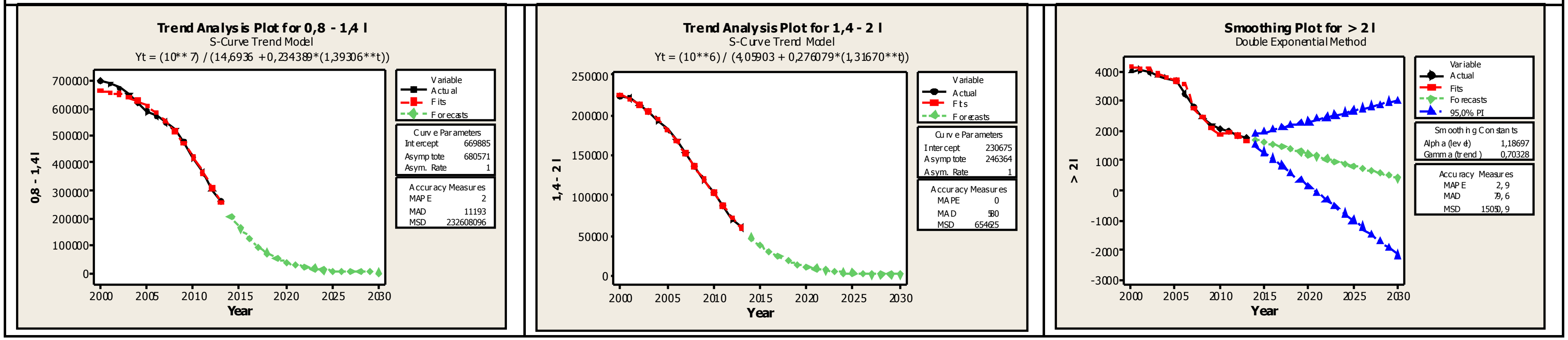
Graphs of Actual and Predicted values for the Number of Vehicles

A1. PASSENGER CARS

Gasoline ECE 15/03

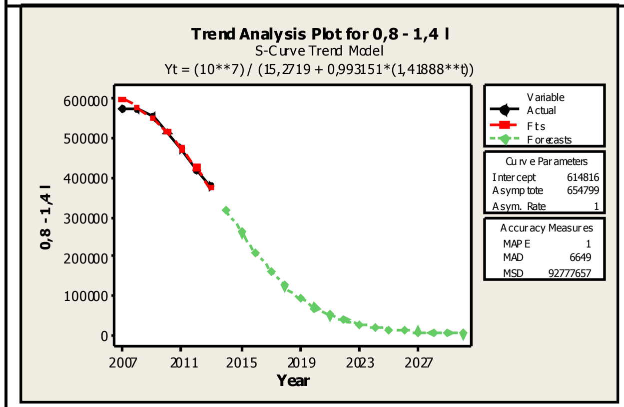


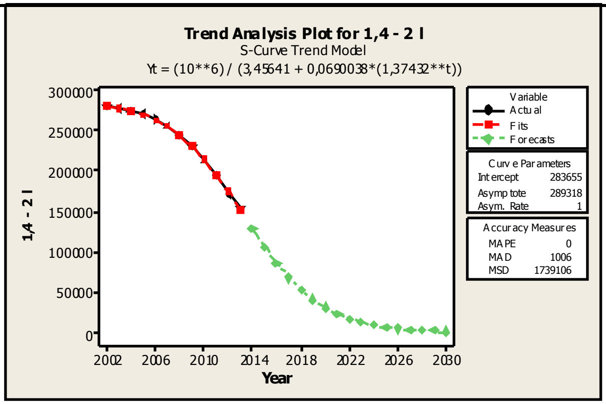
Gasoline ECE 15/04

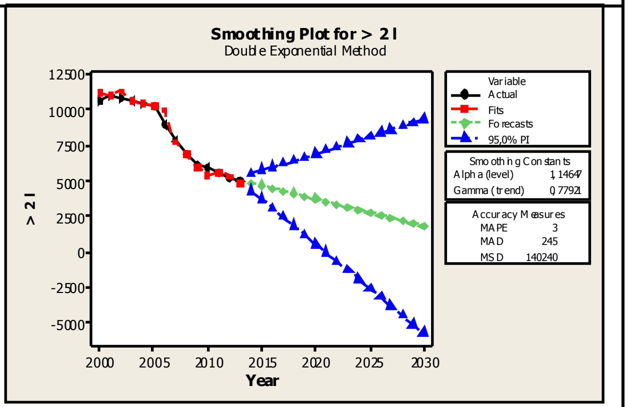


A1. PASSENGER CARS

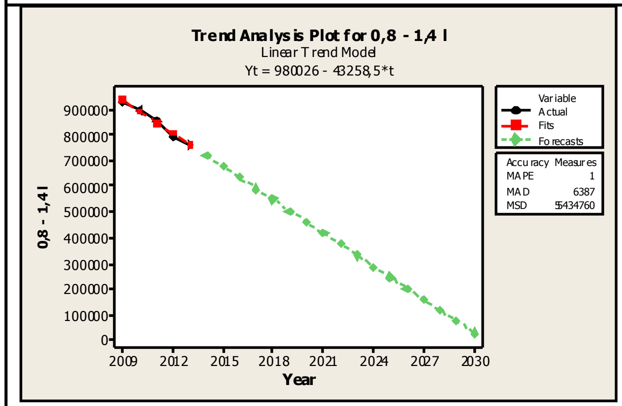
Gasoline Euro 1 - 91/441/EEC

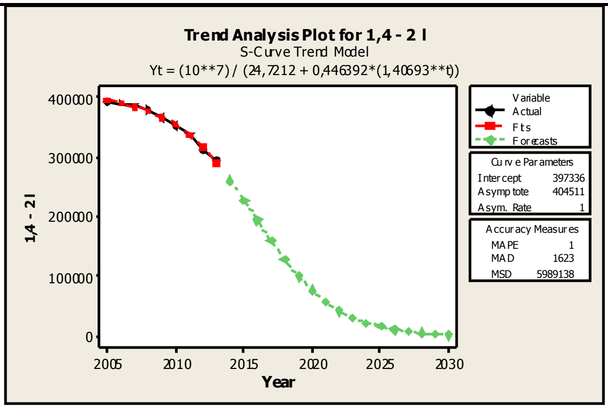


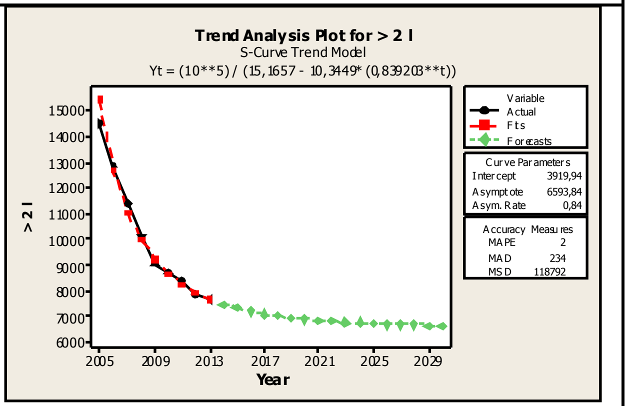




Gasoline Euro 2 - 94/12/EEC

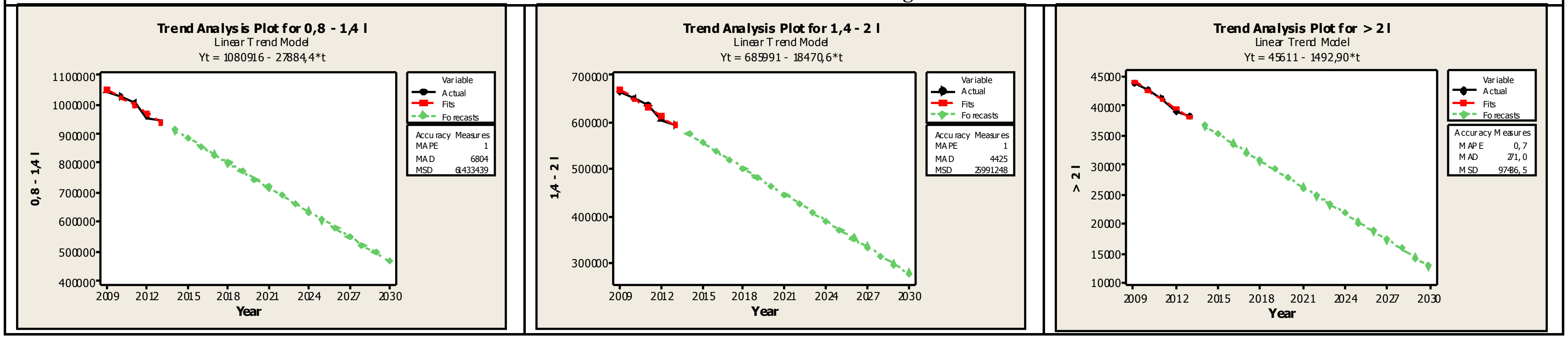




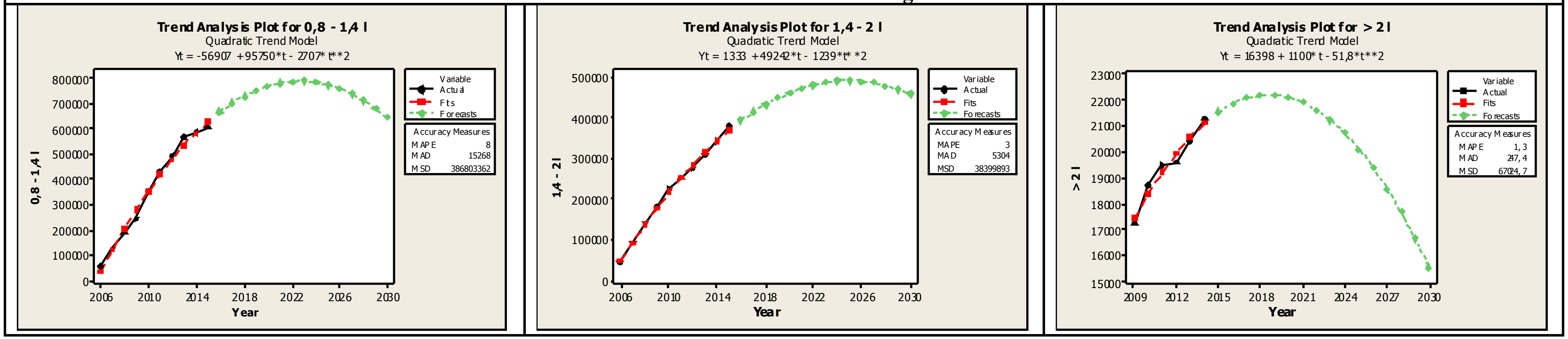


A1. PASSENGER CARS

Gasoline Euro 3 - 98/69/EC Stage2000

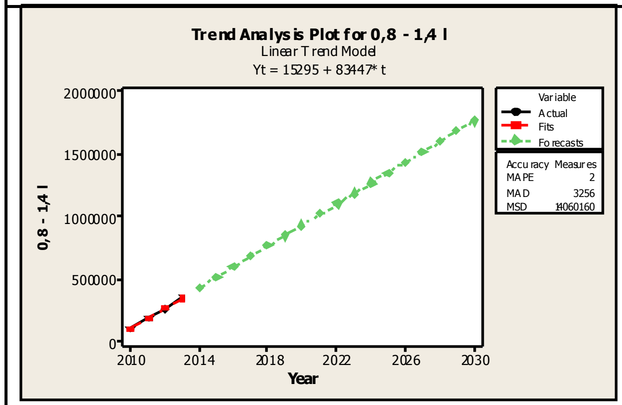


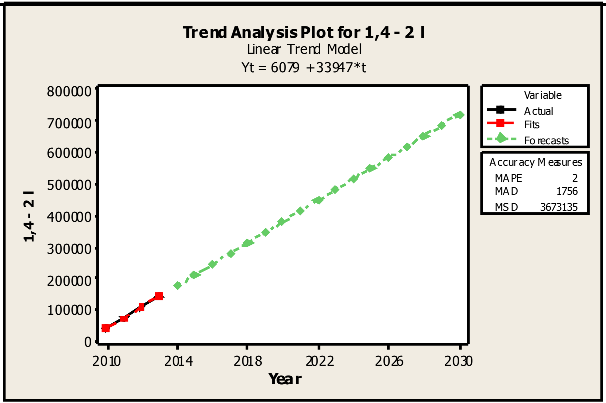
Gasoline Euro 4 - 98/69/EC Stage2005

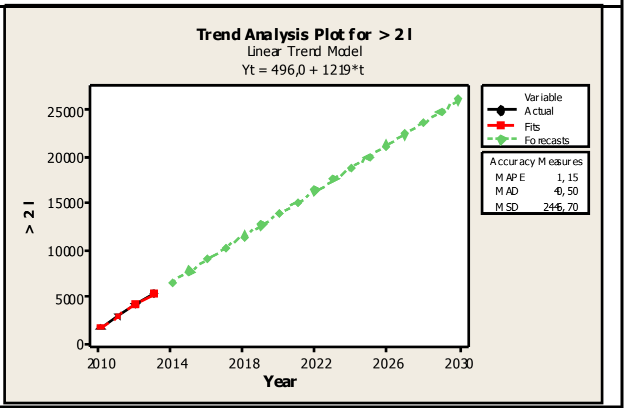


A1. PASSENGER CARS

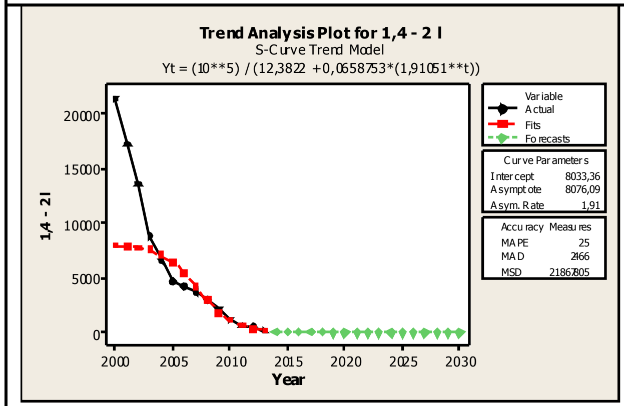
Gasoline PC Euro 5,6 - EC 715/2007



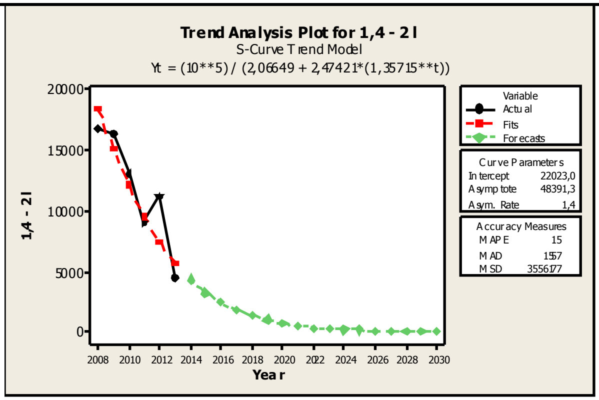


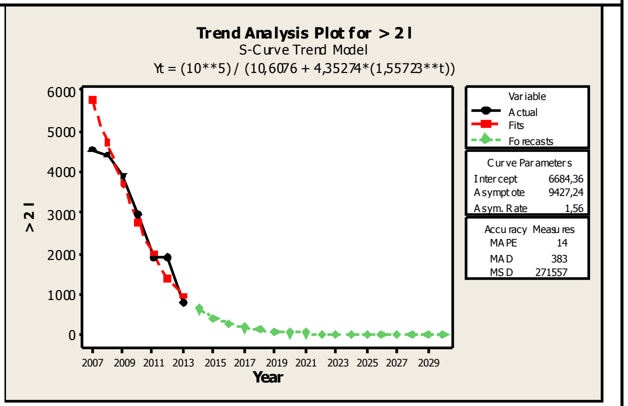


Diesel Conventional



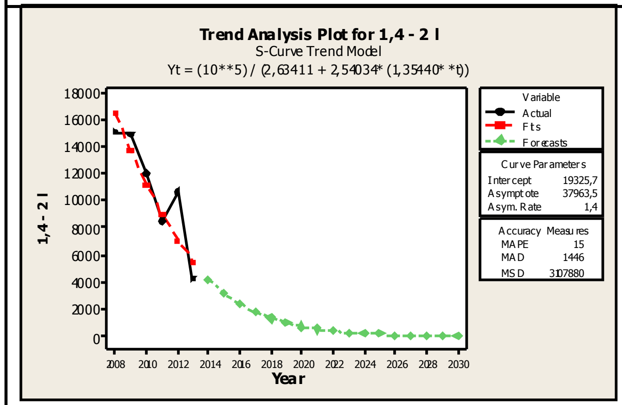
Diesel Euro 1 - 91/441/EEC

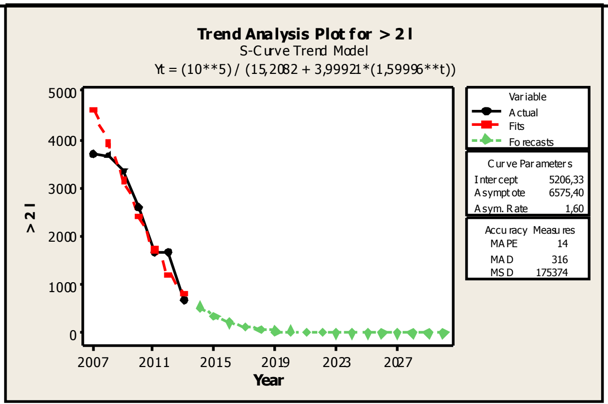




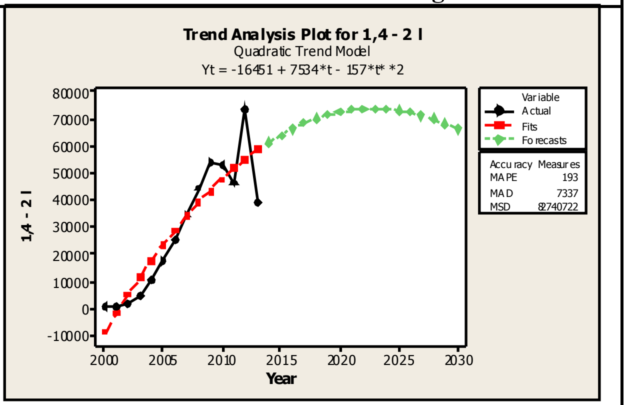
A1. PASSENGER CARS

Diesel Euro 2 - 94/12/EEC

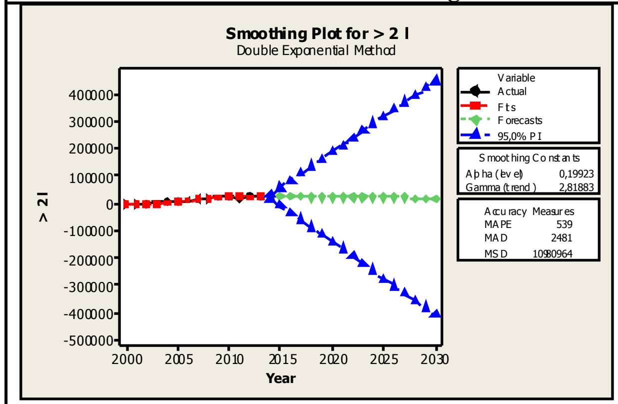




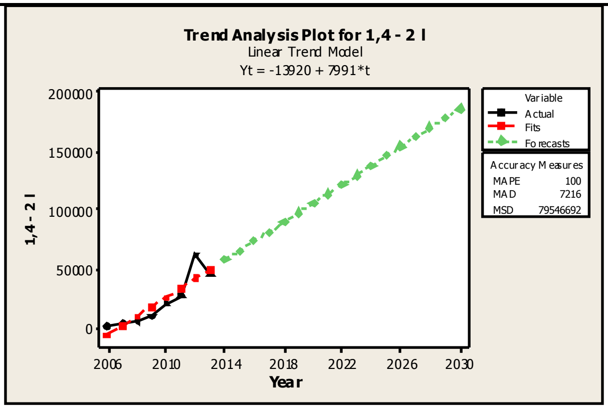
Diesel Euro 3 - 98/69/EC Stage2000

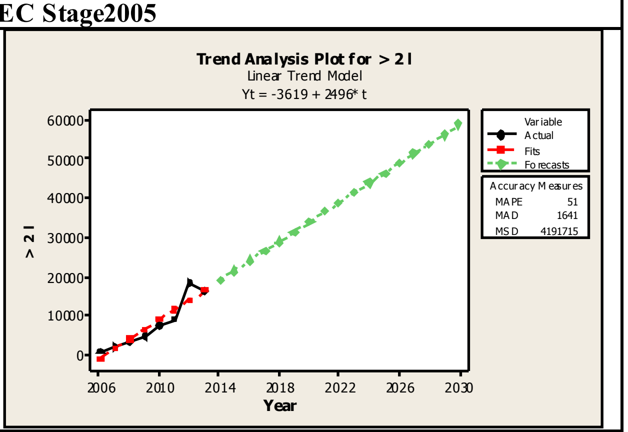


Diesel Euro 3 - 98/69/EC Stage2000



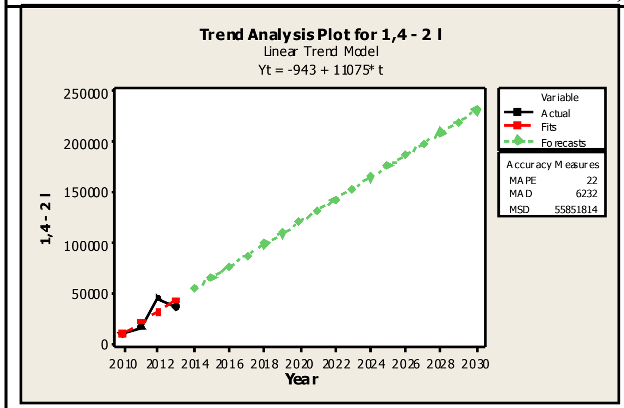
Euro 4 - 98/69/EC Stage2005

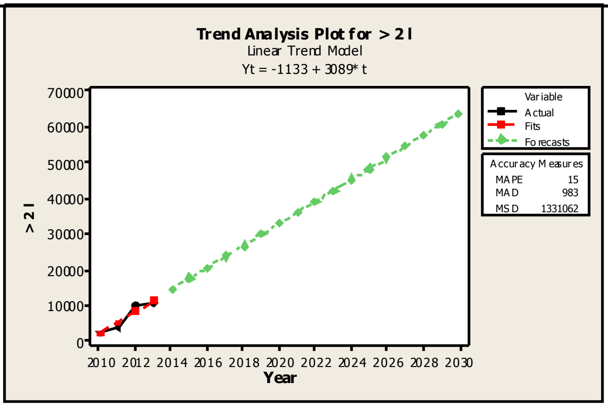




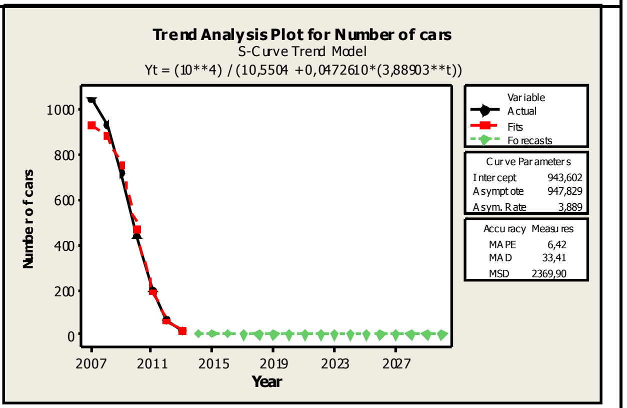
A1. PASSENGER CARS

Diesel Euro 5, 6 - EC 715/2007

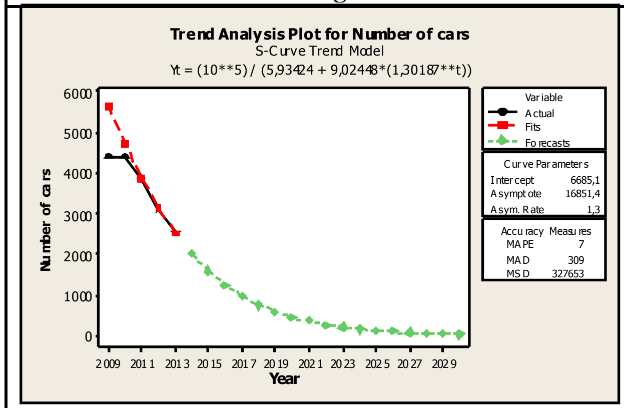




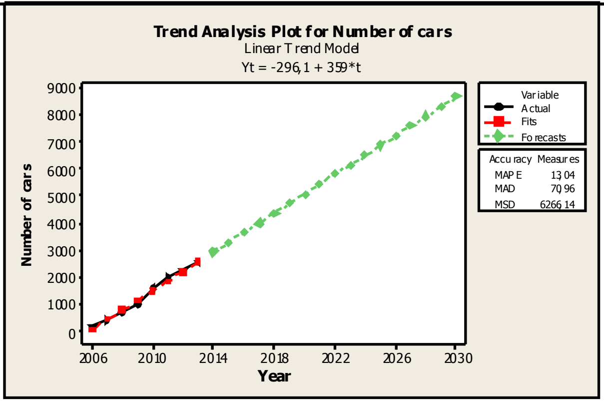
LPG Euro 2 - 94/12/EEC



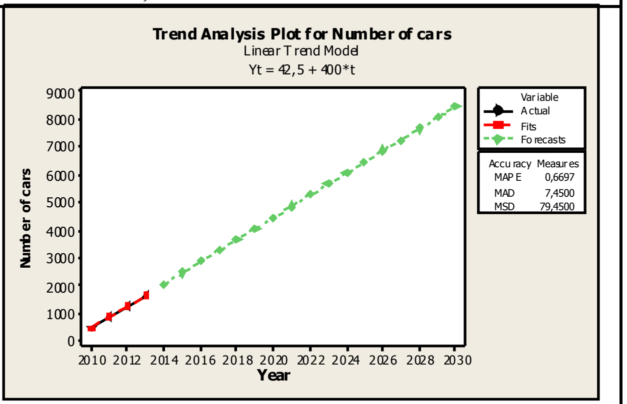
LPG Euro 3 - 98/69/EC Stage2000



LPG Euro 4 - 98/69/EC Stage2005

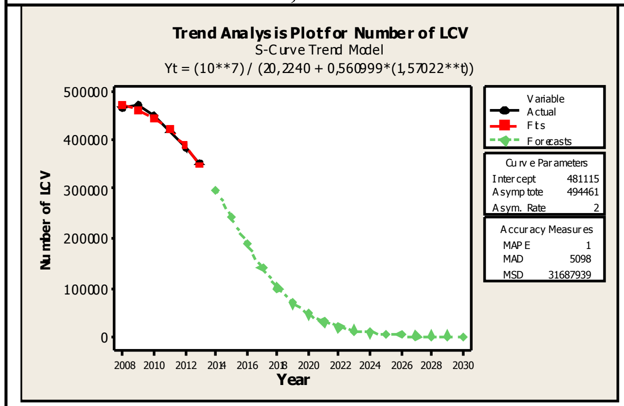


LPG Euro 5,6 - EC 715/2007

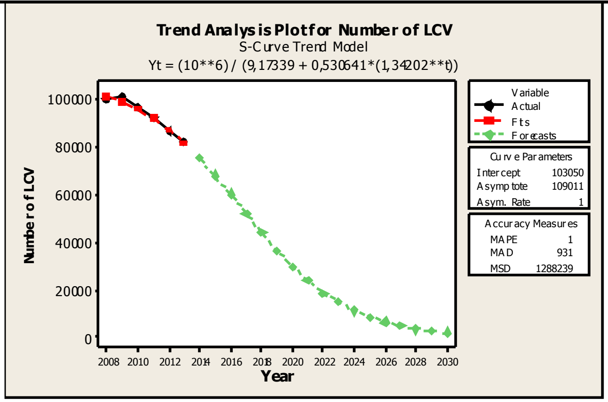


A2. LIGHT COMMERCIAL VEHICLES

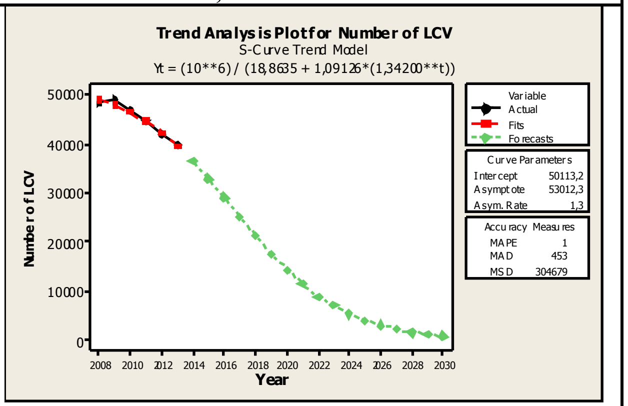
Gasoline <3,5t: Conventional



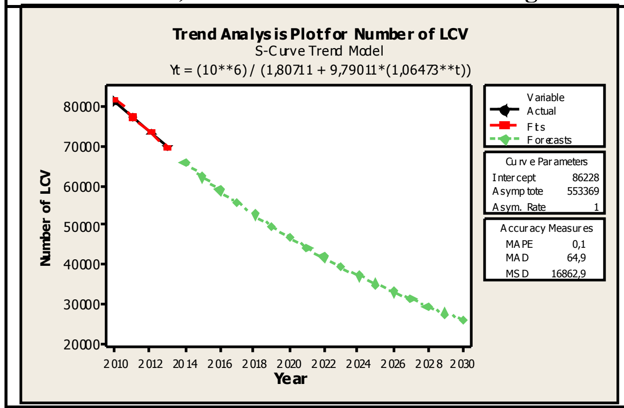
Gasoline <3,5t: LD Euro 1 - 93/59/EEC



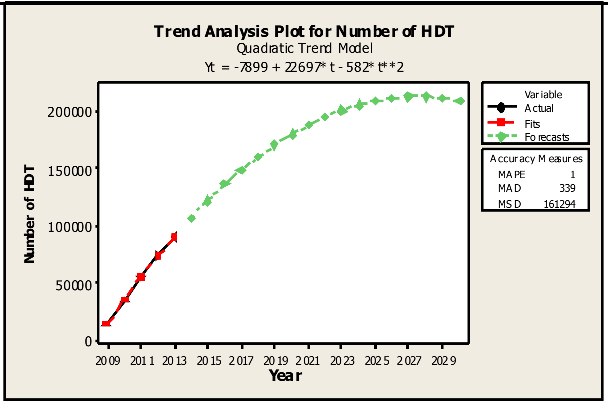
Gasoline <3,5t: LD Euro 2 - 96/69/EEC



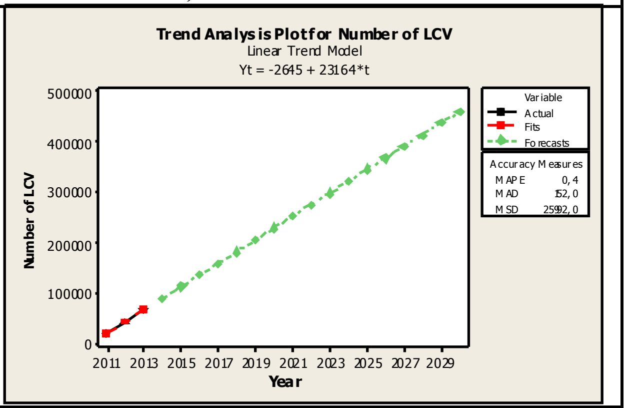
Gasoline <3,5t: LD Euro 3 - 98/69/EC Stage2000



Gasoline <3,5t: LD Euro 4 - 98/69/EC Stage2005

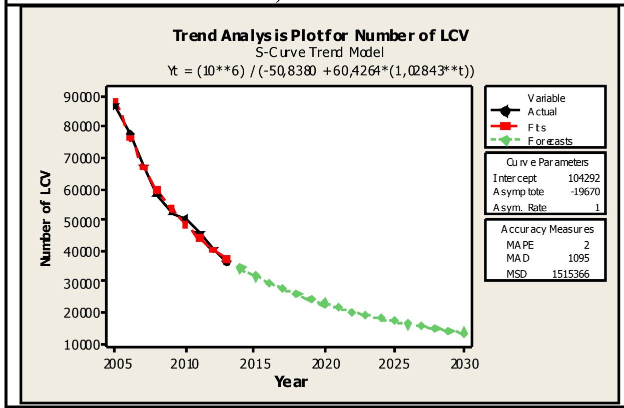


Gasoline <3,5t: LD Euro 5 - 2008 Standards

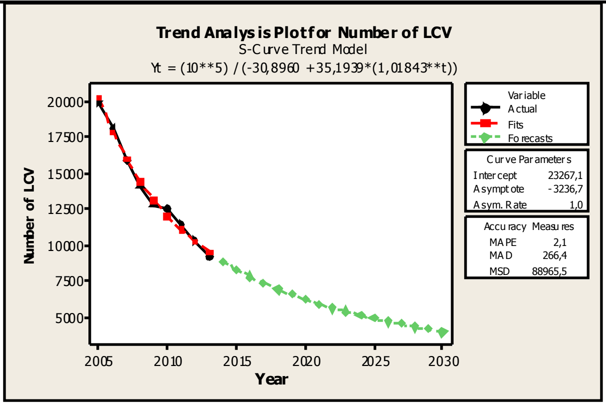


A2. LIGHT COMMERCIAL VEHICLES

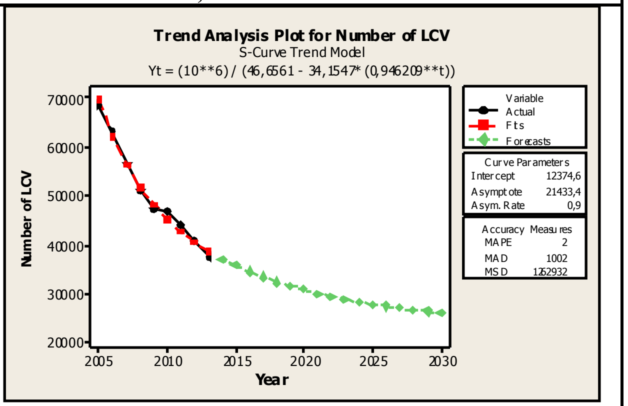
Diesel <3,5t: Conventional



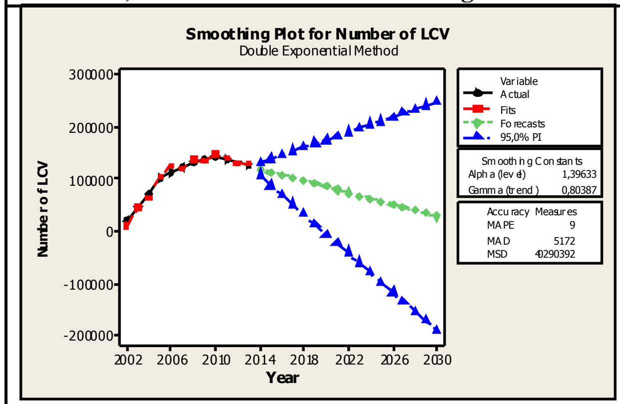
Diesel <3,5t: LD Euro 1 - 93/59/EEC



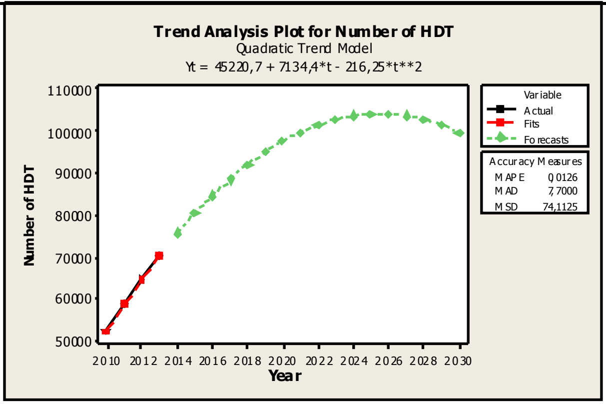
Diesel <3,5t: LD Euro 2 - 96/69/EEC



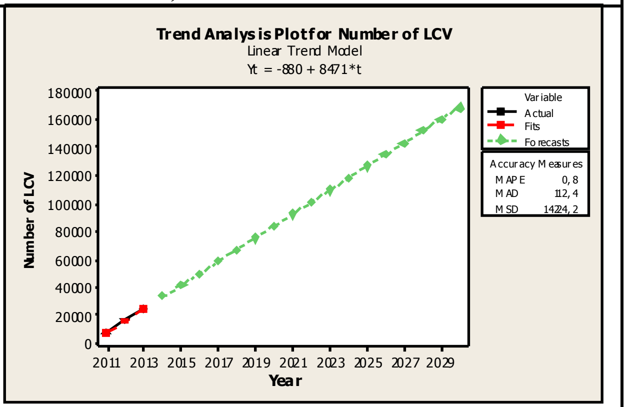
Diesel <3,5t: LD Euro 3 - 98/69/EC Stage2000



Diesel <3,5t: LD Euro 4 - 98/69/EC Stage2005

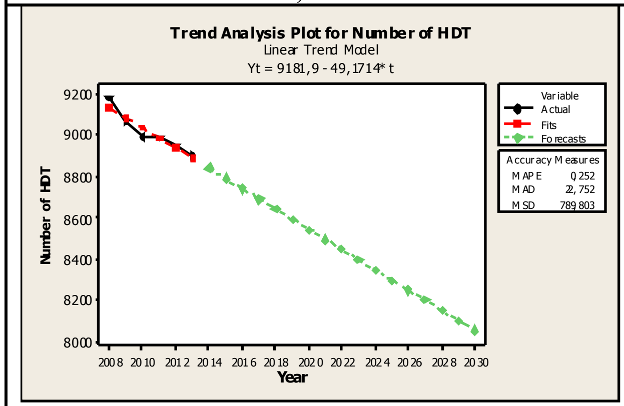


Diesel <3,5t: LD Euro 5 - 2008 Standards

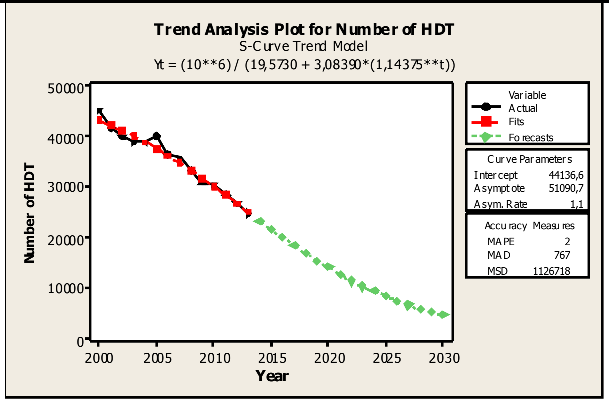


A3. HEAVY DUTY TRUCKS

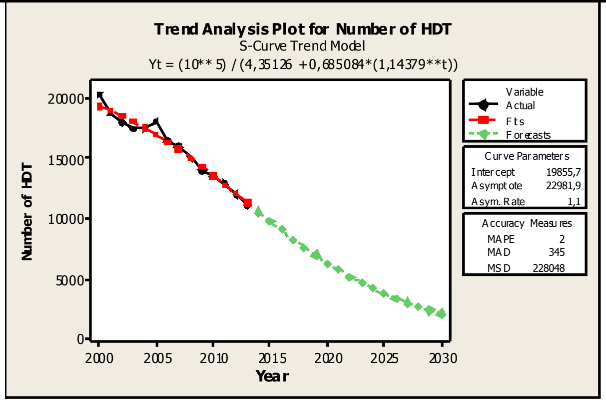
Gasoline > 3,5t: Conventional



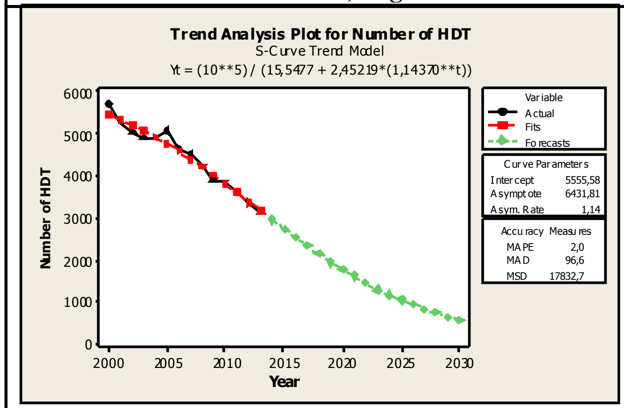
Diesel Conventional, Rigid <=7,5 t



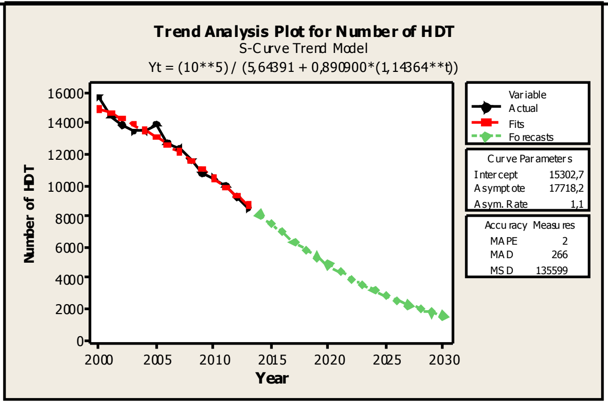
Diesel Conventional, Rigid 7,5 - 12 t



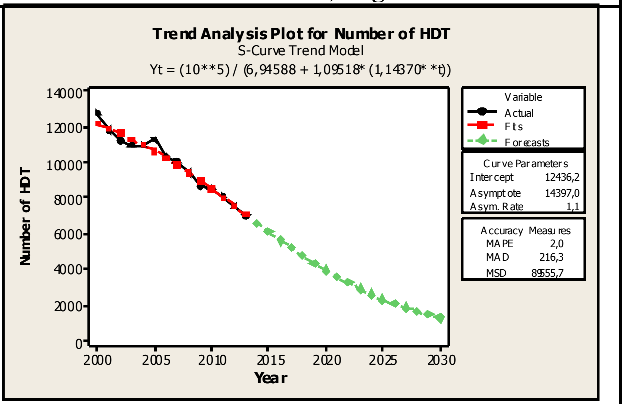
Diesel Conventional, Rigid 12 - 14 t



Diesel Conventional, Rigid 14 - 20 t

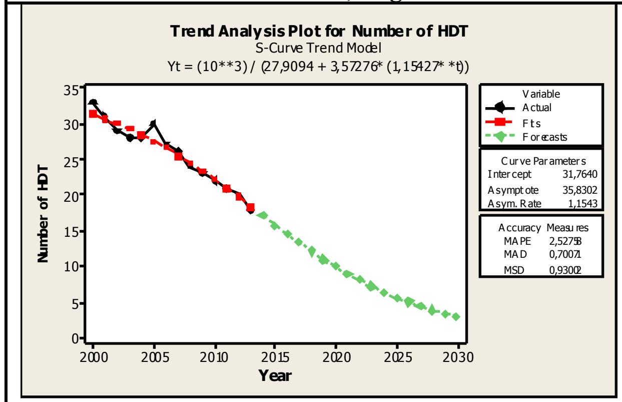


Diesel Conventional, Rigid 20 - 26 t

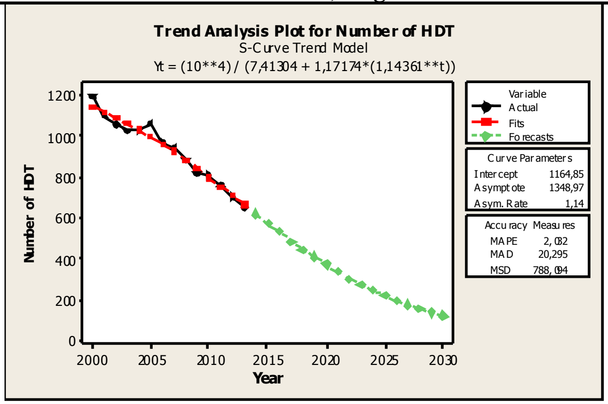


A3. HEAVY DUTY TRUCKS

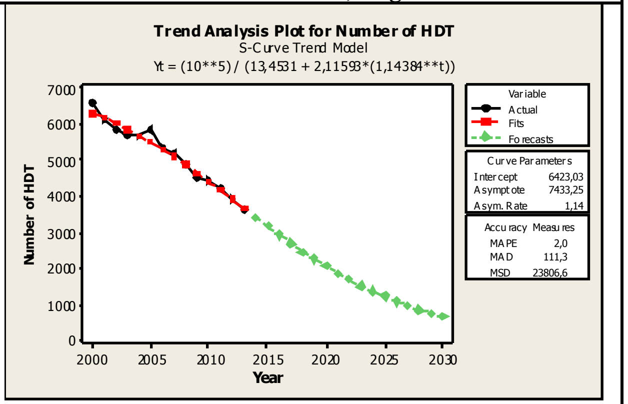
Diesel Conventional, Rigid 26 - 28 t



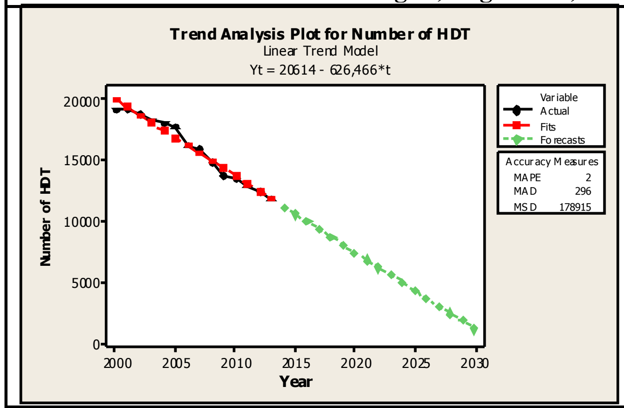
Diesel Conventional, Rigid 28 - 32 t



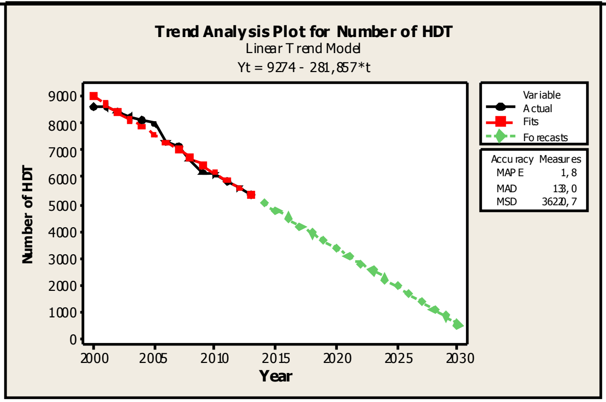
Diesel Conventional, Rigid >32 t



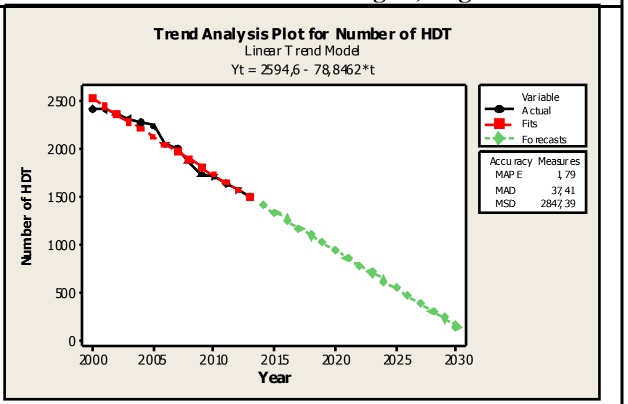
Diesel Euro I - 91/542/EEC Stage I, Rigid <=7,5 t



Diesel Euro I - 91/542/EEC Stage I, Rigid 7,5 - 12 t

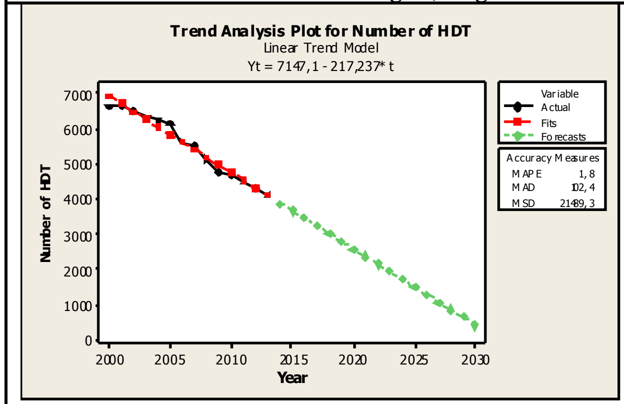


Diesel Euro I - 91/542/EEC Stage I, Rigid 12 - 14 t

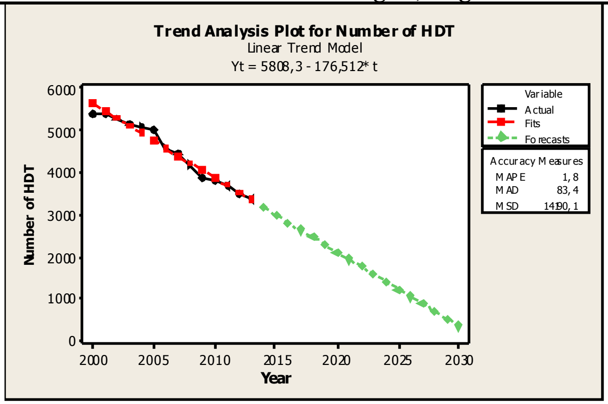


A3. HEAVY DUTY TRUCKS

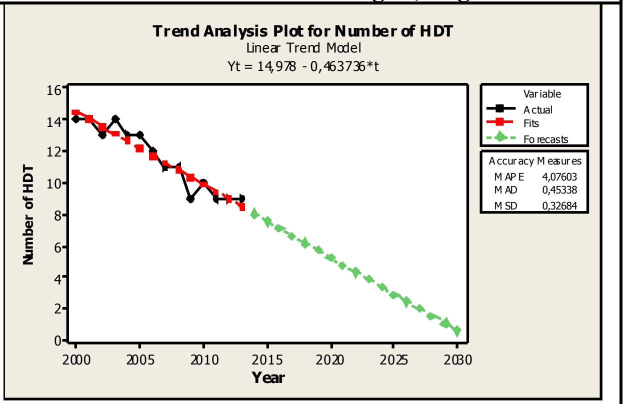
Diesel Euro I - 91/542/EEC Stage I, Rigid 14 - 20 t



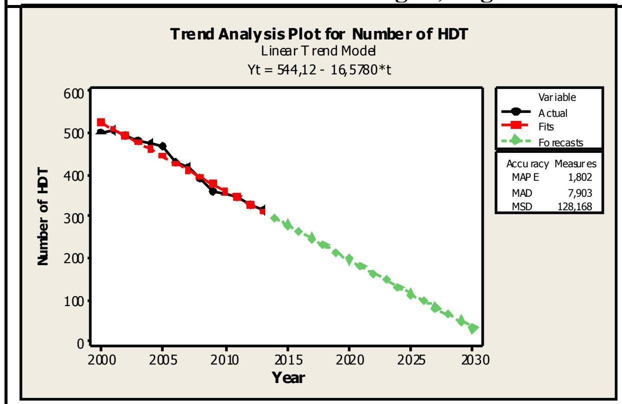
Diesel Euro I - 91/542/EEC Stage I, Rigid 20 - 26 t



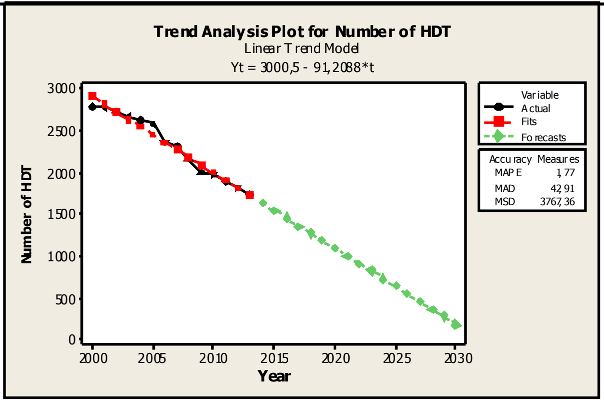
Diesel Euro I - 91/542/EEC Stage I, Rigid 26 - 28 t



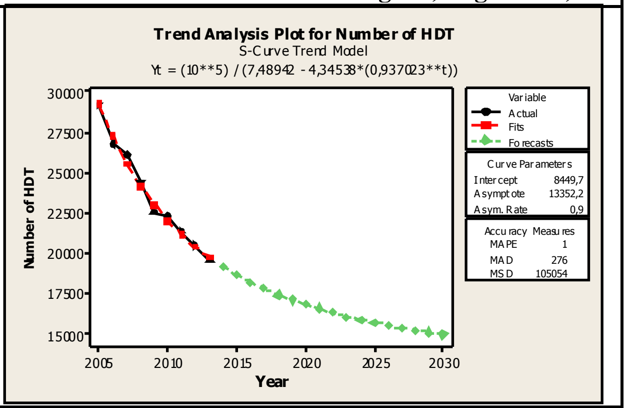
Diesel Euro I - 91/542/EEC Stage I, Rigid 28 - 32 t



Diesel HD Euro I - 91/542/EEC Stage I, Rigid >32 t

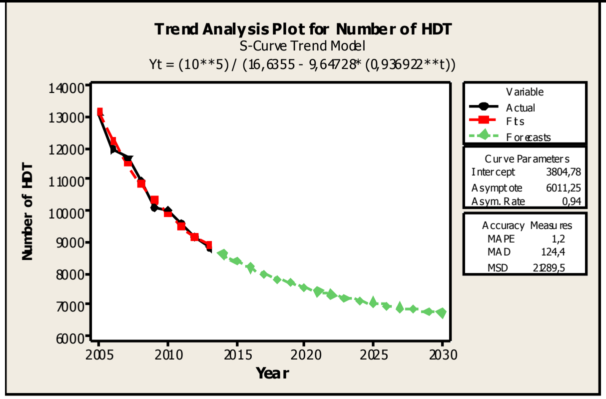


Diesel Euro II - 91/542/EEC Stage II, Rigid <=7,5 t

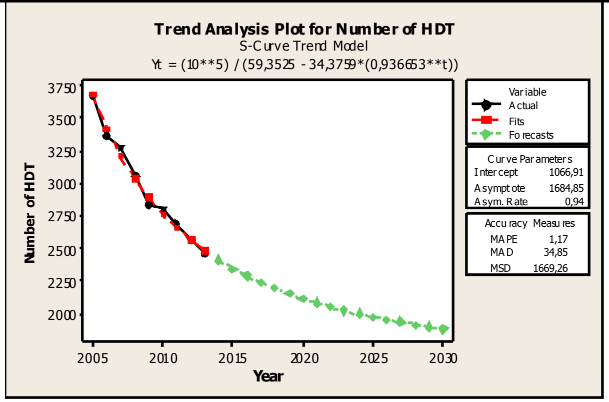


A3. HEAVY DUTY TRUCKS

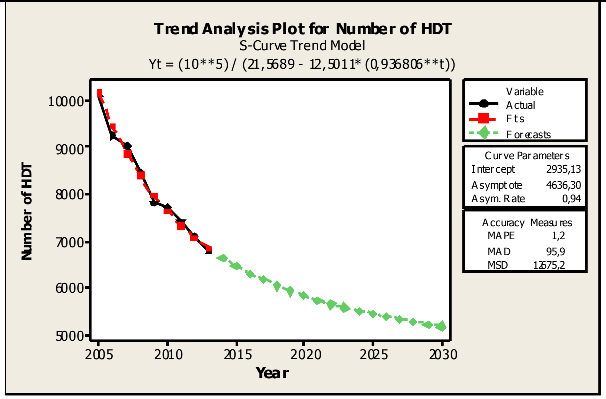
Diesel Euro II - 91/542/EEC Stage II, Rigid 7,5 - 12 t



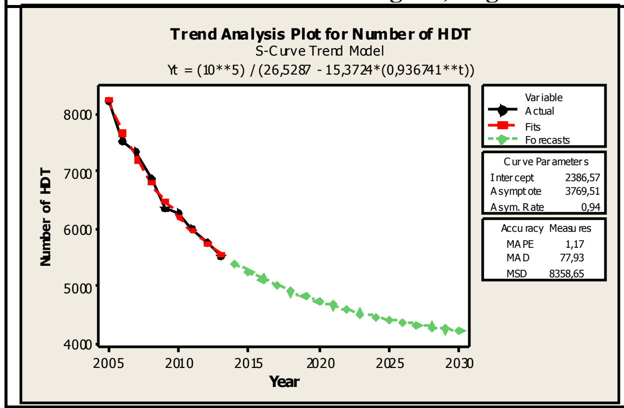
Diesel Euro II - 91/542/EEC Stage II, Rigid 12 - 14 t



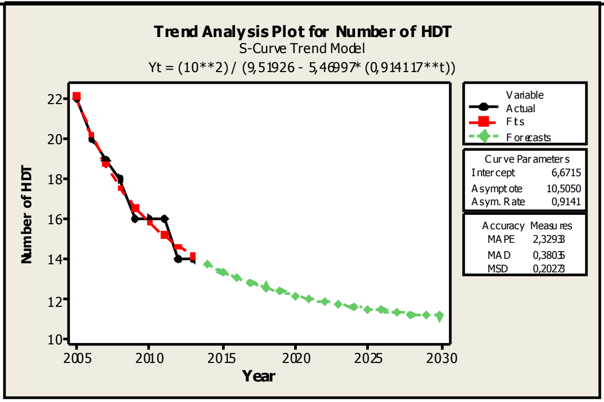
Diesel Euro II - 91/542/EEC Stage II, Rigid 14 - 20 t



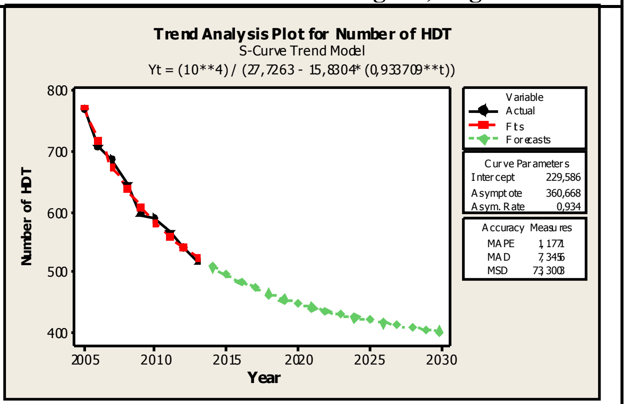
Diesel Euro II - 91/542/EEC Stage II, Rigid 20 - 26 t



Diesel Euro II - 91/542/EEC Stage II, Rigid 26 - 28 t

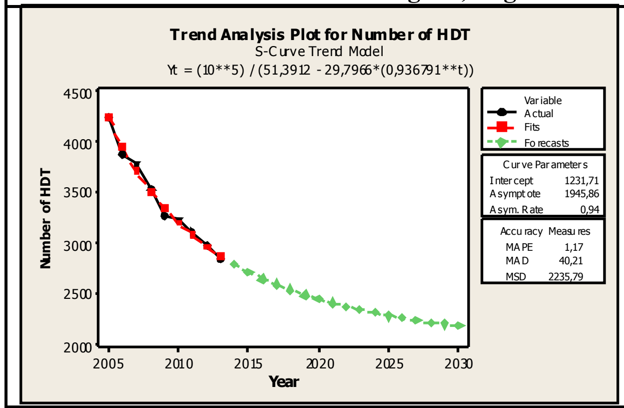


Diesel Euro II - 91/542/EEC Stage II, Rigid 28 - 32 t

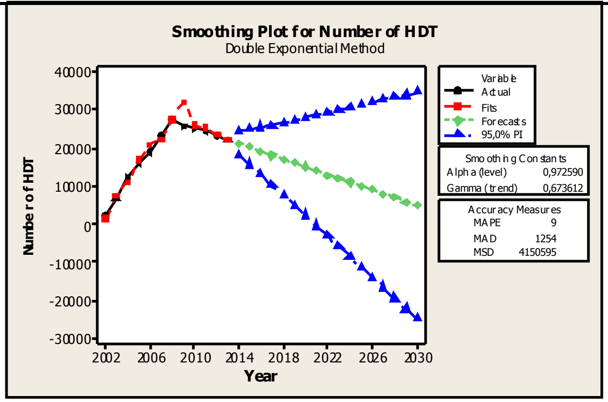


A3. HEAVY DUTY TRUCKS

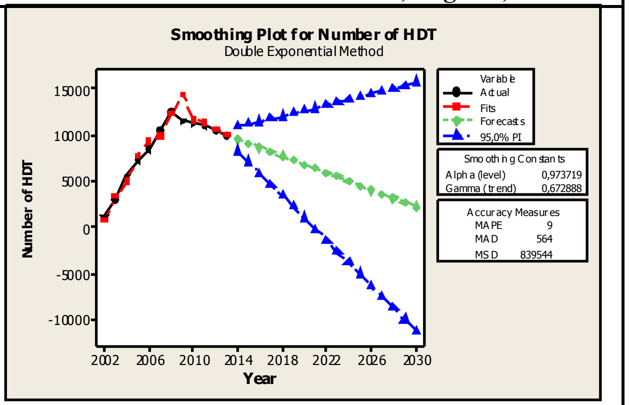
Diesel Euro II - 91/542/EEC Stage II, Rigid >32 t



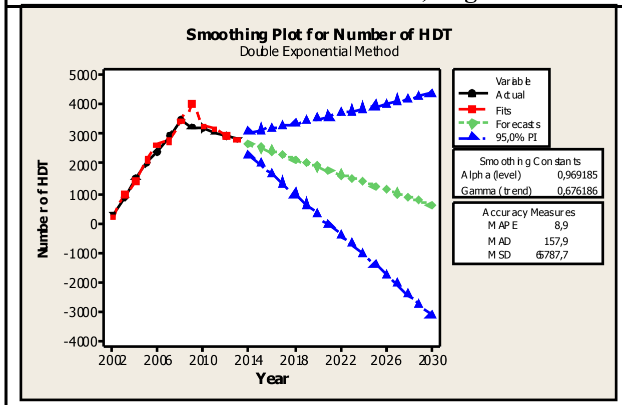
Diesel Euro III - 2000 Standards, Rigid <=7,5 t



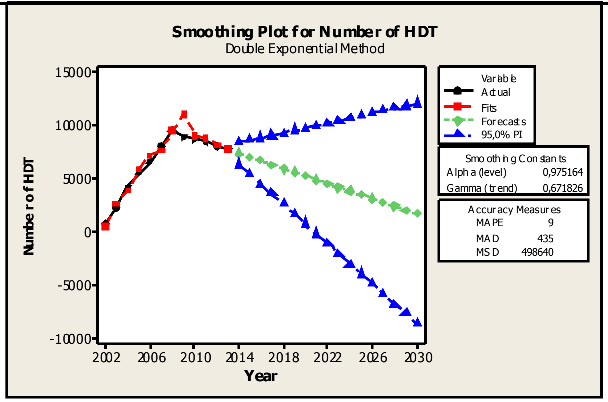
Diesel Euro III - 2000 Standards, Rigid 7,5 - 12 t



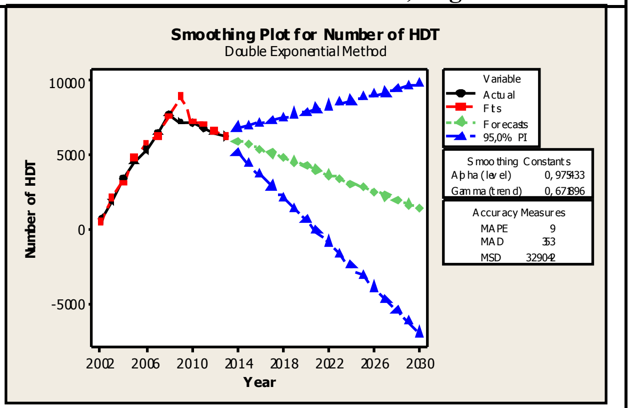
Diesel Euro III - 2000 Standards, Rigid 12 - 14 t



Diesel Euro III - 2000 Standards, Rigid 14 - 20 t

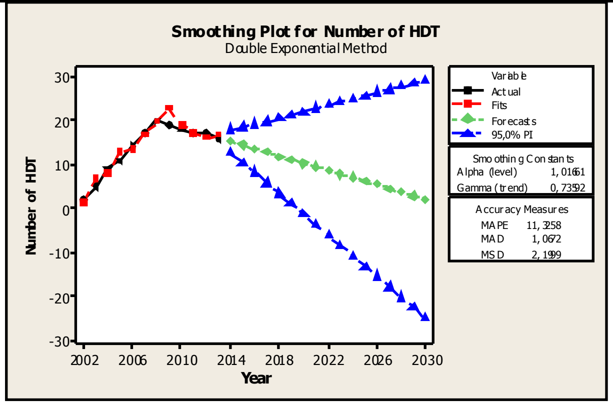


Diesel Euro III - 2000 Standards, Rigid 20 - 26 t

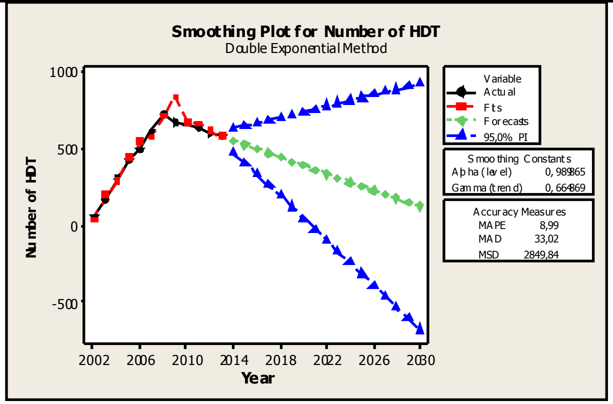


A3. HEAVY DUTY TRUCKS

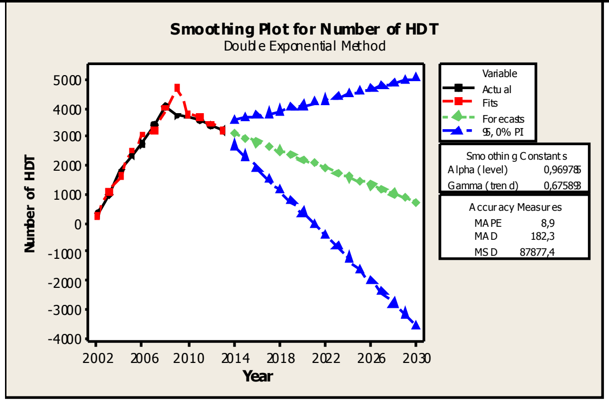
Diesel Euro III - 2000 Standards, Rigid 26 - 28 t



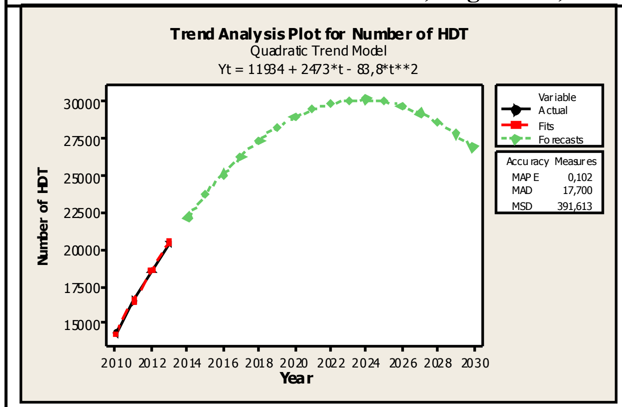
Diesel Euro III - 2000 Standards, Rigid 28 - 32 t



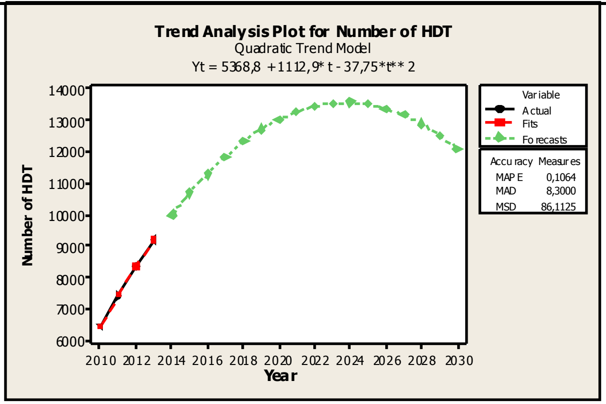
Diesel Euro III - 2000 Standards, Rigid >32 t



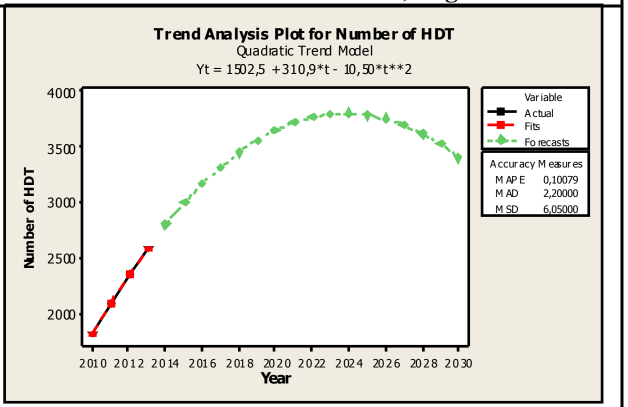
Diesel Euro IV - 2005 Standards, Rigid <=7,5 t



Diesel Euro IV - 2005 Standards, Rigid 7,5 - 12 t

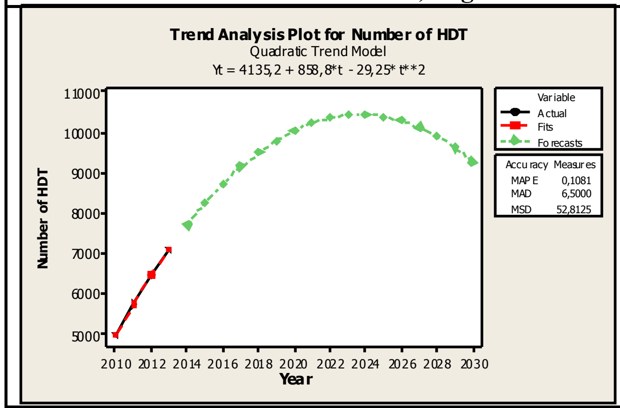


Diesel Euro IV - 2005 Standards, Rigid 12 - 14 t

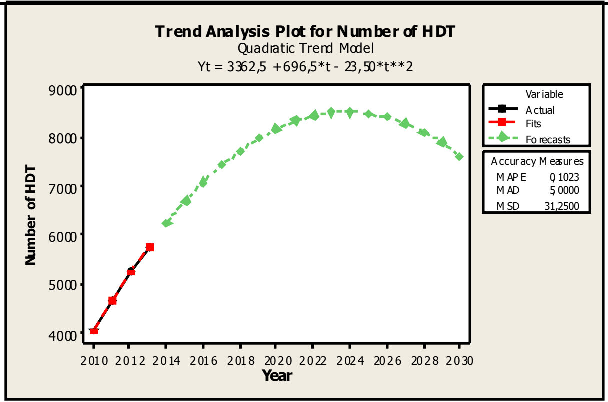


A3. HEAVY DUTY TRUCKS

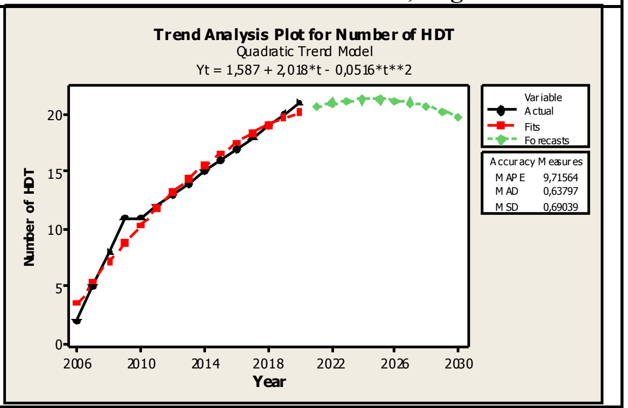
Diesel Euro IV - 2005 Standards, Rigid 14 - 20 t



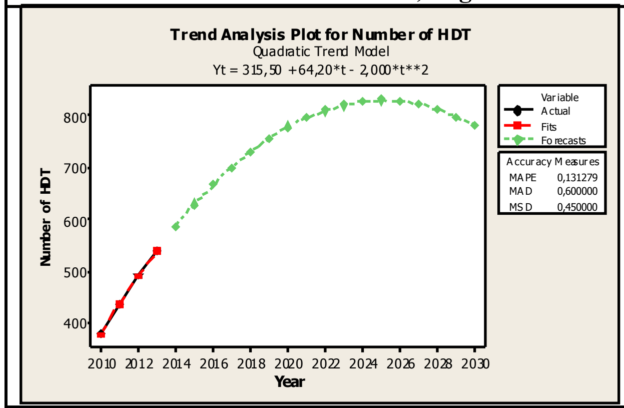
Diesel Euro IV - 2005 Standards, Rigid 20 - 26 t



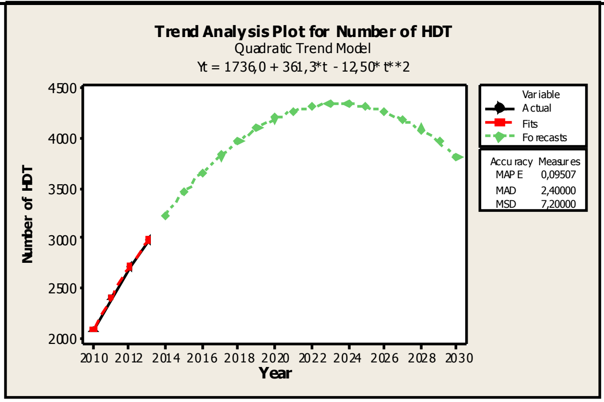
Diesel Euro IV - 2005 Standards, Rigid 26 – 28



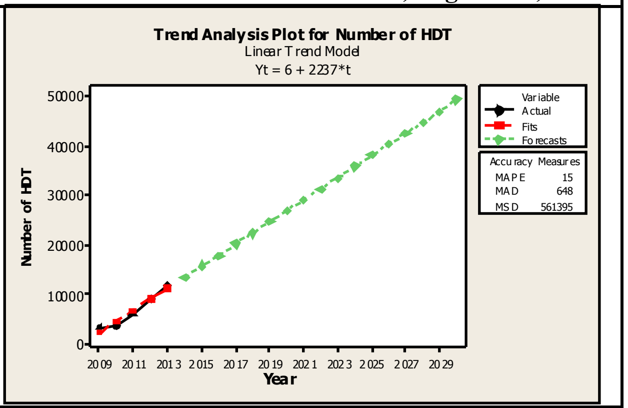
Diesel Euro IV - 2005 Standards, Rigid 28 – 32 t



Diesel Euro IV - 2005 Standards, Rigid >32 t

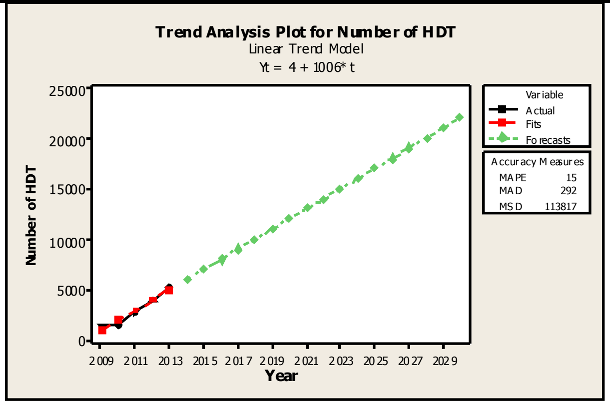


Diesel Euro V - 2008 Standards, Rigid <=7,5 t

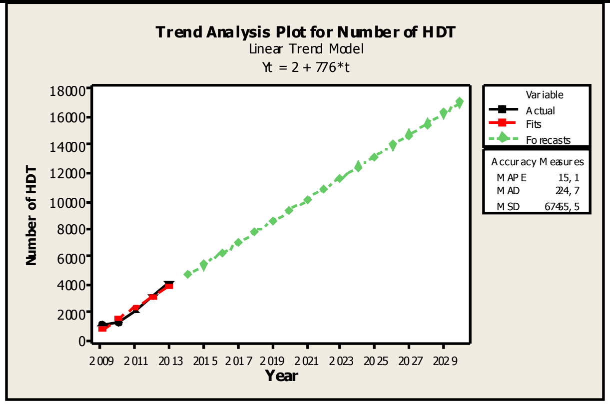


A3. HEAVY DUTY TRUCKS

Diesel Euro V - 2008 Standards, Rigid 7,5 - 12 t



Diesel Euro V - 2008 Standards, Rigid 12 - 14 t



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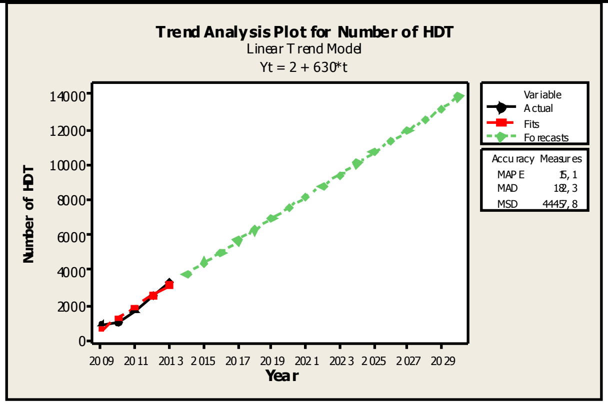
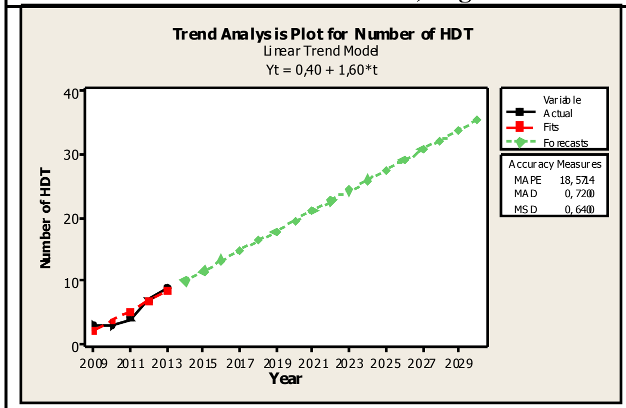
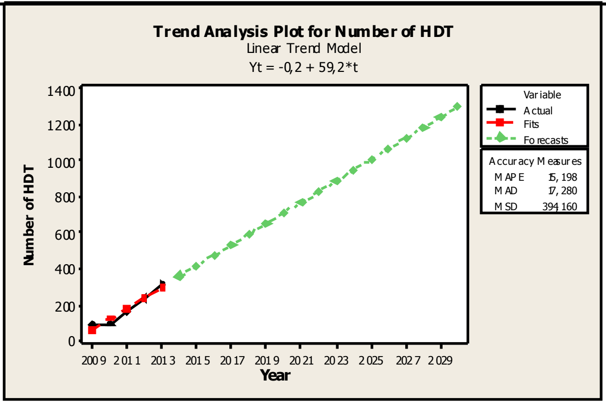


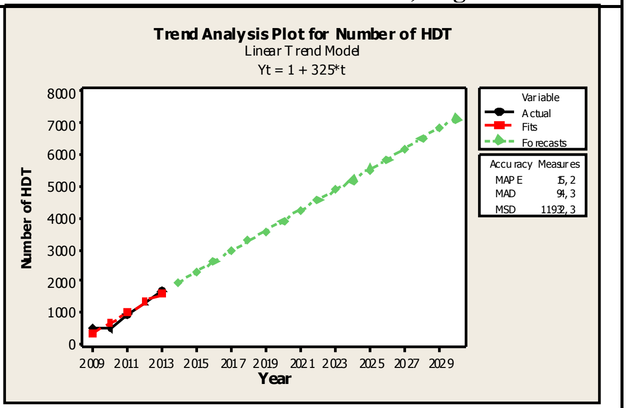
Diesel Euro V - 2008 Standards, Rigid 20 - 26 t



Diesel Euro V - 2008 Standards, Rigid 26 - 28

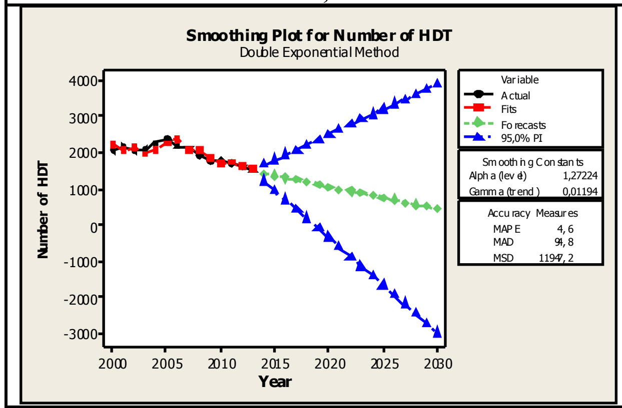


Diesel Euro V - 2008 Standards, Rigid > 32 t

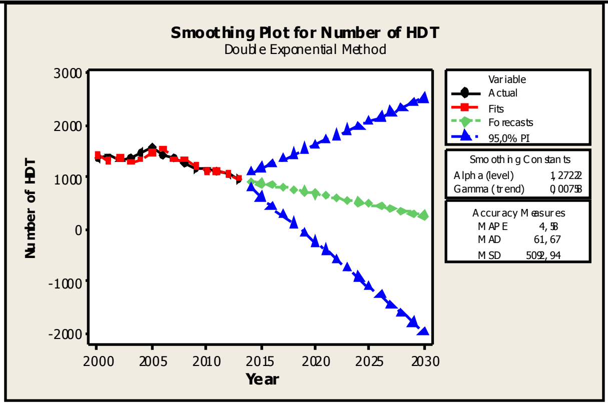


A3. HEAVY DUTY TRUCKS

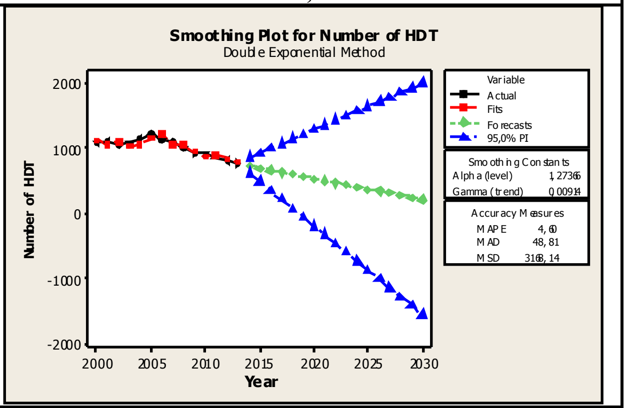
Diesel Conventional, Articulated 14-20 t



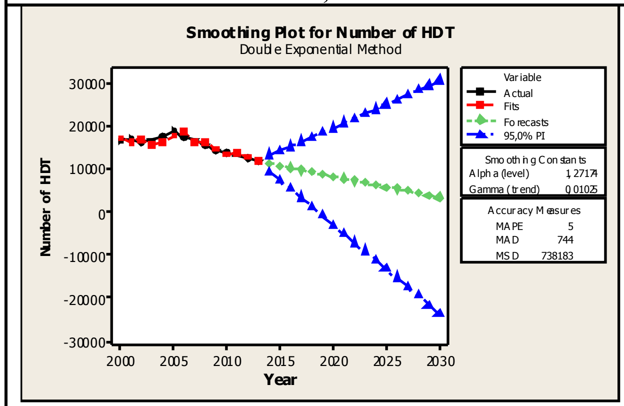
Diesel Conventional, Articulated 20-28 t



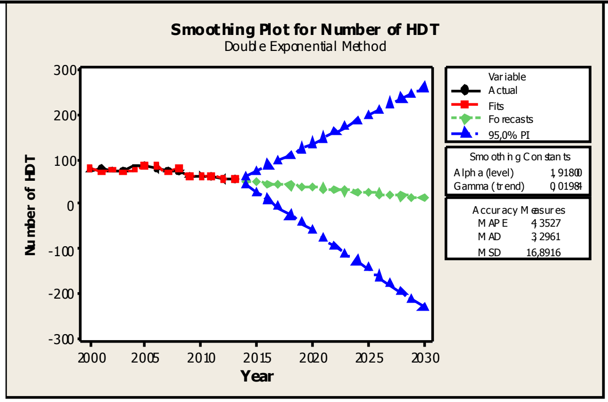
Diesel Conventional, Articulated 28-34 t



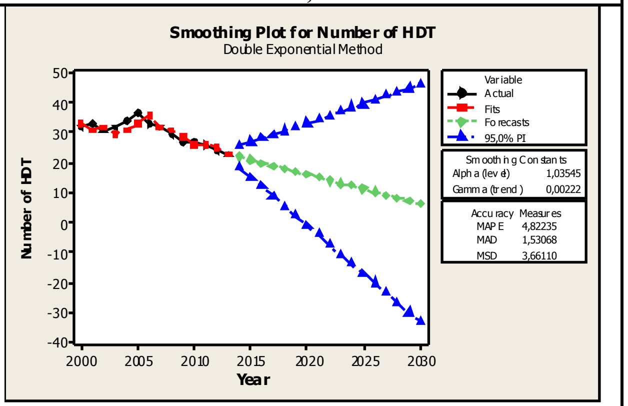
Diesel Conventional, Articulated 34-40 t



Diesel Conventional, Articulated 40-50 t

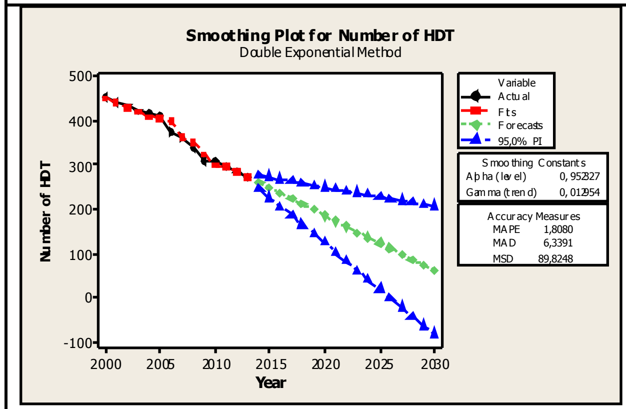


Diesel Conventional, Articulated 50-60 t

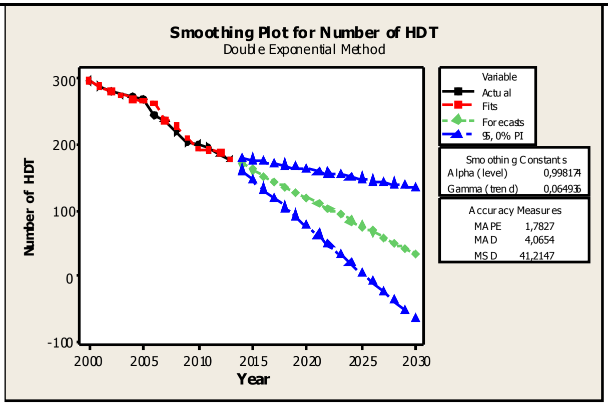


A3. HEAVY DUTY TRUCKS

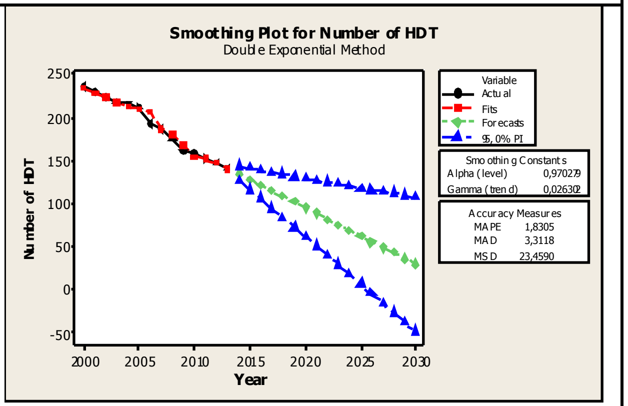
Diesel Euro I - 91/542/EEC Stage I, Articulated 14-20 t



Diesel Euro I - 91/542/EEC Stage I, Articulated 20-28 t



Diesel Euro I - 91/542/EEC Stage I, Articulated 28-34 t



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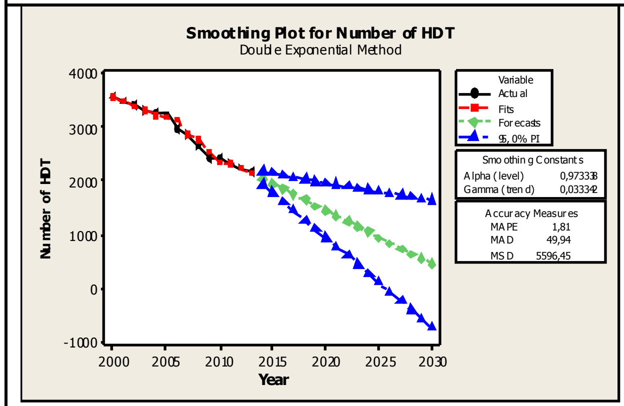
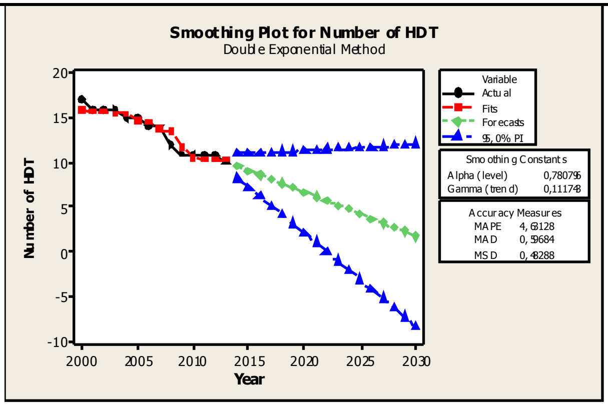
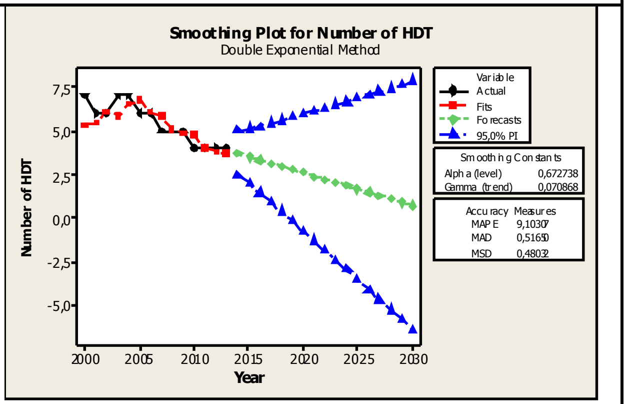


Diesel Euro I - 91/542/EEC Stage I, Articulated 40-50 t

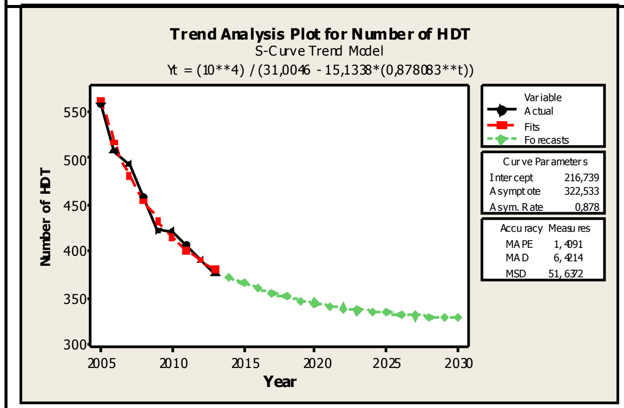


Diesel Euro I - 91/542/EEC Stage I, Articulated 50-60 t

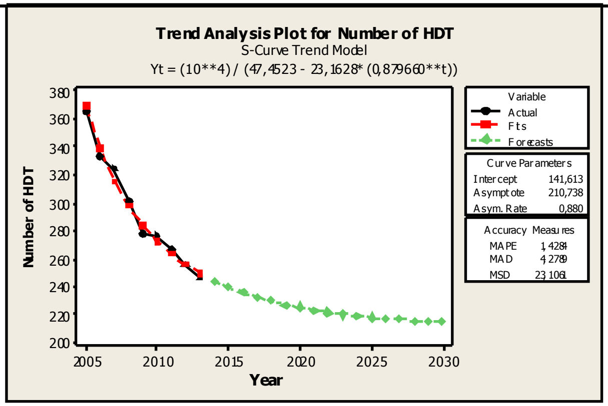


A3. HEAVY DUTY TRUCKS

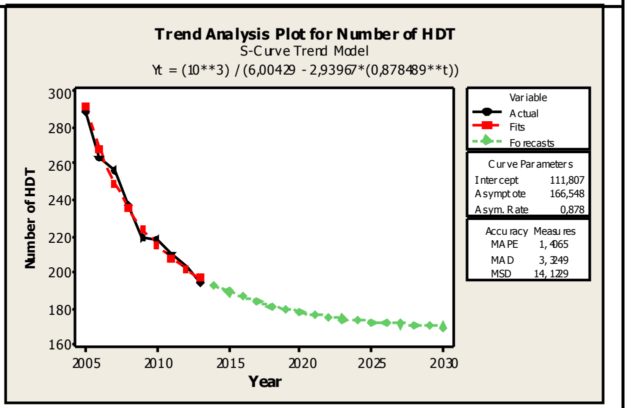
Diesel Euro II - 91/542/EEC Stage II, Articulated 14-20 t



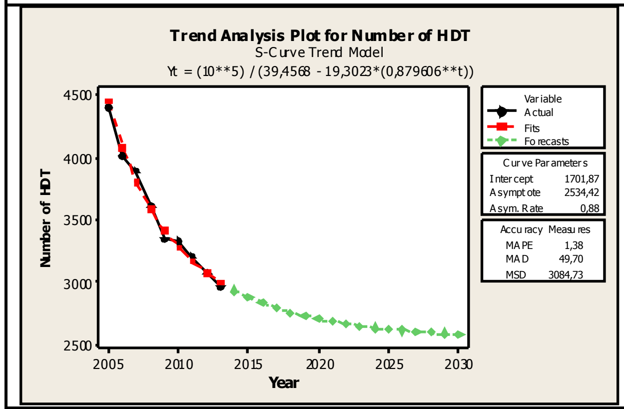
Diesel Euro II - 91/542/EEC Stage II, Articulated 20-28 t



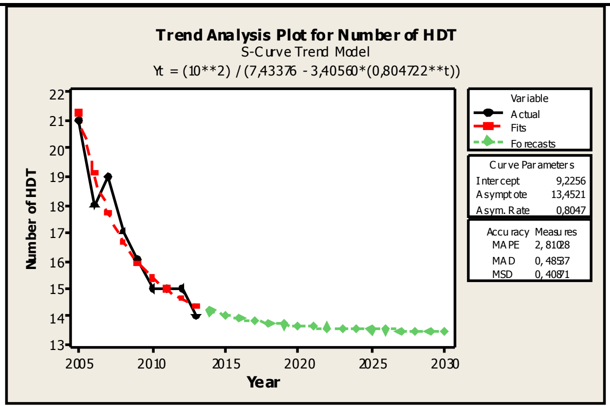
Diesel Euro II - 91/542/EEC Stage II, Articulated 28-34 t



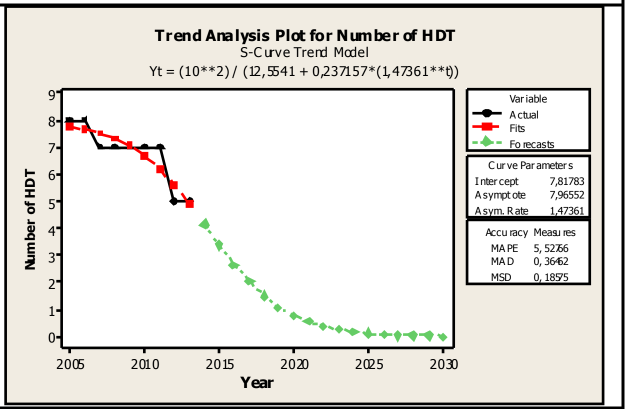
Diesel Euro II - 91/542/EEC Stage II, Articulated 34-40 t



Diesel Euro II - 91/542/EEC Stage II, Articulated 40-50 t

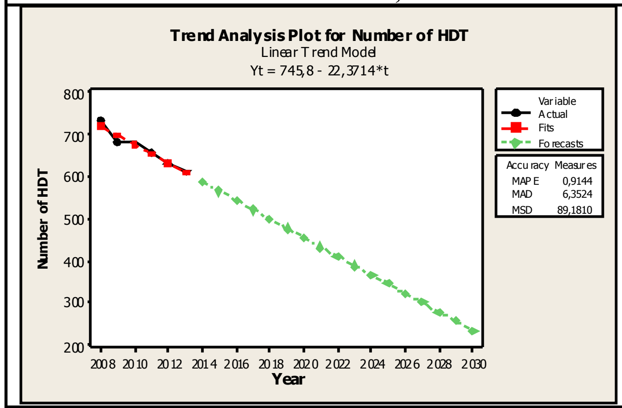


Diesel Euro II - 91/542/EEC Stage II, Articulated 50-60 t

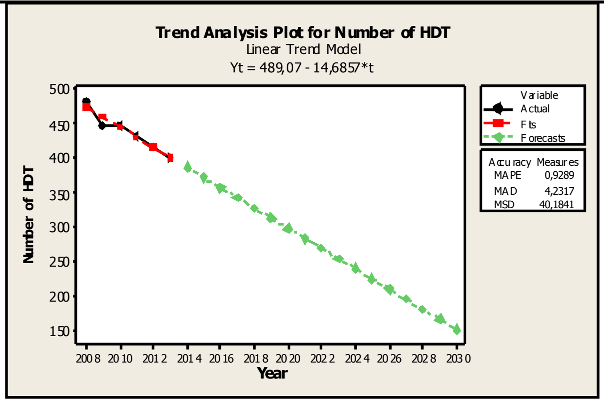


A3. HEAVY DUTY TRUCKS

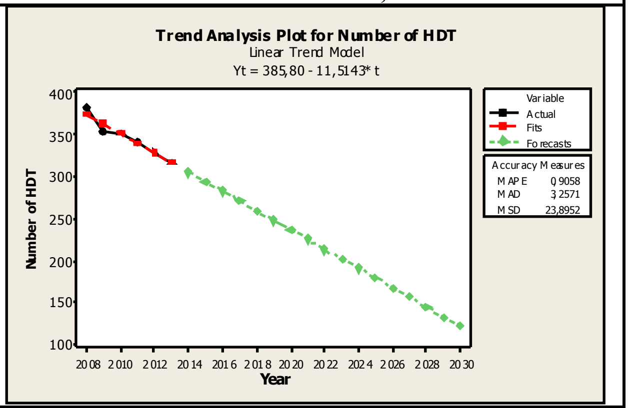
Diesel Euro III - 2000 Standards, Articulated 14-20 t



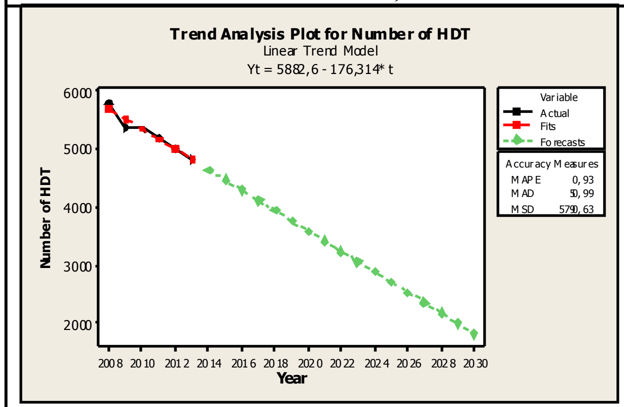
Diesel Euro III - 2000 Standards, Articulated 20-28 t



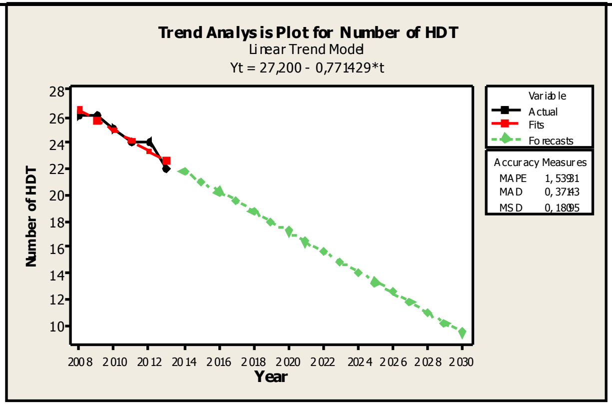
Diesel Euro III - 2000 Standards, Articulated 28-34 t



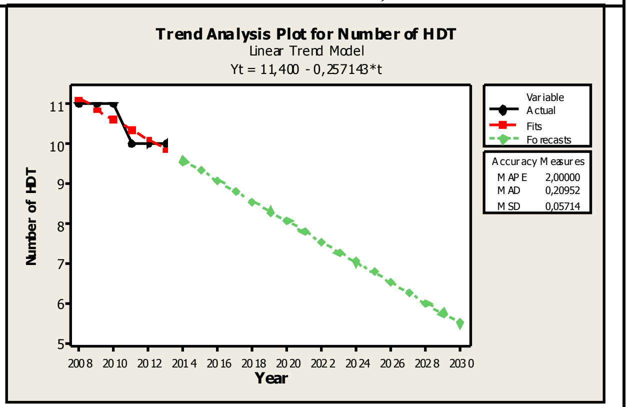
Diesel Euro III - 2000 Standards, Articulated 34-40 t



Diesel Euro III - 2000 Standards, Articulated 40-50 t

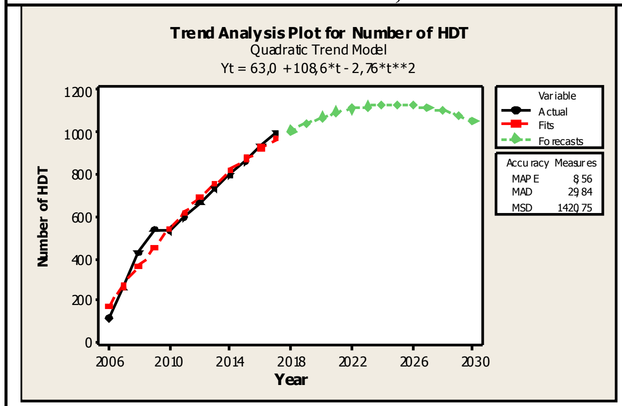


Diesel Euro III - 2000 Standards, Articulated 50-60 t

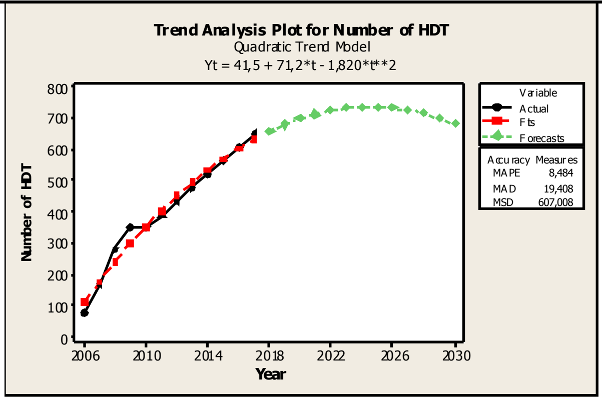


A3. HEAVY DUTY TRUCKS

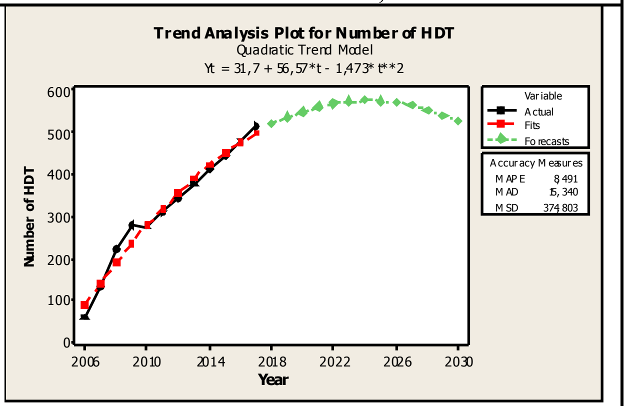
Diesel Euro IV - 2005 Standards, Articulated 14-20 t



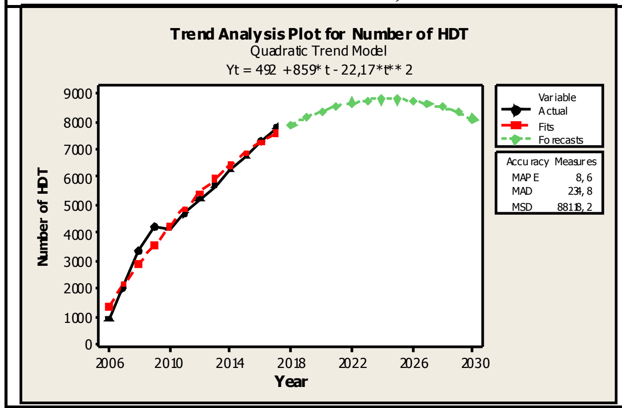
Diesel Euro IV - 2005 Standards, Articulated 20-28 t



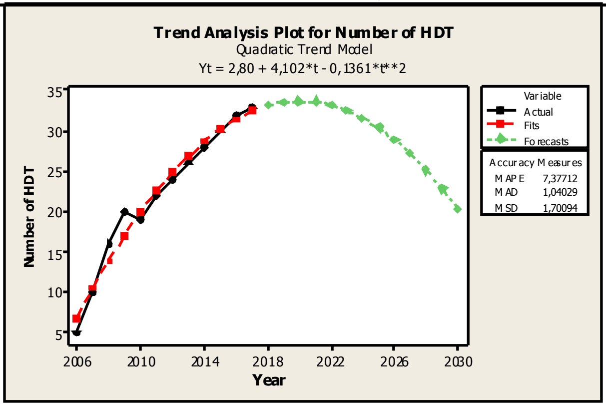
Diesel Euro IV - 2005 Standards, Articulated 28-34 t



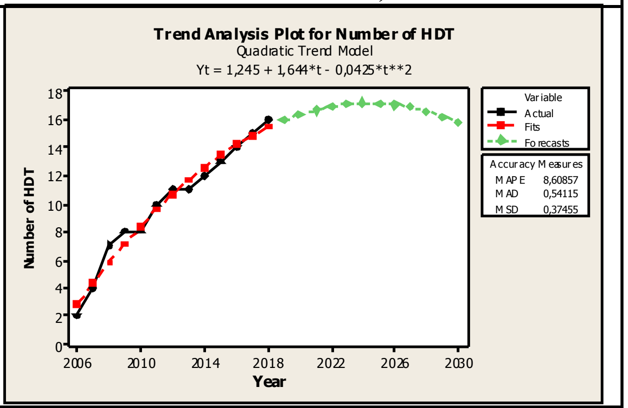
Diesel Euro IV - 2005 Standards, Articulated 34-40 t



Diesel Euro IV - 2005 Standards, Articulated 40-50 t

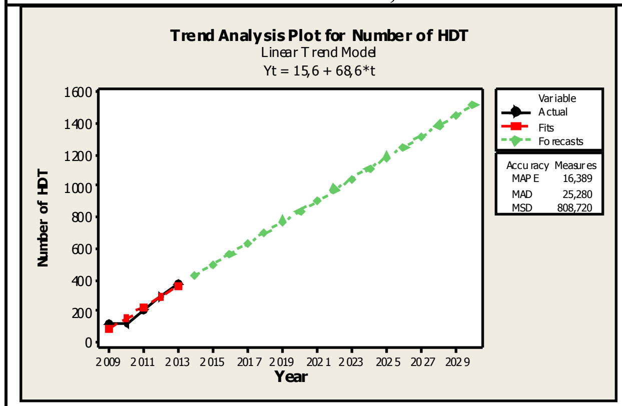


Diesel Euro IV - 2005 Standards, Articulated 50-60 t



A3. HEAVY DUTY TRUCKS

Diesel Euro V - 2008 Standards, Articulated 14-20 t



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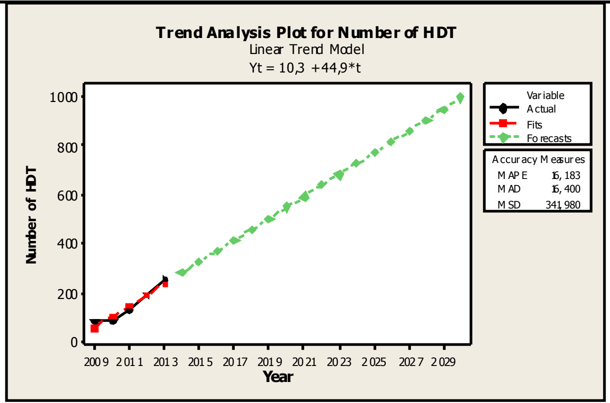
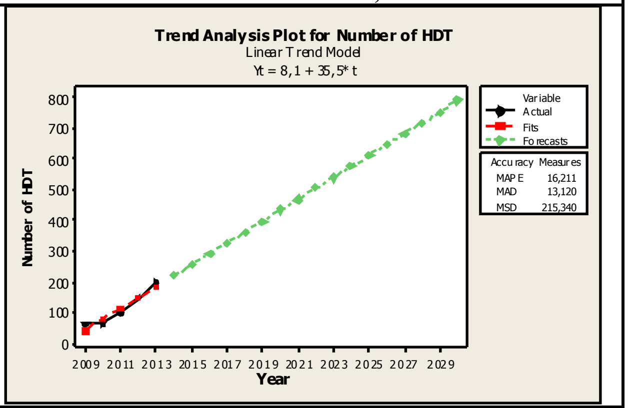


Diesel Euro V - 2008 Standards, Articulated 28-34 t



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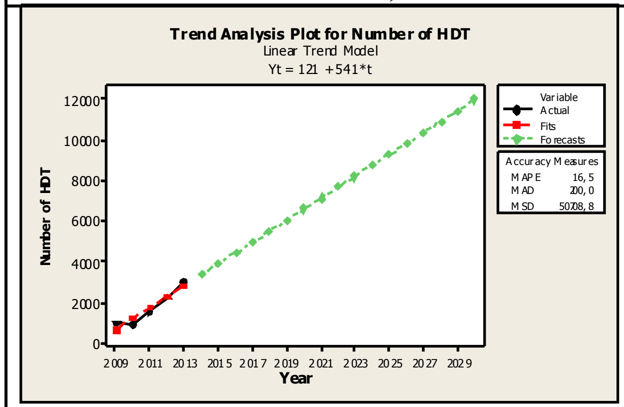

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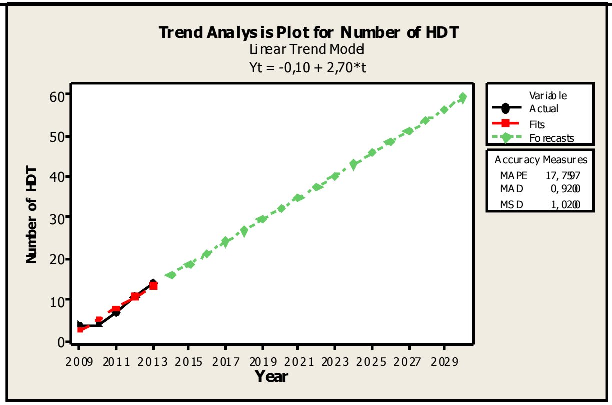
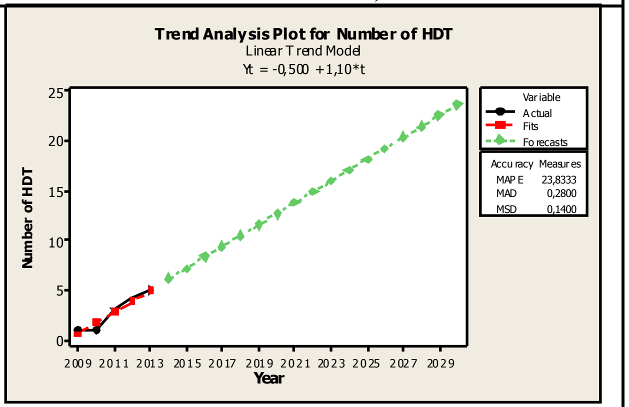
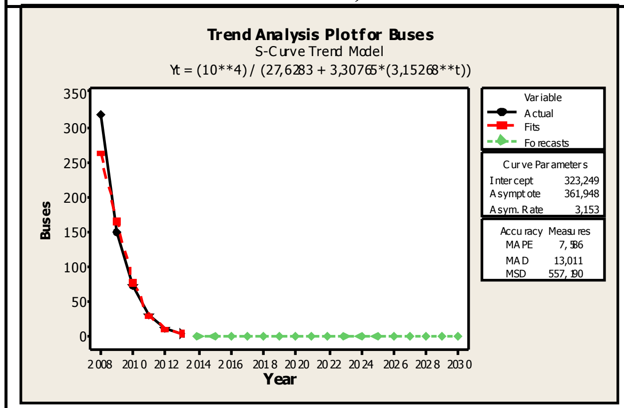


Diesel Euro V - 2008 Standards, Articulated 50-60 t

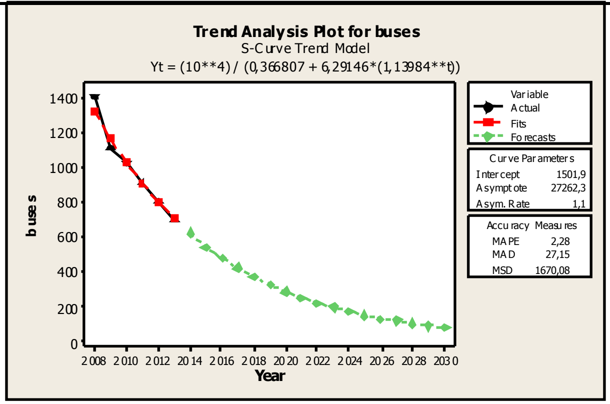


A4. URBAN BUSES

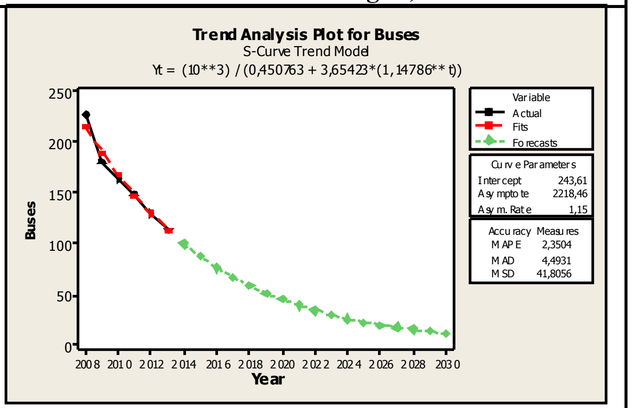
Diesel Conventional, Midi <=15 t



Diesel Euro I - 91/542/EEC Stage I, Midi <=15 t



Diesel Euro I - 91/542/EEC Stage I, Standard 15-18t



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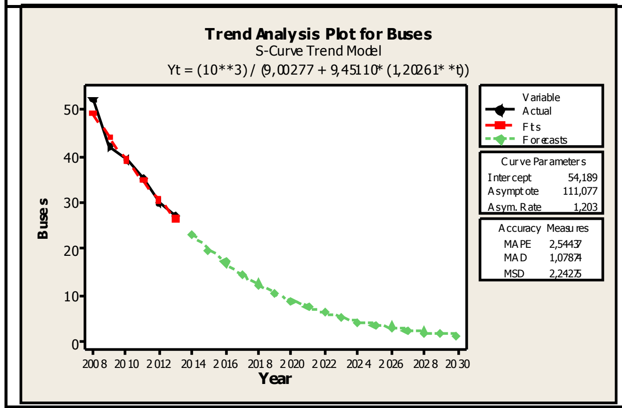
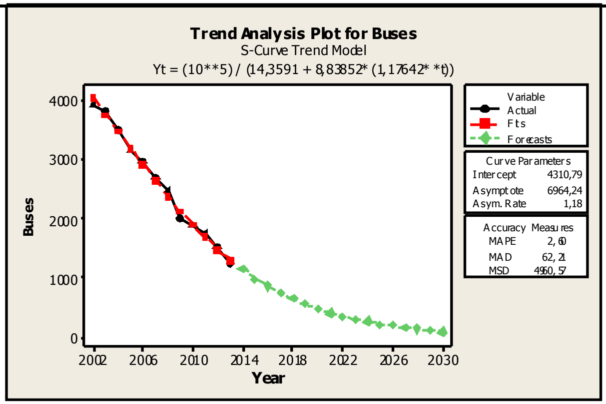
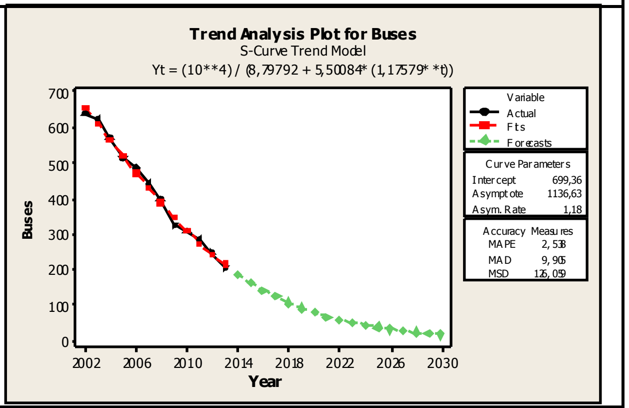


Diesel Euro II - 91/542/EEC Stage II, Midi <=15 t

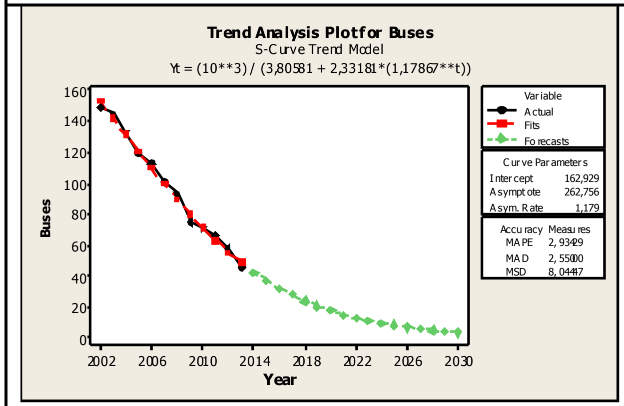


Diesel Euro II - 91/542/EEC Stage II, Standard 15-18t

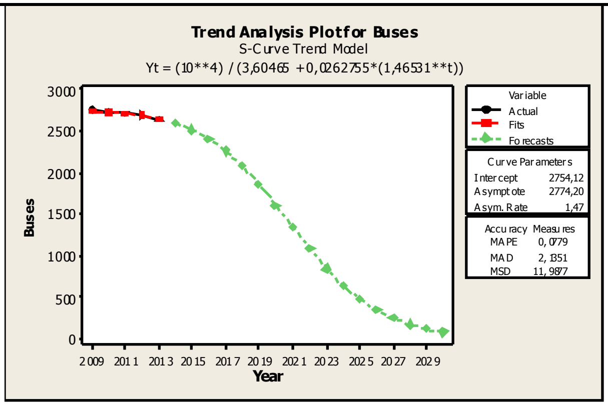


A4. URBAN BUSES

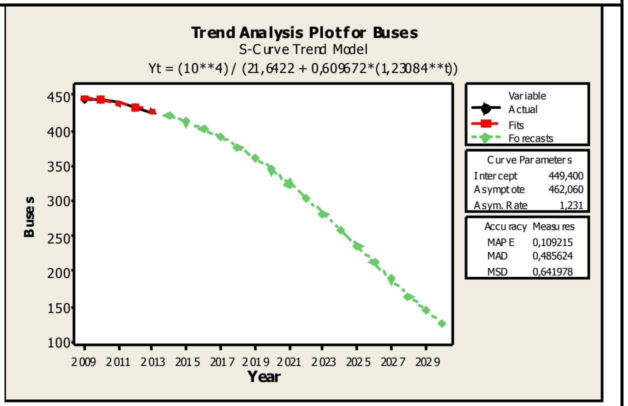
Diesel Euro II - 91/542/EEC Stage II, Articulated >18t



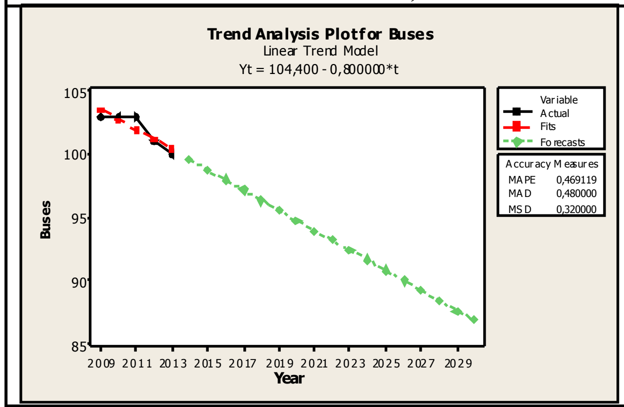
Diesel Euro III - 2000 Standards, Midi <=15 t



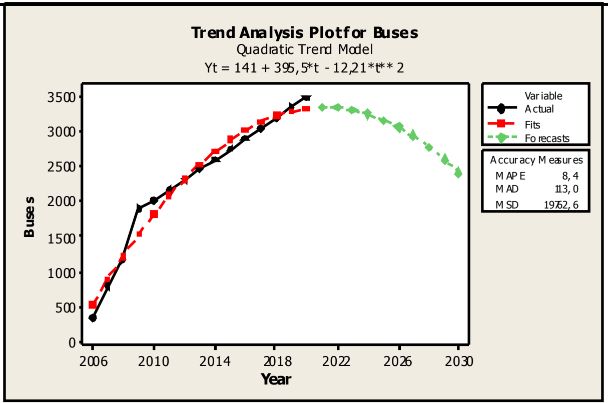
Diesel Euro III - 2000 Standards, Standard 15-18t



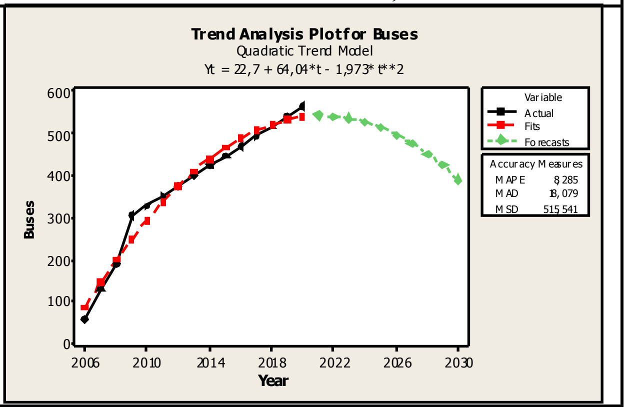
Diesel Euro III - 2000 Standards, Articulated >18t



Diesel Euro IV - 2005 Standards, Midi <=15 t

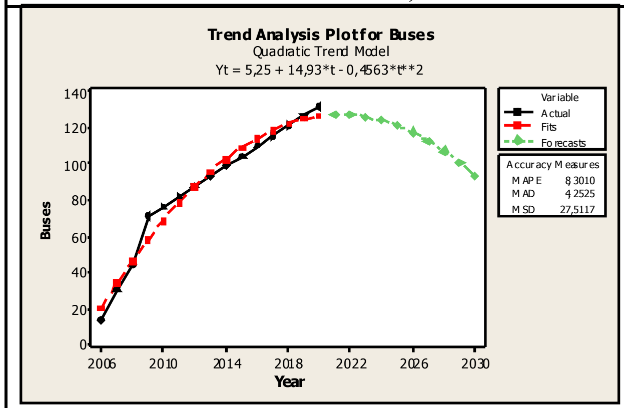


Diesel Euro IV - 2005 Standards, Standard 15-18t

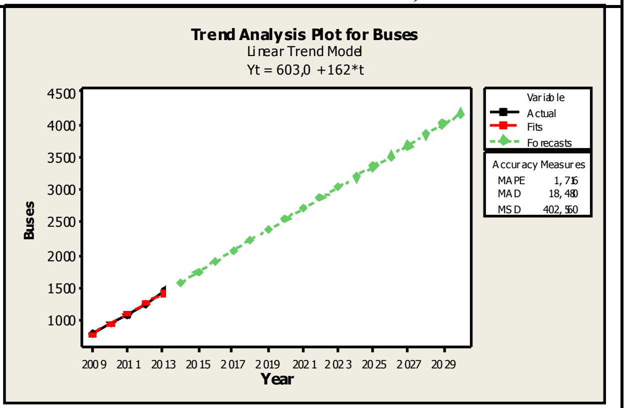


A4. URBAN BUSES

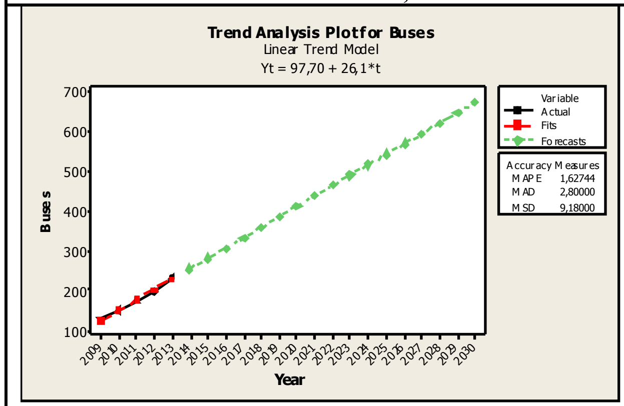
Diesel Euro IV - 2005 Standards, Articulated >18t



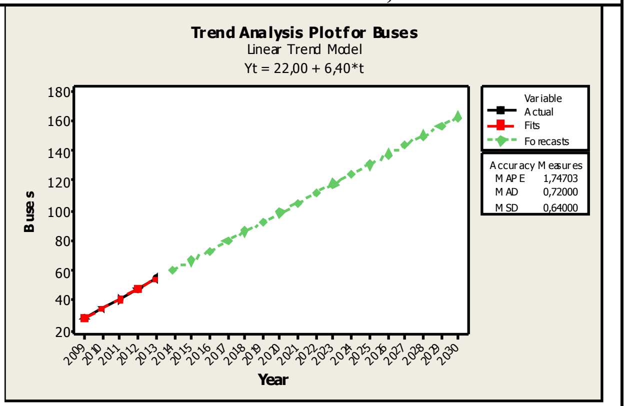
Diesel Euro V - 2008 Standardss, Midi <=15 t



Diesel Euro V - 2008 Standards, Standard 15-18t

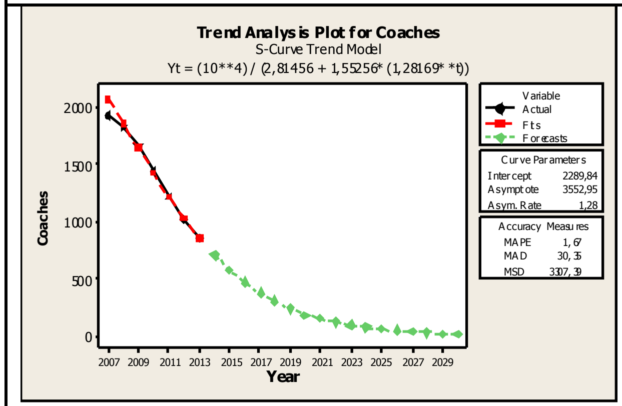


Diesel Euro V - 2008 Standards, Articulated >18t

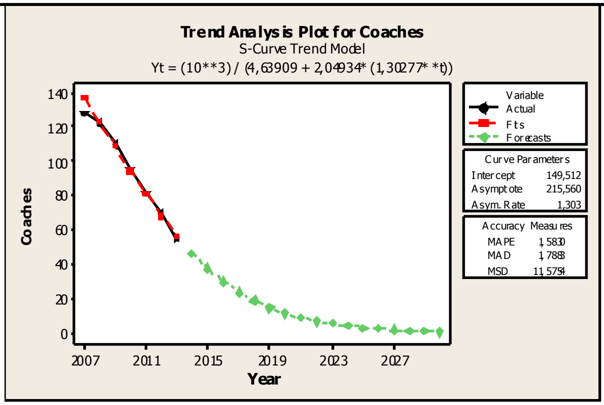


A5. COACHES

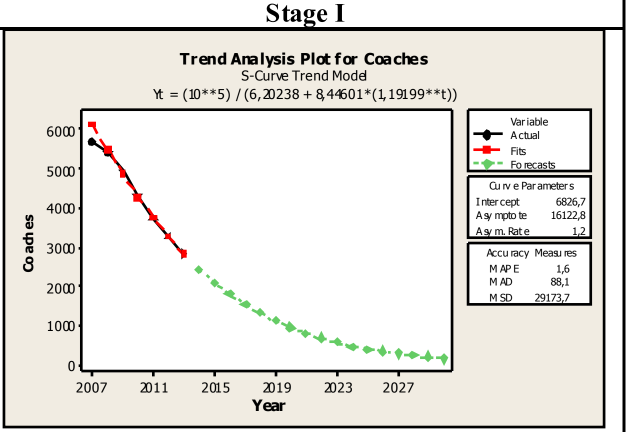
Diesel STANDARD <=18 t: Conventional



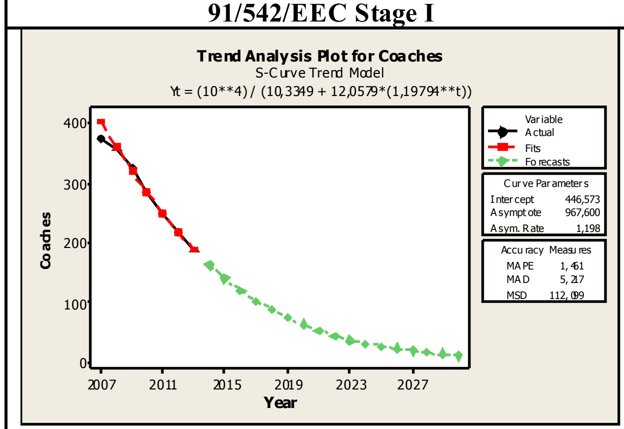
Diesel ARTICULATED >18 t: Conventional



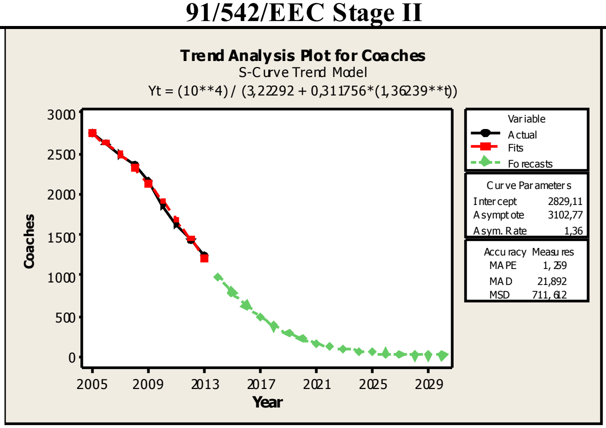
Diesel STANDARD <=18 t: HD Euro I - 91/542/EEC Stage I



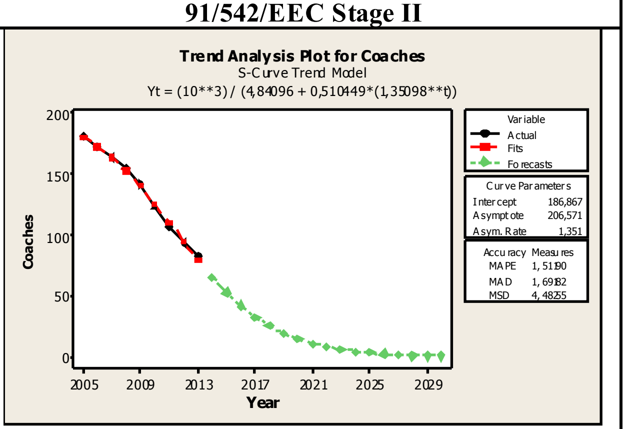
Diesel ARTICULATED >18 t: HD Euro I - 91/542/EEC Stage I



Diesel STANDARD <=18 t: HD Euro II - 91/542/EEC Stage II

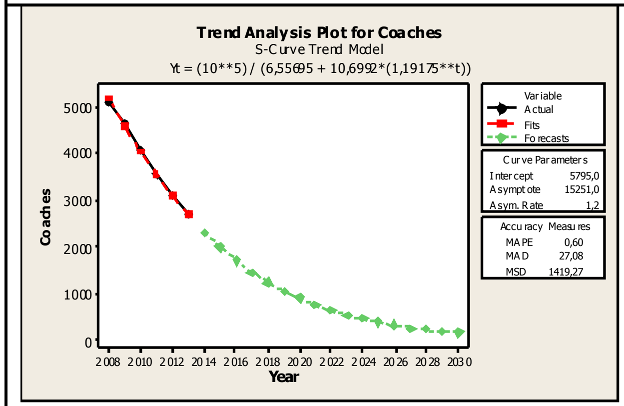


Diesel ARTICULATED >18 t: HD Euro II - 91/542/EEC Stage II

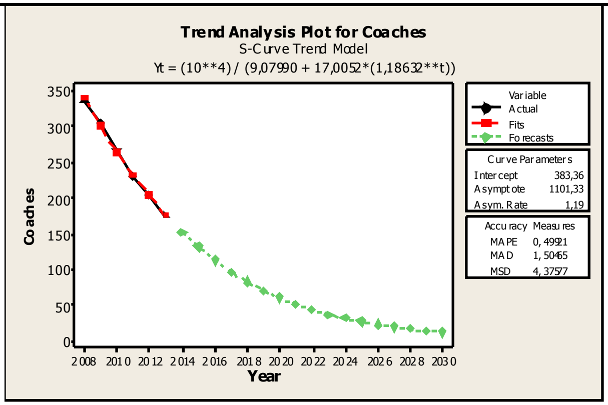


A5. COACHES

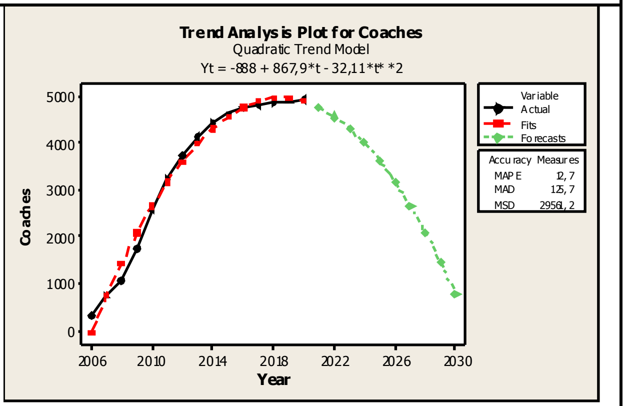
Diesel STANDARD <=18 t: HD Euro III - 2000 Standards



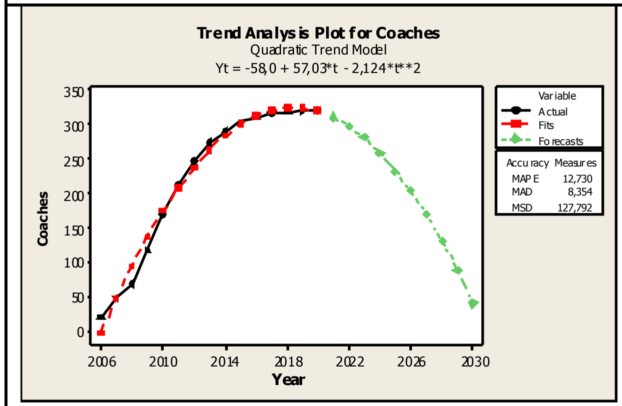
Diesel ARTICULATED >18 t: HD Euro III - 2000 Standards



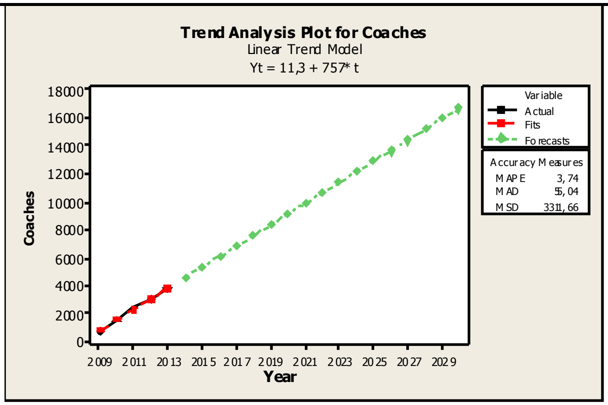
Diesel STANDARD <=18 t: HD Euro IV - 2005 Standards



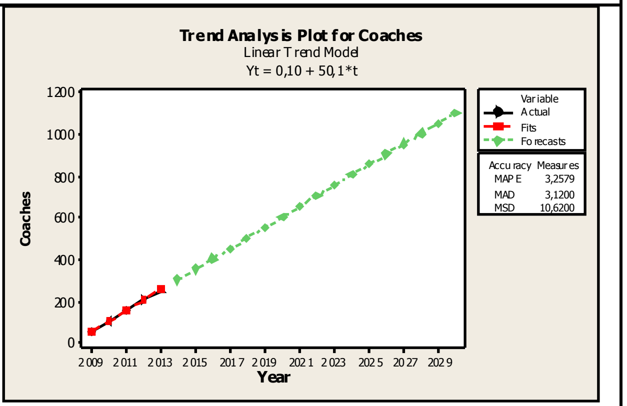
Diesel ARTICULATED >18 t: HD Euro IV - 2005 Standards



Diesel STANDARD <=18 t: HD Euro V - 2008 Standards

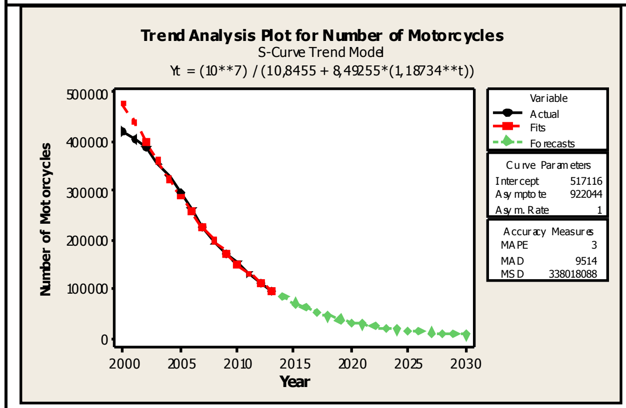


Diesel ARTICULATED >18 t: HD Euro V - 2008 Standards

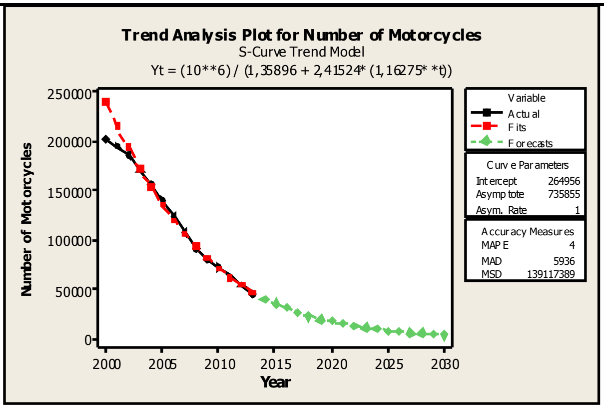


A6. MOTORCYCLES

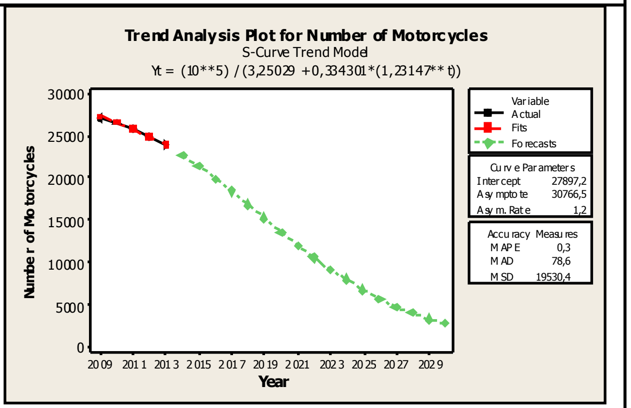
Gasoline Conventional: 4-stroke < 250 cm³



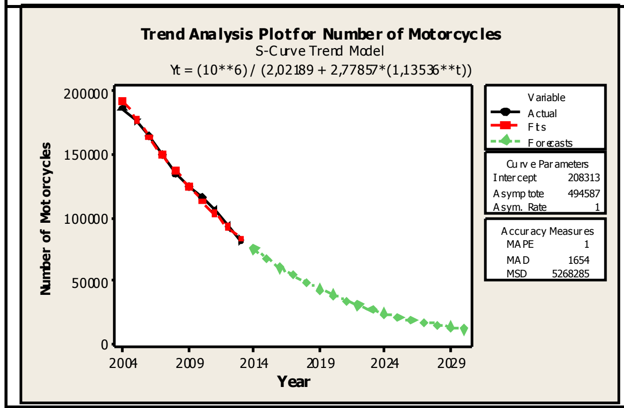
Gasoline Conventional: 4-stroke 250 - 750 cm³



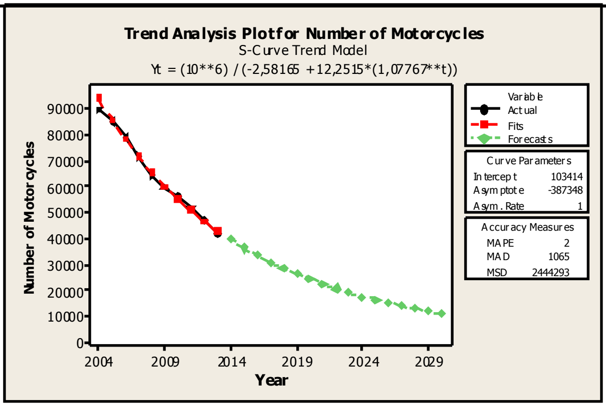
Gasoline Conventional: 4-stroke >750 cm³



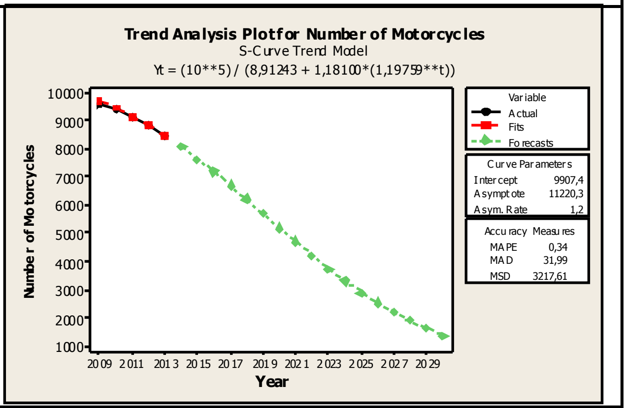
Gasoline Euro I: 4-stroke < 250 cm³



Gasoline Euro I: 4-stroke 250 - 750 cm³

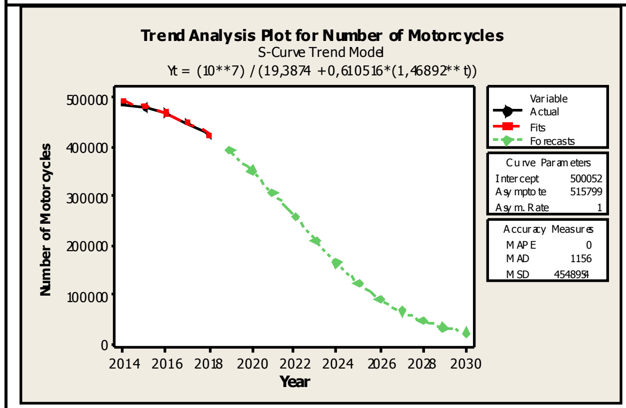


Gasoline Euro I: 4-stroke >750 cm³

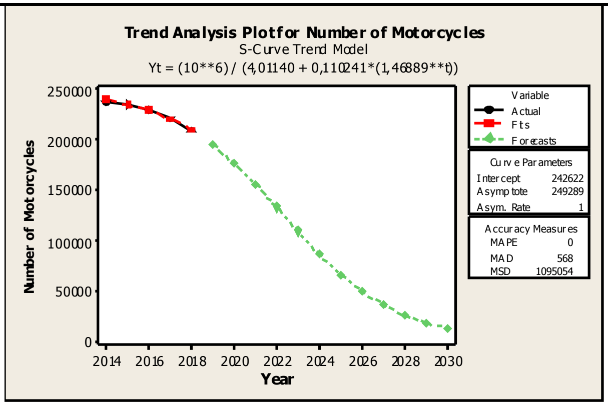


A6. MOTORCYCLES

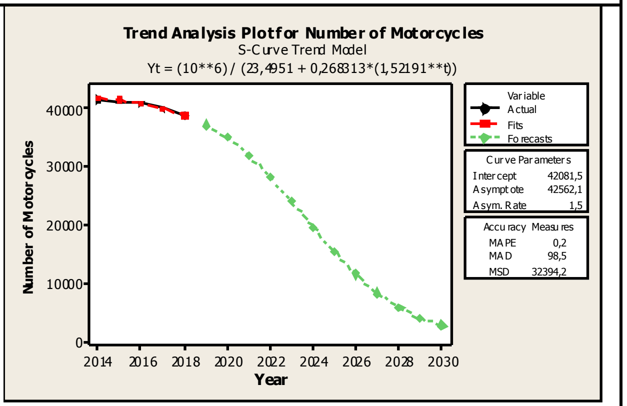
Gasoline Euro II: 2-stroke >50 cm³



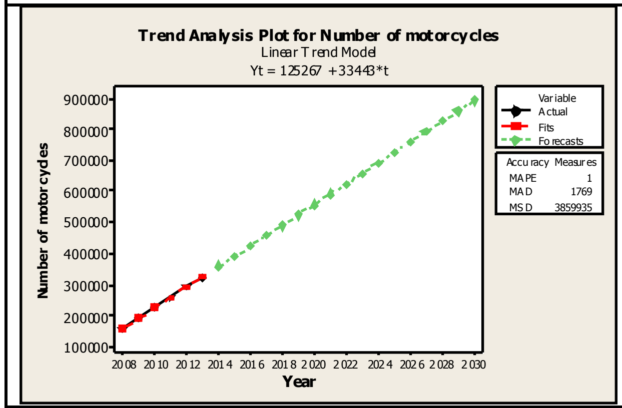
Gasoline Euro II: 4-stroke 250 - 750 cm³



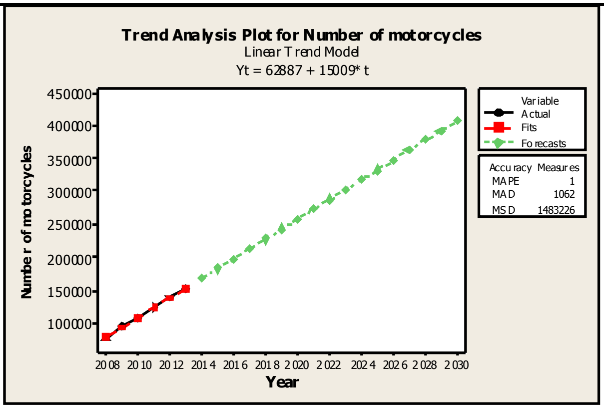
Gasoline Euro II: 4-stroke >750 cm³



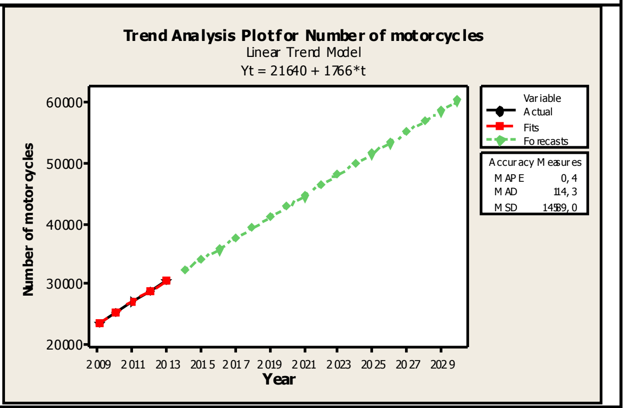
Gasoline Euro III: 2-stroke >50 cm³



Gasoline Euro III: 4-stroke 250 - 750 cm³

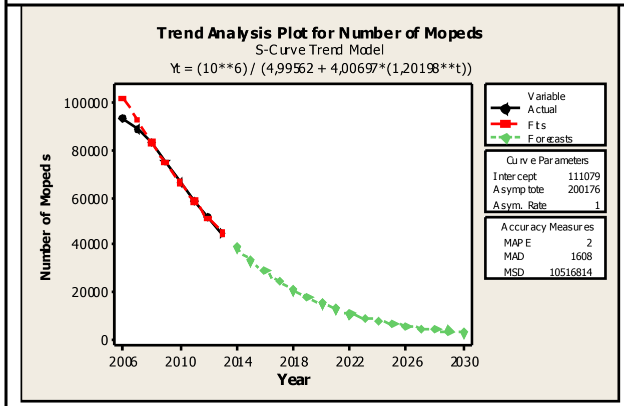


Gasoline Euro III: 4-stroke >750 cm³

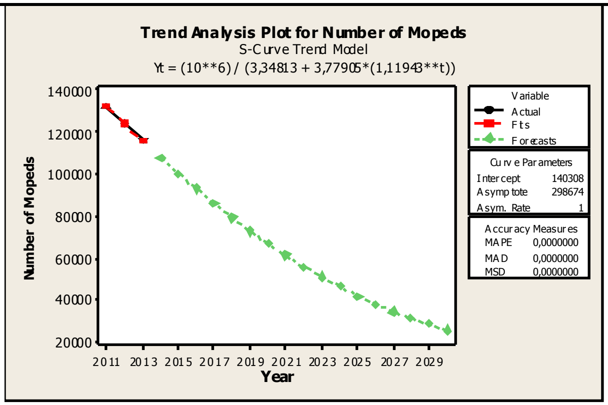


A7. MOPEDS

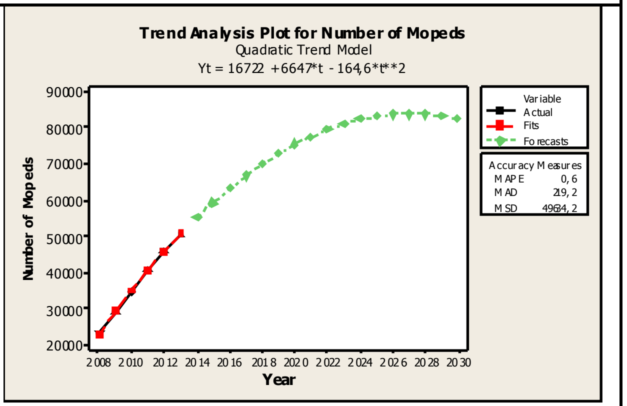
Gasoline Conventional



Gasoline Euro I



Gasoline Euro II



APPENDIX B

ESTIMATION OUTPUTS

ESTIMATION OUTPUT B1: Augmented Dickey-Fuller test Results

Annual change of Number of Passenger Cars (ΔPGC_t)

In Levels

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-0.518226	0.8728	ADF Test Statistic		-0.213010	0.9892
Critical values	1% level	-3.699871		Critical values	1% level	-4.339330	
	5% level	-2.976263			5% level	-3.587527	
	10% level	-2.627420			10% level	-3.229230	

In First Differences

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-4.209121	0.0031	ADF Test Statistic		-4.776286	0.0039
Critical values	1% level	-3.711457		Critical values	1% level	-4.356068	
	5% level	-2.981038			5% level	-3.595026	
	10% level	-2.629906			10% level	-3.233456	

Annual change of Number of Trucks ($\Delta TRUCK_t$)

In Levels

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-1.347784	0.5923	ADF Test Statistic		-1.776043	0.6870
Critical values	1% level	-3.699871		Critical values	1% level	-4.356068	
	5% level	-2.976263			5% level	-3.595026	
	10% level	-2.627420			10% level	-3.233456	

In First Differences

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-3.463729	0.0180	ADF Test Statistic		-5.876613	0.0003
Critical values	1% level	-3.724070		Critical values	1% level	-4.356068	
	5% level	-2.986225			5% level	-3.595026	
	10% level	-2.632604			10% level	-3.233456	

Annual change of Number of Motorcycles ($\Delta MOTO_t$)

In Levels

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		t-Statistic	Prob.*	ADF Test Statistic		0.379818	0.9981
Critical values	1% level	-3.711457		Critical values	1% level	-4.339330	
	5% level	-2.981038			5% level	-3.587527	
	10% level	-2.629906			10% level	-3.229230	

In First Differences

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-3.211602	0.0307	ADF Test Statistic		-4.127516	0.0165
Critical values	1% level	-3.711457		Critical values	1% level	-4.356068	
	5% level	-2.981038			5% level	-3.595026	
	10% level	-2.629906			10% level	-3.233456	

Annual change of Gross Domestic Product (ΔGDP_t)

In Levels

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-0.369684	0.9011	ADF Test Statistic		-0.999731	0.9274
Critical values	1% level	-3.699871		Critical values	1% level	-4.339330	
	5% level	-2.976263			5% level	-3.587527	
	10% level	-2.627420			10% level	-3.229230	

In First Differences

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-3.649036	0.0116	ADF Test Statistic		-3.945489	0.0243
Critical values	1% level	-3.711457		Critical values	1% level	-4.356068	
	5% level	-2.981038			5% level	-3.595026	
	10% level	-2.629906			10% level	-3.233456	

ESTIMATION OUTPUT B2:
Augmented Dickey-Fuller test Results for the Residuals of:

(ΔPGC_t) against (ΔGDP_t)

```
Exogenous: None
================================================================
                                          t-Statistic   Prob.*
================================================================
Augmented Dickey-Fuller test statistic     -2.161752    0.0318
----------------------------------------------------------------
Test critical values:     1% level         -2.653401
                          5% level         -1.953858
                         10% level         -1.609571
================================================================
```

$(\Delta TRUCK_t)$ against (ΔGDP_t)

```
Exogenous: None
================================================================
                                          t-Statistic   Prob.*
================================================================
Augmented Dickey-Fuller test statistic     -3.111745    0.0031
----------------------------------------------------------------
Test critical values:     1% level         -2.653401
                          5% level         -1.953858
                         10% level         -1.609571
================================================================
```

$(\Delta MOTO_t)$ against (ΔGDP_t)

```
Exogenous: None
================================================================
                                          t-Statistic   Prob.*
================================================================
Augmented Dickey-Fuller test statistic     -1.881791    0.0582
----------------------------------------------------------------
Test critical values:     1% level         -2.653401
                          5% level         -1.953858
                         10% level         -1.609571
================================================================
```

ESTIMATION OUTPUT B3: Regression Results

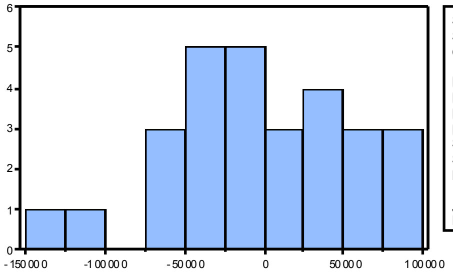
```
Dependent Variable: ΔPGCt
Method: Least Squares
Sample: 1 28
Included observations: 28
==========================================================================
        Variable         Coefficient    Std. Error    t-Statistic    Prob.
==========================================================================
           C              89898.49      13411.18      6.703252      0.0000
         ΔGDPt            8227.007      1321.137      6.227217      0.0000
==========================================================================
R-squared                 0.598631   Mean dependent var         138031.2
Adjusted R-squared        0.583193   S.D. dependent var         89828.04
S.E. of regression        57993.49   Akaike info criterion      24.84280
Sum squared resid         8.74E+10   Schwarz criterion          24.93796
Log likelihood           -345.7992   Hannan-Quinn criter.       24.87189
F-statistic               38.77823   Durbin-Watson stat         0.622589
Prob(F-statistic)         0.000001
==========================================================================
```

```
Dependent Variable: ΔTRUCKt
Method: Least Squares
Sample: 1 28
Included observations: 28
==========================================================================
        Variable         Coefficient    Std. Error    t-Statistic    Prob.
==========================================================================
           C              19276.58      1945.486      9.908365      0.0000
         D_GDP            1100.812      191.6501      5.743863      0.0000
==========================================================================
R-squared                 0.559262   Mean dependent var         25716.96
Adjusted R-squared        0.542311   S.D. dependent var         12435.27
S.E. of regression        8412.800   Akaike info criterion      20.98165
Sum squared resid         1.84E+09   Schwarz criterion          21.07680
Log likelihood           -291.7430   Hannan-Quinn criter.       21.01074
F-statistic               32.99196   Durbin-Watson stat         1.121985
Prob(F-statistic)         0.000005
==========================================================================
```

```
Dependent Variable: ΔMOTOt
Method: Least Squares
Sample: 1 28
Included observations: 28
==========================================================================
        Variable         Coefficient    Std. Error    t-Statistic    Prob.
==========================================================================
           C              41089.94      4842.242      8.485727      0.0000
         D_GDP            1561.402      477.0100      3.273310      0.0030
==========================================================================
R-squared                 0.291834   Mean dependent var         50225.04
Adjusted R-squared        0.264597   S.D. dependent var         24417.22
S.E. of regression        20939.14   Akaike info criterion      22.80538
Sum squared resid         1.14E+10   Schwarz criterion          22.90053
Log likelihood           -317.2753   Hannan-Quinn criter.       22.83447
F-statistic               10.71456   Durbin-Watson stat         0.238547
Prob(F-statistic)         0.003002
==========================================================================
```

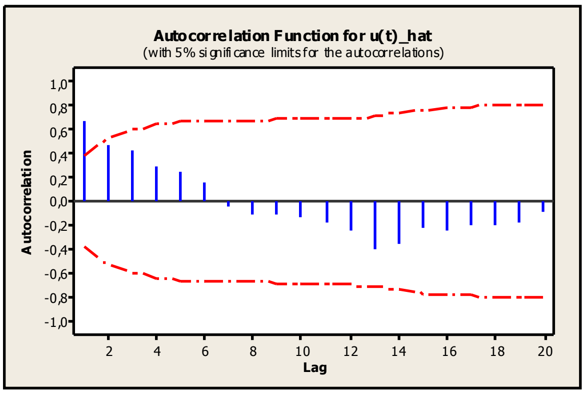
ESTIMATION OUTPUT B4: Residual Diagnostic Tests

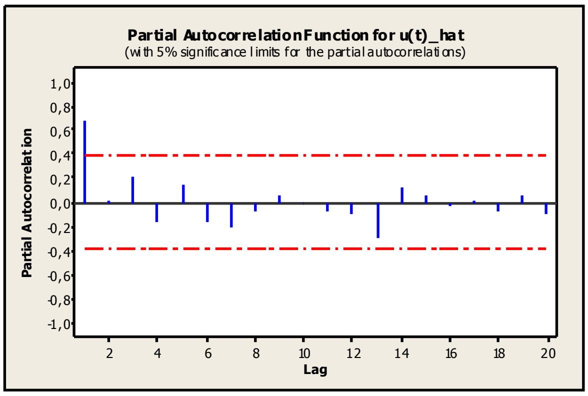
($\boldsymbol{\Delta PGC_t}$) against ($\Delta \mathrm{GDP}_t$)



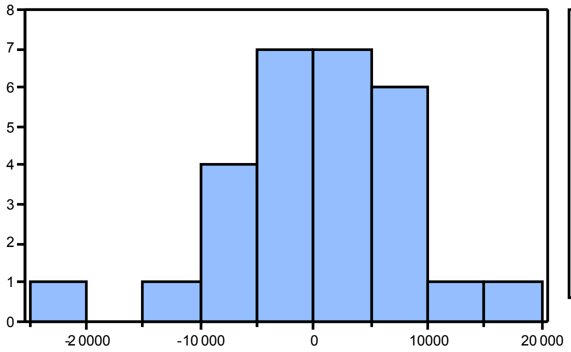
```
Series: Residuals
Sample 1 28
Observations 28

Mean          1.35e-11
Median       -8259.477
Maximum       99489.62
Minimum      -130783.4
Std. Dev.     56909.41
Skewness     -0.199212
Kurtosis      2.611203

Jarque-Bera   0.361556
Probability   0.834621
```

```
Heteroskedasticity Test: ARCH

F-statistic       1.458799    Prob. F(1,25)           0.2384
Obs*R-squared     1.488638    Prob. Chi-Square(1)     0.2224
```





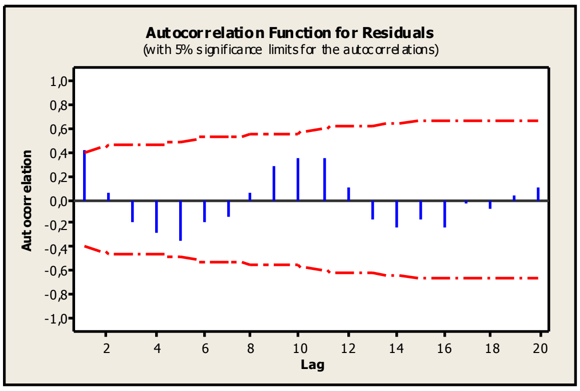
($\boldsymbol{\Delta TRUCK_t}$) against ($\Delta \mathrm{GDP}_t$)

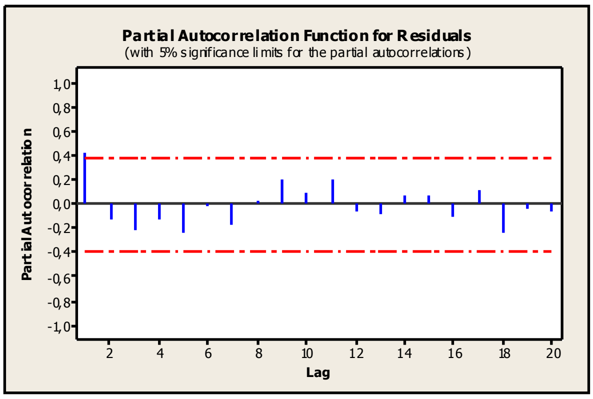


```
Series: Residuals
Sample 1 28
Observations 28

Mean          4.35e-12
Median        462.1330
Maximum       15027.74
Minimum      -23347.99
Std. Dev.     8255.537
Skewness     -0.604213
Kurtosis      3.945631

Jarque-Bera   2.746929
Probability   0.253228
```

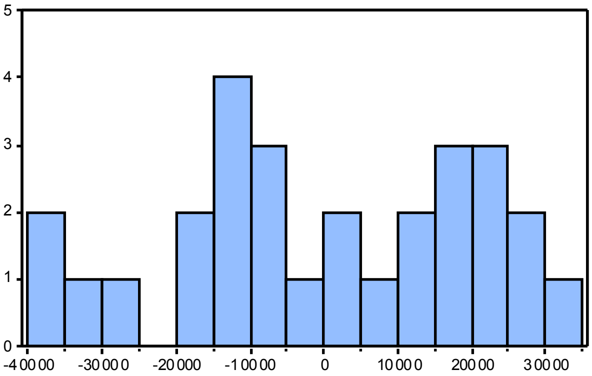
```
Heteroskedasticity Test: ARCH

F-statistic       0.036009    Prob. F(1,25)           0.8510
Obs*R-squared     0.038833    Prob. Chi-Square(1)     0.8438
```

ESTIMATION OUTPUT B4:





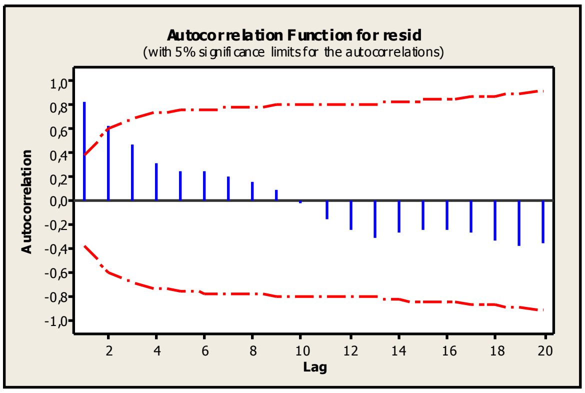
($\Delta MOTO_t$) against (ΔGDP_t)

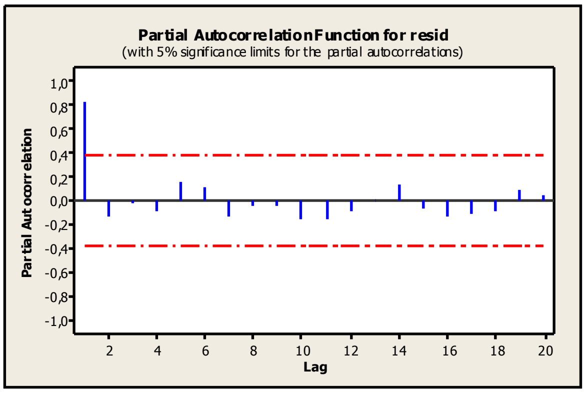


Series: Residuals Sample 1 28 Observations 28	
Mean	4.55e-12
Median	-2098.933
Maximum	33155.71
Minimum	-35835.73
Std. Dev.	20547.72
Skewness	-0.156456
Kurtosis	1.988025
Jarque-Bera	1.309009
Probability	0.519699

Heteroskedasticity Test: ARCH

F-statistic	21.82012	Prob. F(1,25)	0.0001
Obs*R-squared	12.58312	Prob. Chi-Square(1)	0.0004





ESTIMATION OUTPUT B5: Regression Results applying the Cochranne-Orcutt method for correcting autocorrelation

(ΔPGC_t) against (ΔGDP_t)

```
Dependent Variable: Yt
Method: Least Squares
Sample (adjusted): 2 28
Included observations: 27 after adjustments

==========================================================================
         Variable        Coefficient    Std. Error   t-Statistic    Prob.
==========================================================================
            C             32075.95      8527.432      3.761501     0.0009
            Xt            6213.104      1784.463      3.481777     0.0018
==========================================================================
R-squared                  0.326559   Mean dependent var         41703.31
Adjusted R-squared         0.299621   S.D. dependent var         50085.35
S.E. of regression         41915.75   Akaike info criterion      24.19590
Sum squared resid          4.39E+10   Schwarz criterion          24.29189
Log likelihood            -324.6446   Hannan-Quinn criter.       24.22444
F-statistic                12.12277   Durbin-Watson stat         1.778010
Prob(F-statistic)          0.001848
==========================================================================
```

$$Y_t = \Delta PGC_t - \hat{\rho}\,\Delta PGC_{t-1}$$

$$X_t = \Delta GDP_t - \hat{\rho}\,\Delta GDP_{t-1}\ ,\ \hat{\rho} = \sum \hat{u}_t \hat{u}_{t-1} \Big/ \sum \hat{u}_t^2 = 0{,}676286$$

$(\Delta TRUCK_t)$ against (ΔGDP_t)

```
Dependent Variable: Yt
Method: Least Squares
Sample (adjusted): 2 28
Included observations: 27 after adjustments

==========================================================================
         Variable        Coefficient    Std. Error   t-Statistic    Prob.
==========================================================================
            C             11128.69      1712.927      6.496881     0.0000
            Xt            1096.685      256.4186      4.276935     0.0002
==========================================================================
R-squared                  0.422528   Mean dependent var         14724.55
Adjusted R-squared         0.399430   S.D. dependent var         10006.55
S.E. of regression         7754.721   Akaike info criterion      20.82118
Sum squared resid          1.50E+09   Schwarz criterion          20.91717
Log likelihood            -279.0859   Hannan-Quinn criter.       20.84972
F-statistic                18.29217   Durbin-Watson stat         1.813018
Prob(F-statistic)          0.000243
==========================================================================
```

$$Y_t = \Delta TRUCK_t - \hat{\rho}\,\Delta TRUCK_{t-1}$$

$$X_t = \Delta GDP_t - \hat{\rho}\,\Delta GDP_{t-1}\ ,\ \hat{\rho} = \sum \hat{u}_t \hat{u}_{t-1} \Big/ \sum \hat{u}_t^2 = 0{,}409643$$

ESTIMATION OUTPUT B5

($\Delta MOTO_t$) against (ΔGDP_t)

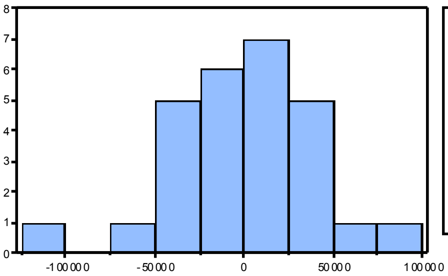
```
Dependent Variable: Yt
Method: Least Squares
Sample (adjusted): 2 28
Included observations: 27 after adjustments
==============================================================================
           Variable       Coefficient    Std. Error    t-Statistic     Prob.
==============================================================================
               C            8563.784      1868.342      4.583629      0.0001
               Xt           1182.089      451.8179      2.616295      0.0149
==============================================================================
R-squared                   0.214947   Mean dependent var           9288.663
Adjusted R-squared          0.183545   S.D. dependent var           10625.36
S.E. of regression          9600.848   Akaike info criterion        21.24828
Sum squared resid           2.30E+09   Schwarz criterion            21.34427
Log likelihood             -284.8517   Hannan-Quinn criter.         21.27682
F-statistic                 6.844999   Durbin-Watson stat           1.524777
Prob(F-statistic)           0.014862
==============================================================================
```

$$Y_t = \Delta MOTO_t - \hat{\rho}\,\Delta MOTO_{t-1}$$

$$X_t = \Delta MOTO_t - \hat{\rho}\,\Delta MOTO_{t-1}\ ,\ \hat{\rho} = \sum \hat{u}_t \hat{u}_{t-1} \Big/ \sum \hat{u}_t^2 = 0{,}820655$$

ESTIMATION OUTPUT B6: Residual diagnostics tests for the estimated model with the Cochranne-Orcutt method for correcting autocorrelation

(***ΔPGC***$_t$) against (ΔGDP_t)



Series: Residuals
Sample 2 28
Observations 27

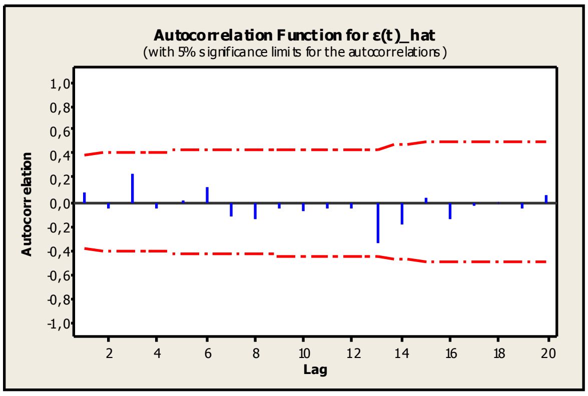
Mean	1.24e-11
Median	5589.368
Maximum	94161.57
Minimum	-109958.5
Std. Dev.	41101.77
Skewness	-0.233027
Kurtosis	3.770507
Jarque-Bera	0.912249
Probability	0.633735

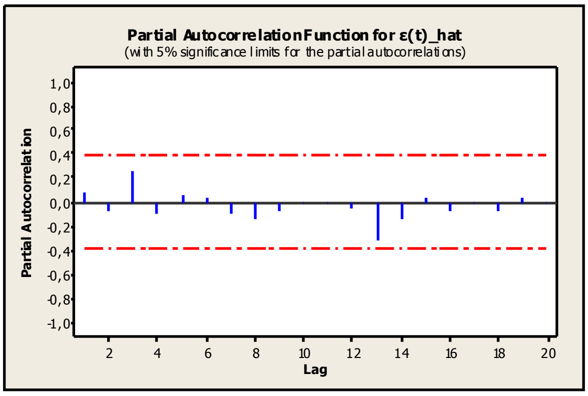
Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.127529	Prob. F(2,23)	0.8809
Obs*R-squared	0.296131	Prob. Chi-Square(2)	0.8624

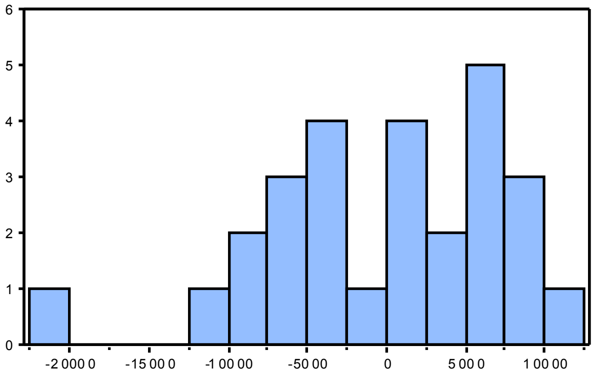
Heteroskedasticity Test: ARCH

F-statistic	0.528613	Prob. F(1,24)	0.4742
Obs*R-squared	0.560322	Prob. Chi-Square(1)	0.4541





(***ΔTRUCK***$_t$) against (ΔGDP_t)



Series: Residuals
Sample 2 28
Observations 27

Mean	1.68e-12
Median	1064.559
Maximum	12174.42
Minimum	-21432.48
Std. Dev.	7604.130
Skewness	-0.737515
Kurtosis	3.536429
Jarque-Bera	2.771407
Probability	0.250148

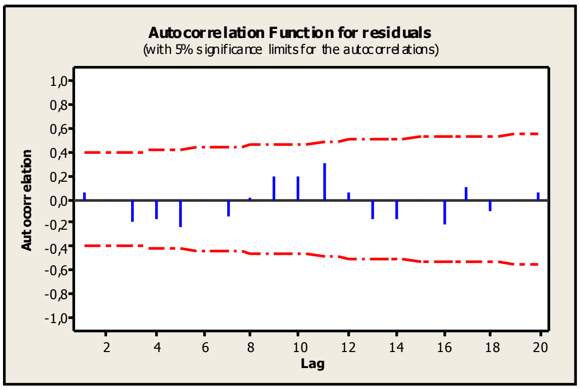
ESTIMATION OUTPUT B6

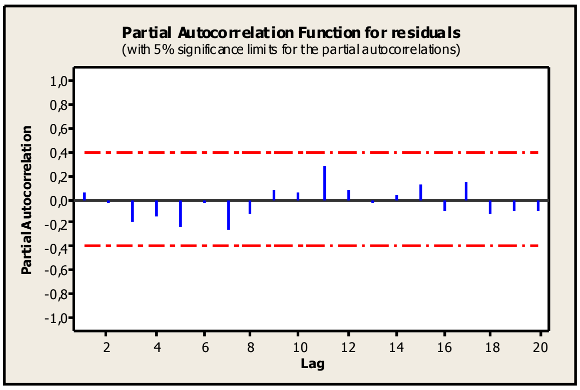
Breusch-Godfrey Serial Correlation LM Test:

```
F-statistic        0.054004    Prob. F(2,23)           0.9475
Obs*R-squared      0.126200    Prob. Chi-Square(2)     0.9388
```

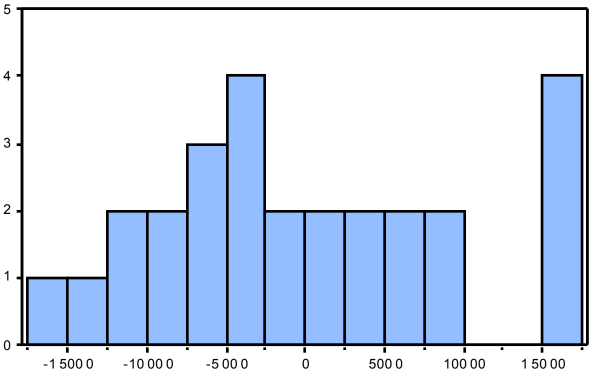
Heteroskedasticity Test: ARCH

```
F-statistic        1.357204    Prob. F(1,24)           0.2555
Obs*R-squared      1.391608    Prob. Chi-Square(1)     0.2381
```





($\Delta MOTO_t$) against (ΔGDP$_t$)



```
Series: Residuals
Sample 2 28
Observations 27

Mean         -1.48e-12
Median       -602.4497
Maximum       16967.08
Minimum      -15455.40
Std. Dev.     9414.406
Skewness      0.369967
Kurtosis      2.138645

Jarque-Bera   1.450613
Probability   0.484176
```

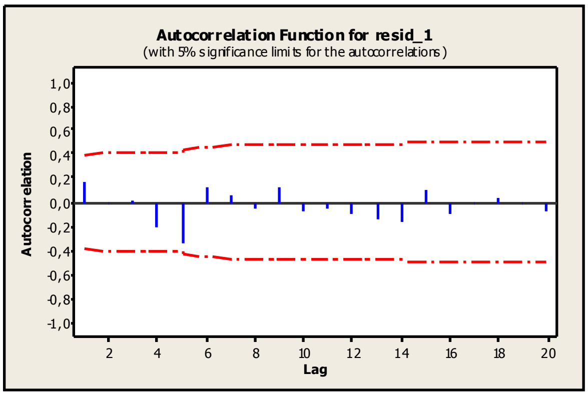
Breusch-Godfrey Serial Correlation LM Test:

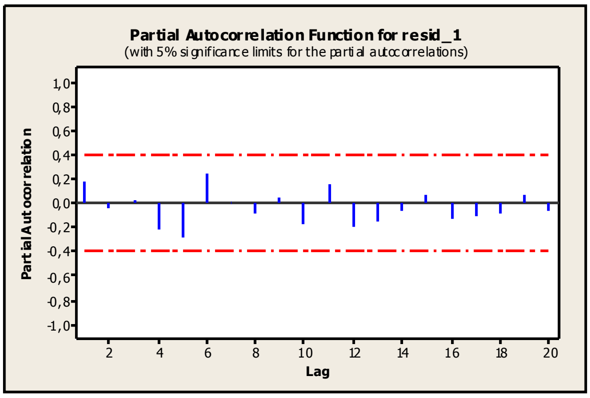
```
F-statistic        0.398569    Prob. F(2,23)           0.6758
Obs*R-squared      0.904424    Prob. Chi-Square(2)     0.6362
```

Heteroskedasticity Test: ARCH

```
F-statistic        0.088319    Prob. F(1,24)           0.7689
Obs*R-squared      0.095328    Prob. Chi-Square(1)     0.7575
```

ESTIMATION OUTPUT B6


Autocorrelation Function for resid_1
(with 5% significance limits for the autocorrelations)
Autocorrelation
1,0
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
-1,0
2
4
6
8
10
12
14
16
18
20
Lag


Partial Autocorrelation Function for resid_1
(with 5% significance limits for the partial autocorrelations)
Partial Autocorrelation
1,0
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
-1,0
2
4
6
8
10
12
14
16
18
20
Lag

ESTIMATION OUTPUT B7: Augmented Dickey-Fuller test Result for "number of Buses" and "GDP"

In Levels

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-2.628240	0.0998	ADF Test Statistic		0.827712	0.9996
Critical values	1% level	-3.699871		Critical values	1% level	-4.323979	
	5% level	-2.976263			5% level	-3.580623	
	10% level	-2.627420			10% level	-3.225334	

In First Differences

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-1.672709	0.4332	ADF Test Statistic		-3.255490	0.0953
Critical values	1% level	-3.699871		Critical values	1% level	-4.339330	
	5% level	-2.976263			5% level	-3.587527	
	10% level	-2.627420			10% level	-3.229230	

In Second Differences

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-6.902718	0.0000	ADF Test Statistic		-6.941248	0.0000
Critical values	1% level	-3.711457		Critical values	1% level	-4.356068	
	5% level	-2.981038			5% level	-3.595026	
	10% level	-2.629906			10% level	-3.233456	

GDP in Levels

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-2.356653	0.1628	ADF Test Statistic		-2.672492	0.2545
Critical values	1% level	-3.699871		Critical values	1% level	-4.339330	
	5% level	-2.976263			5% level	-3.587527	
	10% level	-2.627420			10% level	-3.229230	

GDP In First Differences

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-0.369684	0.9011	ADF Test Statistic		-0.999731	0.9274
Critical values	1% level	-3.699871		Critical values	1% level	-4.339330	
	5% level	-2.976263			5% level	-3.587527	
	10% level	-2.627420			10% level	-3.229230	

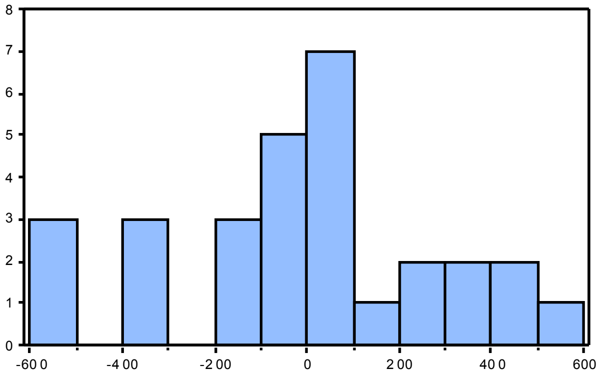
GDP In Second Differences

Exogenous: Constant				**Exogenous: Constant, Linear Trend**			
		t-statistic	Prob			t-statistic	Prob
ADF Test Statistic		-3.649036	0.0116	ADF Test Statistic		-3.945489	0.0243
Critical values	1% level	-3.711457		Critical values	1% level	-4.356068	
	5% level	-2.981038			5% level	-3.595026	
	10% level	-2.629906			10% level	-3.233456	

ESTIMATION OUTPUT B8: Estimated Regression Model of "number of Buses" on "GDP" and "GDP-squared"

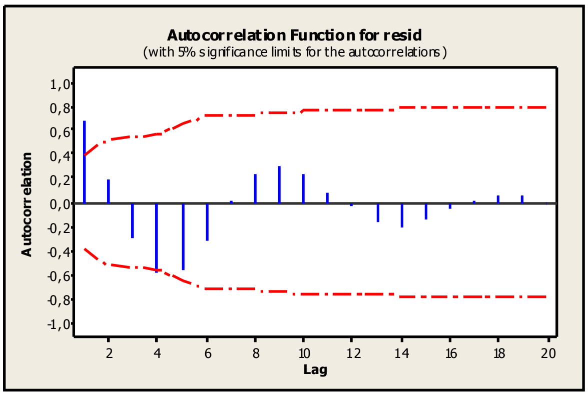
```
Dependent Variable: BUS
Method: Least Squares
Sample: 1 29
Included observations: 29
==========================================================================
       Variable         Coefficient    Std. Error    t-Statistic    Prob.
==========================================================================
          C               17304.53      195.3851      88.56631     0.0000
         GDP              106.2185      3.790708      28.02075     0.0000
        GDP^2            -0.280749      0.014802     -18.96633     0.0000
==========================================================================
R-squared                 0.988902   Mean dependent var          24806.86
Adjusted R-squared        0.988049   S.D. dependent var          2871.237
S.E. of regression        313.8902   Akaike info criterion       14.43366
Sum squared resid         2561704.   Schwarz criterion           14.57511
Log likelihood           -206.2881   Hannan-Quinn criter.        14.47796
F-statistic               1158.414   Durbin-Watson stat          0.523813
Prob(F-statistic)         0.000000
==========================================================================

Exogenous: None
Lag Length: 3 (Automatic - based on SIC, maxlag=6)
==========================================================================
                                                 t-Statistic     Prob.*
==========================================================================
Augmented Dickey-Fuller test statistic            -4.545624      0.0001
--------------------------------------------------------------------------
Test critical values:        1% level             -2.660720
                             5% level             -1.955020
                             10% level            -1.609070
==========================================================================
*MacKinnon (1996) one-sided p-values.
```

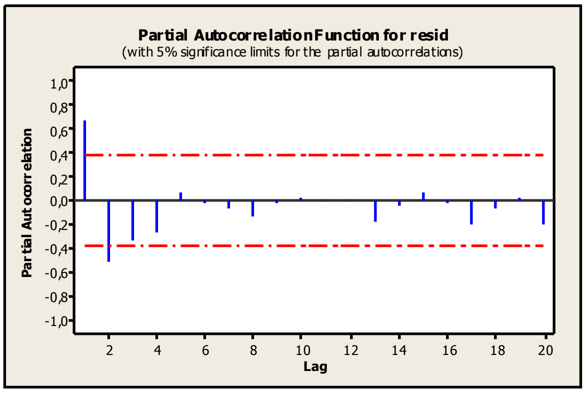
ESTIMATION OUTPUT B9: Diagnostic tests on the residuals from the regression "number of Buses" on "GDP" and "GDP-squared"



```
Series: Residuals
Sample 1 29
Observations 29

Mean          2.08e-12
Median        2.010179
Maximum       532.6133
Minimum      -566.9318
Std. Dev.     302.4722
Skewness     -0.151529
Kurtosis      2.412414

Jarque-Bera   0.528163
Probability   0.767911
```

```
Heteroskedasticity Test: ARCH

F-statistic          6.963469    Prob. F(1,26)             0.0139
Obs*R-squared        5.914946    Prob. Chi-Square(1)       0.0150
```

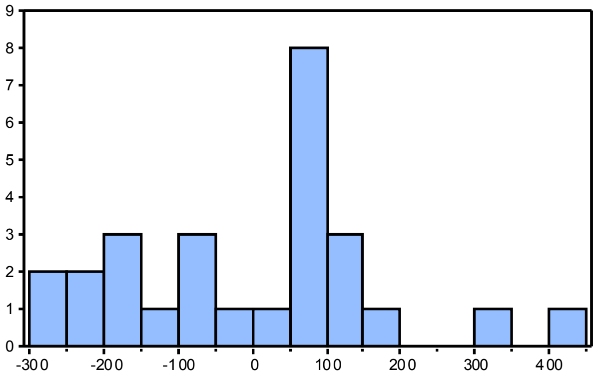




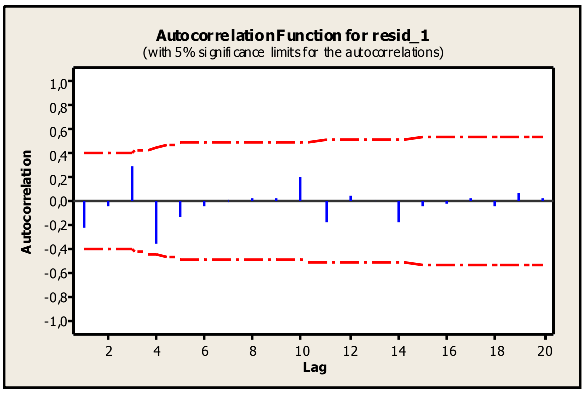
ESTIMATION OUTPUT B10: Fitting an AR(2) model to the residuals from the regression "number of Buses" on "GDP" and "GDP-squared"

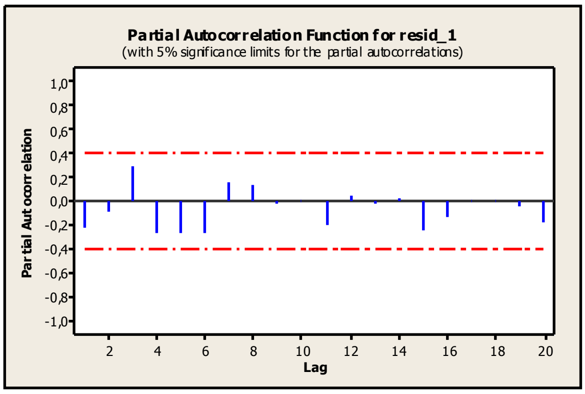
```
Dependent Variable: εt-hat
Method: Least Squares
Sample (adjusted): 3 29
Included observations: 27 after adjustments
Convergence achieved after 3 iterations

================================================================
     Variable        Coefficient   Std. Error   t-Statistic   Prob.
================================================================
      AR(1)            1.218280     0.161153     7.559784     0.0000
      AR(2)           -0.660226     0.166434    -3.966897     0.0005
================================================================
R-squared               0.707696  Mean dependent var       -3.023000
Adjusted R-squared      0.696004  S.D. dependent var        313.4245
S.E. of regression      172.8093  Akaike info criterion     13.21344
Sum squared resid       746576.3  Schwarz criterion         13.30943
Log likelihood         -176.3815  Hannan-Quinn criter.      13.24198
Durbin-Watson stat      2.383664
================================================================
```

```
Heteroskedasticity Test: ARCH

================================================================
F-statistic             1.447654  Prob. F(1,24)               0.2406
Obs*R-squared           1.479076  Prob. Chi-Square(1)         0.2239
================================================================
```



```
Series: Residuals
Sample 3 29
Observations 27

Mean          -1.211734
Median         53.45961
Maximum        404.8585
Minimum       -299.0574
Std. Dev.      169.4490
Skewness       0.216530
Kurtosis       2.886626

Jarque-Bera    0.225444
Probability    0.893399
```

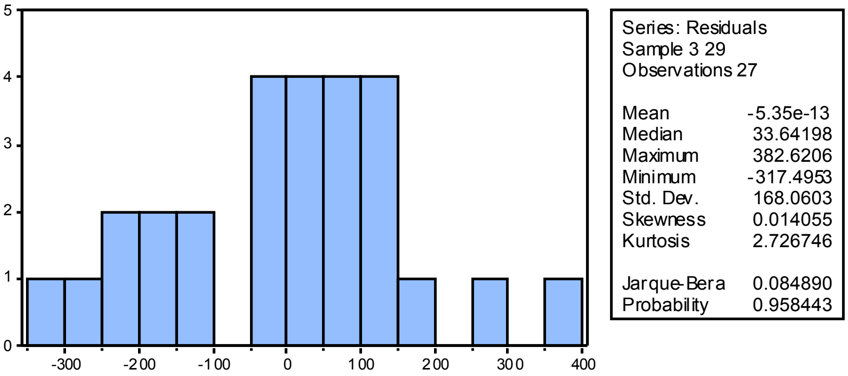




ESTIMATION OUTPUT B11: Estimated regression of "number of Buses" on "GDP" and "GDP-squared" with uncorrelated errors

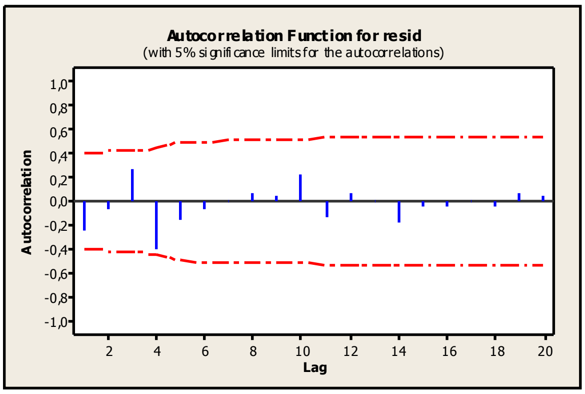
```
Dependent Variable: Yt
Method: Least Squares
Sample (adjusted): 3 29
Included observations: 27 after adjustments

        Variable          Coefficient    Std. Error    t-Statistic     Prob.

           C               7598.282      141.7882      53.58895      0.0000
           Xt              109.2363      6.076583      17.97660      0.0000
           Zt             -0.293841      0.023327     -12.59680      0.0000

R-squared                  0.977421   Mean dependent var          11103.59
Adjusted R-squared         0.975539   S.D. dependent var          1118.432
S.E. of regression         174.9227   Akaike info criterion       13.27100
Sum squared resid          734351.1   Schwarz criterion           13.41499
Log likelihood            -176.1586   Hannan-Quinn criter.        13.31382
F-statistic                519.4592   Durbin-Watson stat          2.417478
Prob(F-statistic)          0.000000
```

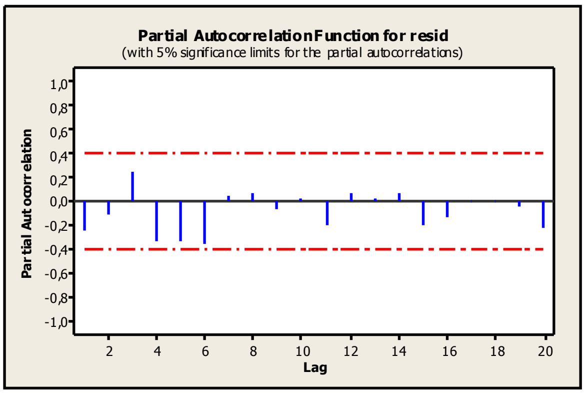
Residual Diagnostic Tests



```
Series: Residuals
Sample 3 29
Observations 27

Mean         -5.35e-13
Median        33.64198
Maximum       382.6206
Minimum      -317.4953
Std. Dev.     168.0603
Skewness      0.014055
Kurtosis      2.726746

Jarque-Bera   0.084890
Probability   0.958443
```

```
Heteroskedasticity Test: ARCH

F-statistic                2.222208   Prob. F(1,24)                 0.1491
Obs*R-squared              2.203377   Prob. Chi-Square(1)           0.1377
```





ESTIMATION OUTPUT B12: Estimating the total number of MOPEDS

$\Delta MOPED_t$ in Levels

Exogenous: Constant, Linear Trend

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.122250	0.1453
Test critical values:	1% level	-4.992279	
	5% level	-3.875302	
	10% level	-3.388330	

$\Delta MOPED_t$ in First Differences

Exogenous: Constant

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-5.010683	0.0030
Test critical values:	1% level	-4.200056	
	5% level	-3.175352	
	10% level	-2.728985	

Exogenous: Constant, Linear Trend

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.823716	0.0150
Test critical values:	1% level	-5.124875	
	5% level	-3.933364	
	10% level	-3.420030	

ADF test on the residuals from the linear regression of $\Delta MOPED_t$ *on* ΔGDP_t

Exogenous: None

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.628313	0.0017
Test critical values:	1% level	-2.771926	
	5% level	-1.974028	
	10% level	-1.602922	

ESTIMATION OUTPUT B12:

Linear Regression of $\Delta MOPED_t$ on ΔGDP_t

```
Dependent Variable: ΔMOPEDt
Method: Least Squares
Sample (adjusted): 2 14
Included observations: 13 after adjustments
==============================================================================
       Variable          Coefficient     Std. Error     t-Statistic     Prob.
==============================================================================
          C               3968.040       3418.974        1.160594      0.2704
        D_GDP             365.4959       285.4764        1.280302      0.2268
==============================================================================
R-squared                 0.129690   Mean dependent var              5254.923
Adjusted R-squared        0.050571   S.D. dependent var              12092.25
S.E. of regression        11782.53   Akaike info criterion           21.72726
Sum squared resid         1.53E+09   Schwarz criterion               21.81418
Log likelihood           -139.2272   Hannan-Quinn criter.            21.70940
F-statistic               1.639173   Durbin-Watson stat              2.126718
Prob(F-statistic)         0.226778
==============================================================================
```

Residual Diagnostic Tests

```
Breusch-Godfrey Serial Correlation LM Test:
==============================================================================
F-statistic               0.273073   Prob. F(2,9)                      0.7671
Obs*R-squared             0.743745   Prob. Chi-Square(2)               0.6894
==============================================================================
```

```
Heteroskedasticity Test: ARCH
==============================================================================
F-statistic               0.037312   Prob. F(1,10)                     0.8507
Obs*R-squared             0.044608   Prob. Chi-Square(1)               0.8327
==============================================================================
```

Section 7

Policy Implications

An overview

This part of the report consists of two sections. In the first section the basic analytical tools of policy evaluation are presented alongside with the relative literature review. Then the analytical results from the marginal abatement cost (MAC) curves for energy, transport and industry are presented and evaluated. In the last section a nonparametric analysis known as data envelopment analysis (DEA) is applied in order to evaluate the efficiency of the energy policies adopted over the hypothetical scenarios introduced earlier in the report.

Key findings

- There are many alternative technologies which can be adopted for medication purposes.
- The results from the MAC curve indicate that costless policy adoptions will be able to reduce pollution compared to the baseline scenario.
- There are several command and control policies which can be adopted as a result of a costless strategy to reduce pollution.
- The relative medication potential associated with the energy sector even though there are more costly, if adopted will have a significant impact on the reduction of pollution compared to industry sector.
- There is only one valid choice (among the other technologies) of abatement option for the transport sector which is cost effective.
- The efficiency of the renewable energy commitments set by the Greek government under the Law 3851/2010 will not be sufficient to decrease systematically the generated GHG emissions.

7.1 Introduction

Marginal abatement cost (MAC) curve is a popular tool for assessing abatement options because it approaches the complex issue of cost-effective options in a simple and straightforward manner. MAC curve demonstrates graphically the cost effective way to reduce carbon emissions. Specifically, MAC curves contrast the marginal abatement cost (€/tCO_2 eq.) on the y axis for varying amounts of emission reductions (thousand tCO_2 eq.). These emission reductions are compared relative to the business as usual economic activity where no CO_2 reduction policy will be implemented. A negative abatement cost indicates that the business as usual economic activity costs more than the implementation of an abatement policy.

The popularity of MAC curves concept is based on its simplicity as it can yield the marginal abatement cost for any given amount of pollution reduction. In addition, we can set a desired amount of emissions to be abated and calculate the total abatement cost required for this reduction. A MAC curve can also yield the average abatement costs. However, MAC curve concept has a number of drawbacks (Elkins et al., 2011). At first, the curve is a snapshot and it is limited only at a point of time. Furthermore, the curve offers no path dependency or technological structure for the abatement options as the decision maker can apply any option in order to achieve a desired emission reduction. In addition, uncertainty is a significant issue for MAC curves which becomes more significant as the time horizon widens e.g. 2050. Finally, the reduction of emissions might probably yield a number of additional benefits which are not included in the curve such as health benefits. A number of alternative models have been proposed across the literature, which aim to solve some of the aforementioned drawbacks, such as the model proposed by Ward (2014).

MAC curves have been widely used across the literature. Halsnaes et al. (1994) constructed MAC curves for ten countries for short and long term targets for the needs of UNEP Greenhouse Gas Abatement Costing Project. The objective of the Project was to perform studies at a country level and to provide a unified framework for countries which have signed the United Nation's Framework Convention on Climate Change in 1994. Soloveitchik et al. (2002) studied the electricity sector of Israel for the time period 2003-2013. The authors presented MAC curves in order to address emissions mitigation problem and to assist the decision maker to set the optimal taxation. Baker et al. (2008) investigated how technical change via innovation affects the marginal abatement cost and emissions mitigation and they employed MAC curves for their analysis. Kuik et al. (2009) conducted a meta-analysis of GHGs mitigation studies and found abatement costs are sensitive to many factors such as business as usual emissions, a number of model assumptions and control variables. They constructed long-run MAC curves and found that strict long term targets set by the European Commission appear to be highly uncertain. Park and Lim (2009) presented MAC curve for the electricity sector in Korea in order to evaluate alternative mitigation options. They provide insights which are willing to assist the power plants to harmonize with the imposed regulation. Recent studies by Garg et al. (2014) and Vogt-Schilb et al. (2014) constructed MAC curves for India and Brazil respectively.

7.1.1. Types of MAC curves

According to Kesicki (2011) there are two types of MAC curves, expert-based MAC curves and model-derived MAC curves. Expert-based MAC curves are developed based on assumptions made by experts and they present detailed technological options. Each bar represents an abatement option. The width of the bar represents the abatement potential of this abatement option and the height of the bar represents the cost for each year, relative to the business as usual economic activity. The width of all bars together reveals the total abatement potential. Furthermore, the left side of the curve demonstrates the cheapest abatement options and as we move to the right side the costs are being raised. Among the advantages of this type of MAC curve is the easy understanding, the simple representation of the technological options and the ability to account for marker distortions. On the other hand, the principal disadvantage is the simplification of the assumptions. Furthermore, other drawbacks of expert-based MAC curve are the inability to account for any possible interactions among the abatement options or for any other interactions, time uncertainty and inconsistency of business as usual emissions (Kesicki, 2011).

Recently, expert-based MAC curve has received great attention because of the McKinsey's (2010) work which published MAC curves for 14 countries and a global MAC curve (Naucler and Enkvist, 2009). The government and scientific communities in United Kingdom have also adopted the concept of expert-based MAC curve. Atomic Energy Authority (2008) published a report for Ecofys and Committee on Climate Change with MAC curves for industrial, domestic and non-domestic sectors. The Stationary Office (2008) has issued a report regarding UK's emission targets towards 2050, the mitigation choices between CO2 and other GHG emissions and other guidelines regarding the optimal abatement strategy. They include expert-based MAC curves in their analysis for energy, residential, non-domestic buildings, industrial and transport sectors. The Department of Energy & Climate Change (2009a,b) constructed MAC curves for the entire UK economy including domestic, non-domestic, transport, industry, agriculture and wastes sectors. The target of the reports is to assess the mitigation policies under the EU Emissions Trading System (ETS) and those which are not included in the ETS and to propose the optimal mitigation strategy for United Kingdom. Johnson et al. (2009) constructed expert-based MAC curves for Mexico including agriculture and forestry, oil and gas, energy end-use, transport and electricity sectors. O'Brien et al. (2014) also used an expert-based MAC curve in order to evaluated abatement options for GHG emissions in Irish agricultural sector.

The second type of MAC curve, the model-derived MAC curve, is to calculate the abatement costs and potentials via energy models. Model-derived MAC curves avoid a number of drawbacks of expert-based curves, such as the interactions between abatement options, model uncertainty and the incorporation of additional benefits (Kesicki 2011). On the other hand, this type of MAC curve does not offer any insights on technological abatement options and can not handle negative costs. Kesicki and Strachan (2011) present two types of model-derived MAC curves, those which are based on partial equilibrium bottom-up models which consider only one sector, and top-down models such as the computable general equilibrium (CGE) models which account for the entire economy. Regarding the strengths and drawbacks of each model, bottom-up models offer the ability for a detailed presentation and in-depth analysis of energy sector; however all the other sectors are not included in the analysis. Furthermore, bottom-up models are susceptible to small changes in costs and they tend to underestimate abatement costs (Edenhofer et al. 2006). Top-down models offer no technological details and no in-depth sectoral analysis; however they incorporate macroeconomic effects from the whole economy.

Beaumont and Tinch (2004) investigated whether environmental regulation on industrial wastes can result in improvement for both industrial activity and the environment. The authors used a bottom-up approach and constructed MAC curves for copper pollution in Humber Estuary, UK. Criqui et al. (2006) used the bottom up AGRIPOL model to evaluate the mitigation options for GHG emissions and created MAC curves for agricultural sector. Simoes et al. (2008) used TIMES_PT which is a bottom-up model, in order to create MAC curves and study the CO2 emissions in Portuguese energy sector. Delarue et al. (2010) used a simulation bottom-up model in order to study the electricity sector in Europe. In addition the authors constructed a 3D abatement curve where they included gas to coal price ratio in order to capture more complex connections. Kiuila and Rutherford (2013) proposed a methodology about a piecewise smoothing approximation for bottom-up MAC curves. The methodology could be introduced to any sector with decreasing returns to scale technologies.

Rasmussen (2001) constructed a multi-sector MAC curve for Denmark using a top-down general equilibrium model in order to study the effects of learning-by-doing in renewable energy. Sands (2004) applied the Second Generation Model which is a top-down collection of CGE models and constructed MAC curves over time for GHG emissions abatement. Klepper and Peterson (2006) used the top-down CGE model DART and studied the MAC curves in a country level are affected by global abatement efforts and energy prices. The findings indicate that global actions affect national MAC curves. Bernard et al. (2006) investigate the global economy using a top-down CGE model for different regions in multiple countries. The authors found that the incorporation of more GHGs than CO2 in the analysis results in a cost reduction in long term. Bohringer et al. (2009) applied the CGE PACE model to examine the impact of EU climate policies on international trade and the use of energy. Dellink et al. (2004) integrated a bottom-up and a top-down approach in a dynamic CGE framework. Kiuila and Rutherford (2013) also deal with the incorporation of bottom-up approach inside the top-down framework. The above approaches aim to tackle the entire economy (top-down model) and to benefit from the detailed information for the sector (bottom-up).

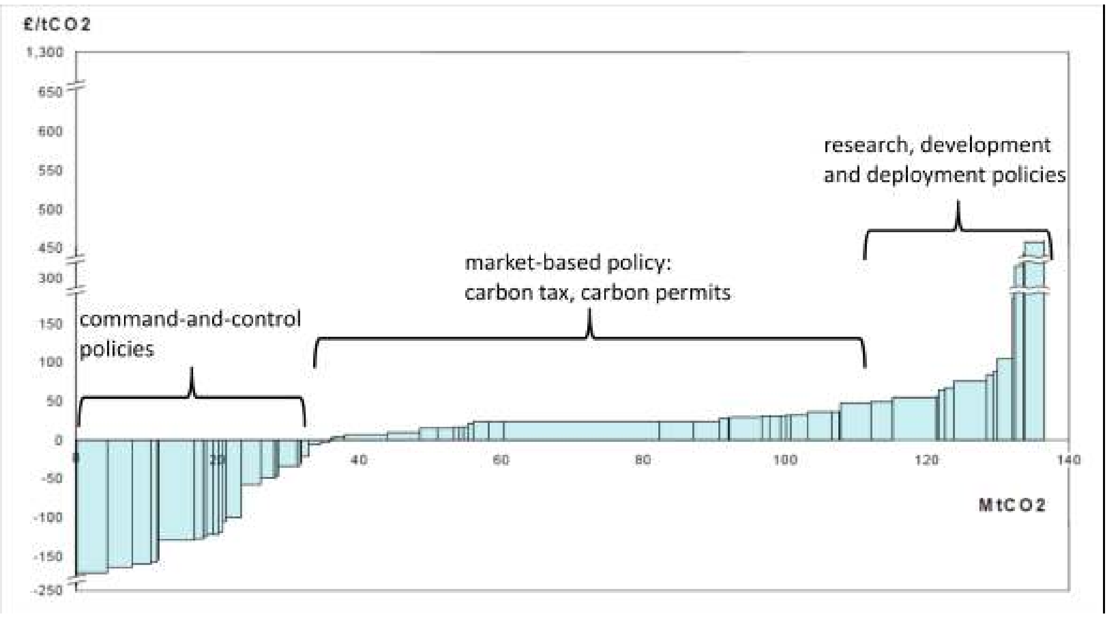
7.1.2. Determining mitigation policy through MAC curves

Following Kesicki (2011) mitigation policies can be divided into two categories, incentive and non-incentive based instruments. On the one hand, incentive based instruments create incentives for the emitters to reduce their emissions. They are proffered relative to non-incentive instruments because they do not enforce a solution; on the contrary they motivate toward a lower level of emissions and let the market to choose the optimal solution. Incentive based instruments might take two forms, price-based instruments such as taxes and quantity-based instruments such as tradable permits. Both of these instruments set a limit for the emissions and it is assumed that up to this point all the available abatement options will take place. Specifically, taxation on emissions incentivizes an emitting firm to internalize the cost of its emissions. The firm who wishes to maximize its profits will control the emissions through mitigation policy up to the point which it costs less than the imposed tax. A cap and trade system creates a market for emission permits which are tradable. These permits define the amount of emissions which any source is able to emit. Any emissions above this point or without any permit are charged with large fines. The total amount of permits inside a market defines the optimal level of emissions.

Non-incentive based instruments are considered less efficient than incentive based instruments because they are less flexible and they do not let the market to choose the optimal solution. However, they are considered as necessary in the presence of market imperfections. Non-incentive based instruments can be divided in two categories, command and control policies and research and development and deployment policies (Keisicki 2011). Command and control policies are enforced through regulation and they can not be ignored by any party. They are useful in case of market failures such as imperfect information and they can be enforced at the first part of the MAC curve, the negative part. As we mentioned previously, negative cost for an abatement option means that this option cost less than the business as usual economic activity. This market failure can be easily tackled with command and control policies. Command and control policies among others might take the form of standards, voluntary agreements and subsides. Conversely research and development policies are useful for the last part of the MAC curve where the marginal abatement cost is very high. The target is to promote innovation through academic and non-academic research and projects. Deployment policies are also useful for the last part of the MAC curve and they might the form of fiscal or non-fiscal policies.

In Figure 7.1 climate policy instruments are presented on a MAC curve (Kesicki 2011). The first part of MAC curve, where negative marginal abatement costs are present due to market imperfections, command and control policies are the best available option. The second part of the MAC curve where the marginal abatement cost is positive the optimal policies are price or quantity market-based instruments such as taxes and tradable permits. The last part of the MAC curve, where marginal abatement costs are very high, requires research and development or deployment policies.

Figure 7.1: MAC curves and climate policy instruments



Source: Kesicki (2011) pp.12

Next in Figures 7.2 we present the overall MAC curve which we have constructed for energy, industry and transport sectors. The business as usual activity refers to the activity which is currently in action. The business as usual activity in energy sector is to continue with the current fuel composition which is based on lignite. Similar assumption holds for industry and transport sectors. At the left part of the MAC curve, which is the negative part, there are six abatement options. Specifically, the gasoline bundle for conventional heavy duty trucks over 3.5 tons can abate up to 918.14 thousand tCO_2 eq. for a marginal abatement cost of -89.25 euro/tCO_2 equivalent. Next is small-hydro abatement option which offers the ability to abate 2412.14 thousand tCO_2 eq. for a marginal abatement cost of -19.93 euro/tCO_2 equivalent. Behavioral changes in petroleum refineries offers the opportunity to abate up to 2426.90 thousand tCO_2 eq for a marginal abatement cost of -0.51 €/ tCO_2 eq. Next there are three abatement options for iron and steel subsector which are all negative. Specifically, direct casting abatement options for iron and steel can abate up to 2421.35 thousand tCO_2 eq. for a marginal abatement cost of -0.48 €/ tCO_2 eq. Smelt reduction abatement option for iron and steel can abate up to 2439.13 thousand tCO2 eq. for a marginal abatement cost of -0.41 €/ tCO_2 eq. Co-generation abatement option for iron and steel offers the opportunity to abate up to 2470.25 thousand t CO_2 eq. for a marginal abatement cost of -0.18 €/ tCO_2 eq.

Considering the above analysis this might be a result of market imperfection such as split incentives, imperfect information or other barriers. The optimal strategy for this abatement option is to impose command and control policies in order to build more small-hydro plants. Innes and Bial (2002) found evidence that support setting environmental standards as a better option than market-based instruments such as taxes. In addition, Requate and Unold (2003) compared a number of alternative climate change policies and found that in some cases command and control policies, and specifically imposing standards, appear to perform better than other instruments. Bauman et al. (2008) found evidence that command

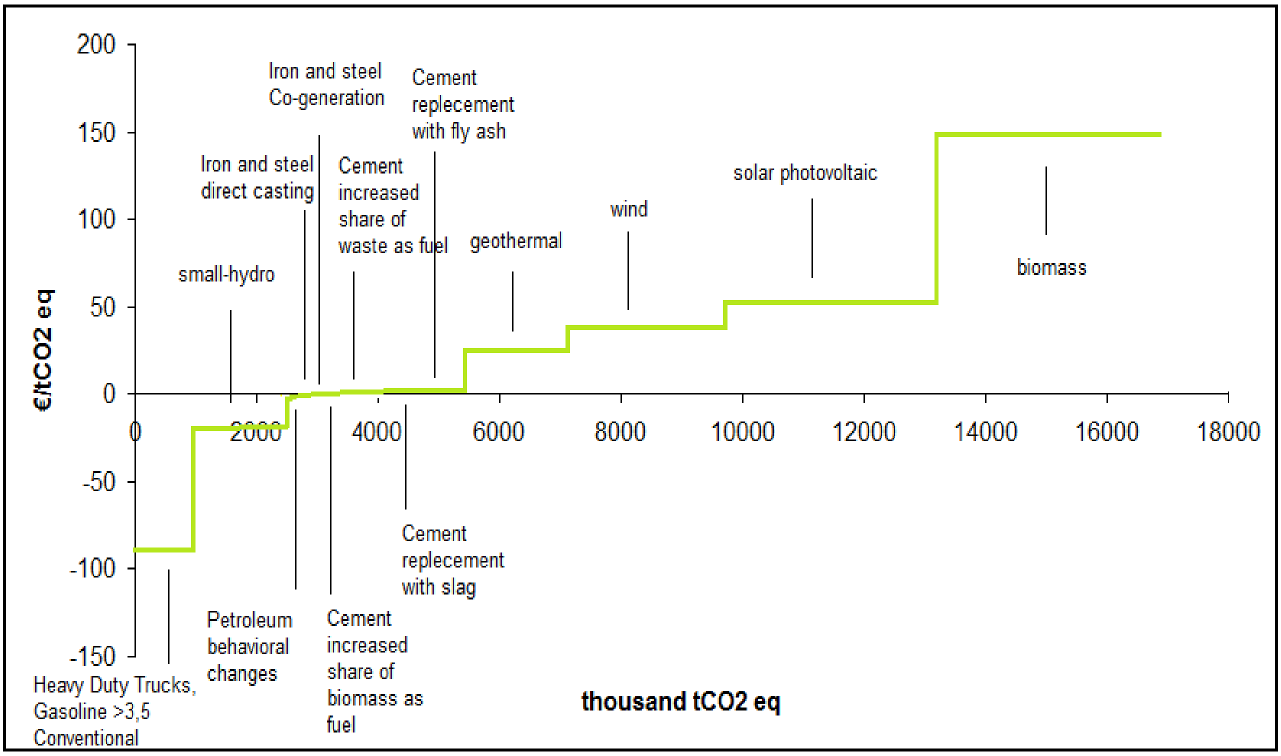
and control policies work better than market-based instruments for the case of Korean energy sector.

Moreover, at the second part of the MAC curve there are seven abatement options. In this part of the MAC curve market-based policies are the optimal strategy. To start with, increased share of biomass as a fuel at cement plants offers the opportunity to abate up to 2954.09 thousand tCO_2 eq for a marginal abatement cost of 0.22 €/ tCO_2 eq. Increased share of wastes as a fuel at cement plants can abate up to 3437.93 thousand tCO_2 eq for a marginal abatement cost of 0.65 €/ t CO_2 eq. Clinker replacement with slag at cement plants can abate up to 4333.93 thousand tCO_2 eq for a marginal abatement cost of 0.77 €/ tCO_2 eq. Clinker replacement with fly-ash at cement plants can abate up to 5229.93 thousand tCO_2 eq. for a marginal abatement cost of 0.91 €/ tCO_2 eq. Next, there are three abatement options for energy sector. Geothermal energy options offers the opportunity to abate up to 6972.73 thousand t CO_2 eq. for a marginal abatement cost of 23.58 €/ tCO_2 eq. Wind power abatement option can abate up to 9595.73 thousand t CO_2 eq. for a marginal abatement cost of 38.49 €/ tCO_2 eq. Solar power has a potential to abate up to 13081.73 thousand t CO_2 eq. for a marginal abatement cost of 52.60 €/ tCO_2 eq. Price-based instruments such as taxes or quantity-based instruments such as tradable permits are among others the optimal options towards the realization of these abatement options.

There are mixed results across the literature about taxes and permits. Jung et al. (1996) examined auctioned and tradable permits, emission taxes and subsidies and standards. The authors found that permits provide the best results followed by taxes. Kennedy and Laplante (1999) examined taxes and permit and found that taxes perform slightly better although the differences are not large. Carlson et al. (2000) examine the market for SO_2 tradable permits. They found that tradable permits have lowered the marginal abatement costs. Montero (2002) compared four climate change policies, namely emission and performance standards and tradable and auctioned permits. The author found in perfect competition permits perform equally or better than standards. Requate and Unold (2003) support that taxes is a better instrument than permits in terms of providing incentives to lower emissions. Since all the abatement options in industrial subsectors have low marginal abatement costs we did not propose any abatement options which require R&D or deployment policies without implying that innovative and more cost-effective control methods are not always encouraged.

Biomass abatement option is on the far right corner of our energy MAC curve with an extremely high marginal abatement cost at 148.57 €/ tCO_2 eq., and also very high abatement potential up to 16800.13 thousand tCO_2 eq. The very high marginal abatement cost should be addressed with R&D or deployment policies. There are controversial findings regarding these policies across the literature. According to Parry (1998) welfare gains from these policies (e.g. R&D subsidies) are insignificant. Innes and Bial (2002) argue that innovating firms among others benefit from the high cost of their rivals after their successful innovation. Bauman et al. (2008) found no support than innovations lower marginal abatement costs; on the contrary some innovations increased the marginal abatement costs for Korean energy sector. Loschel (2002) found evidence that technical change through innovation and R&D leads to lower marginal abatement costs, more efficient environmental policy both in terms of mitigation potential and time, positive spillovers and negative leakage.

Figure 7.2: Overall Marginal Abatement Cost curve for energy, industry and transport sectors



7.2 Evaluation of the scenario based renewable energy policies based on nonparametric approaches

7.2.1 Methodological strategy

In order to evaluate the efficiency of the Greek government's energy renewable policies, we need to evaluate also their ability to reduce greenhouse gases (GHG) under the four energy policy scenarios described previously (BAU, TAR20, TAR30 and GREEN). Specifically, we need to evaluate under the four scenarios generated in LEAP for the period 1990-2030 the estimated energy usage of renewable sources of the Greek main sectors (industry, transport and energy) alongside with the generated greenhouse gases (GHG) produced. This can be accomplished by creating a composite performance index which can be comparable among the four renewable energy scenarios and among the sectors for the period

1990-2030. As a result this will enable us to evaluate the efficiency of the renewable energy policy (EREP) based on the future estimates produced using LEAP.[98]

In order to do so we apply a nonparametric approach known as data envelopment analysis (DEA). DEA is a mathematical programming technique which enables us to evaluate a specific process which is based on the estimation of a benchmark frontier – a relative frontier against which the decision making units (DMUs) are assessed, using specified DMUs' inputs and outputs (Daraio and Simar, 2007). Then the efficiency is calculated as the distance of each DMU from the estimated ('efficient') frontier. In our case the role of the DMUs are the years of each sector under the four energy scenario. Typically the DEA methodology is applied in a production framework investigating the efficiency of specific inputs to produce specific outputs.

However, in our study we follow a similar approach as the one initiated by Kuosmanen and Kortelainen (2005). They suggest an eco-efficiency indicator which involves the calculation of the ratio of value added (i.e. the good output/GDP) to the environmental damage or pressure index (i.e. the bad output/pollutant), approaching therefore the environmental efficiency from a social point of view rather than from the managerial point of view. Therefore their proposed index excludes the primary production factors even though they are important cost factors in technical and economic efficiency analysis (Kuosmanen and Kortelainen 2005, p. 64).

In our case the value added from the renewable energy policy perceptive is the energy consumption (measured in millions Gigajoules) from renewable sources whereas the bad output is the Greenhouse emissions (CO_2, CH_4 and N_2O) which will be produced in the future (based on the scenarios entered in LEAP) from the sectors of industry, energy and transport.

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[98] Halkos and Tzeremes (21014a) discuss the effect of electricity consumption from renewable sources on countries' economic growth levels while Halkos and Tzeremes (2014b) and Halkos (2014) show empirically the effect of countries compliance with the Kyoto protocol agreement (KPA) policies.

Based on the approach by Koopmans (1951) we can define the efficiency of renewable energy policy in a multiple dimensional Euclidean space. For the purpose of our analysis let us have M pollutants (Greenhouse emissions - CO_2, CH_4 and N_2O) measured by the variables $\mathbf{u} = (u_1, ..., u_m)$ and let ρ to denote the energy demand of the three sectors derived only from renewable energy sources (measured in millions Gigajoules). As a result we will be able to define the pollution generating technology set as:

$$T = \left\{ \begin{matrix} (\rho, \mathbf{u}) \in \Re_+^{1+M} \middle| \text{the energy consumption derived from renewable sources } \rho \\ \text{can be generated also with damage } \mathbf{u} \text{ derived from non-renewable energy sources} \end{matrix} \right\} \quad (7.1)$$

Expression (7.1) implies that even though and under the specified energy scenarios there will be a specific percentage of commitment of energy consumption from renewable sources, however, there will be also pollution generated from energy consumption from non-renewable sources. Therefore, in our case for efficiency the renewable energy policies implemented by the Greek government will have the aim to reduce the generated pollution. This efficiency can be represented as:

$$EREP_n = \frac{\mathrm{P}_n}{D(\mathbf{U}_n)} \quad (7.2)$$

In ratio (7.2) D represents the damage function of the M pollutants in a weighted average indicator represented as:

$$D(\mathbf{u}) = v_1 u_1 + v_2 u_2 + ... + v_m u_m \quad (7.3)$$

Since the problem of a proper weight (v) on the pollutants is crucial we follow Kuosmanen and Kortelainen (2005) suggesting the *benefit of the doubt* weighting scheme. This approach applies weights that maximize the relative EREP of the evaluated year and industry in comparison with the maximum attainable EREP. This can be calculated as[99]:

---

[99] In our analysis the letters with the upper case are referring to the observed data, whereas the lower case letters are referring to theoretical values.

$$
\begin{aligned}
&\max_{v} EREP_n = \frac{\mathrm{P}_n}{v_1 U_{n1} + v_2 U_{n2} + \ldots + v_M U_{nM}} \\
&s.t. \\
&\frac{\mathrm{P}_1}{v_1 U_{11} + v_2 U_{12} + v_M U_{1M}} \le 1 \\
&\frac{\mathrm{P}_2}{v_1 U_{21} + v_2 U_{22} + v_M U_{2M}} \le 1 \\
&\vdots \\
&\frac{\mathrm{P}_N}{v_1 U_{N1} + v_2 U_{N2} + v_M U_{NM}} \le 1. \\
&v_1, v_2, \ldots, v_M \ge 0
\end{aligned}
\tag{7.4}
$$

Therefore we use weights $v_m \left(m = 1, \ldots, M \right)$ to maximize the EREP ratio, subject to the condition that the highest attainable efficiency score does not exceed the maximum index value of one when the same weights are applied across all other years and industries. As can be observed the weights are not negative and the efficiency score can take the values between 0 and 1. As can be realised the value of 1 indicates an efficient renewable energy policy whereas values below 1 indicate inefficient policies. Furthermore, the program in (7.4) is fractional can is difficult to be solved. However by following Charnes and Cooper (1962) and Charnes et al. (1978) we can transform the fractional program presented in (7.4) into a linear program as:

$$
\begin{aligned}
&\min_{v} EREP_n^{-1} = v_1 \frac{U_{n1}}{\mathrm{P}_n} + v_2 \frac{U_{n2}}{\mathrm{P}_n} + \ldots + v_M \frac{U_{nM}}{\mathrm{P}_n} \\
&s.t. \\
&v_1 \frac{U_{11}}{\mathrm{P}_1} + v_2 \frac{U_{12}}{\mathrm{P}_1} + \ldots + v_M \frac{U_{1M}}{\mathrm{P}_1} \ge 1 \\
&v_1 \frac{U_{21}}{\mathrm{P}_2} + v_2 \frac{U_{22}}{\mathrm{P}_2} + \ldots + v_M \frac{U_{2M}}{\mathrm{P}_2} \ge 1, \\
&\vdots \\
&v_1 \frac{U_{N1}}{\mathrm{P}_N} + v_2 \frac{U_{N2}}{\mathrm{P}_N} + \ldots + v_M \frac{U_{NM}}{\mathrm{P}_N} \ge 1 \\
&v_1, v_2, \ldots, v_M \ge 0.
\end{aligned}
\tag{7.5}
$$

Then by using the distance function approach Shephard (1970) having k years in our analysis we can express our linear program as:

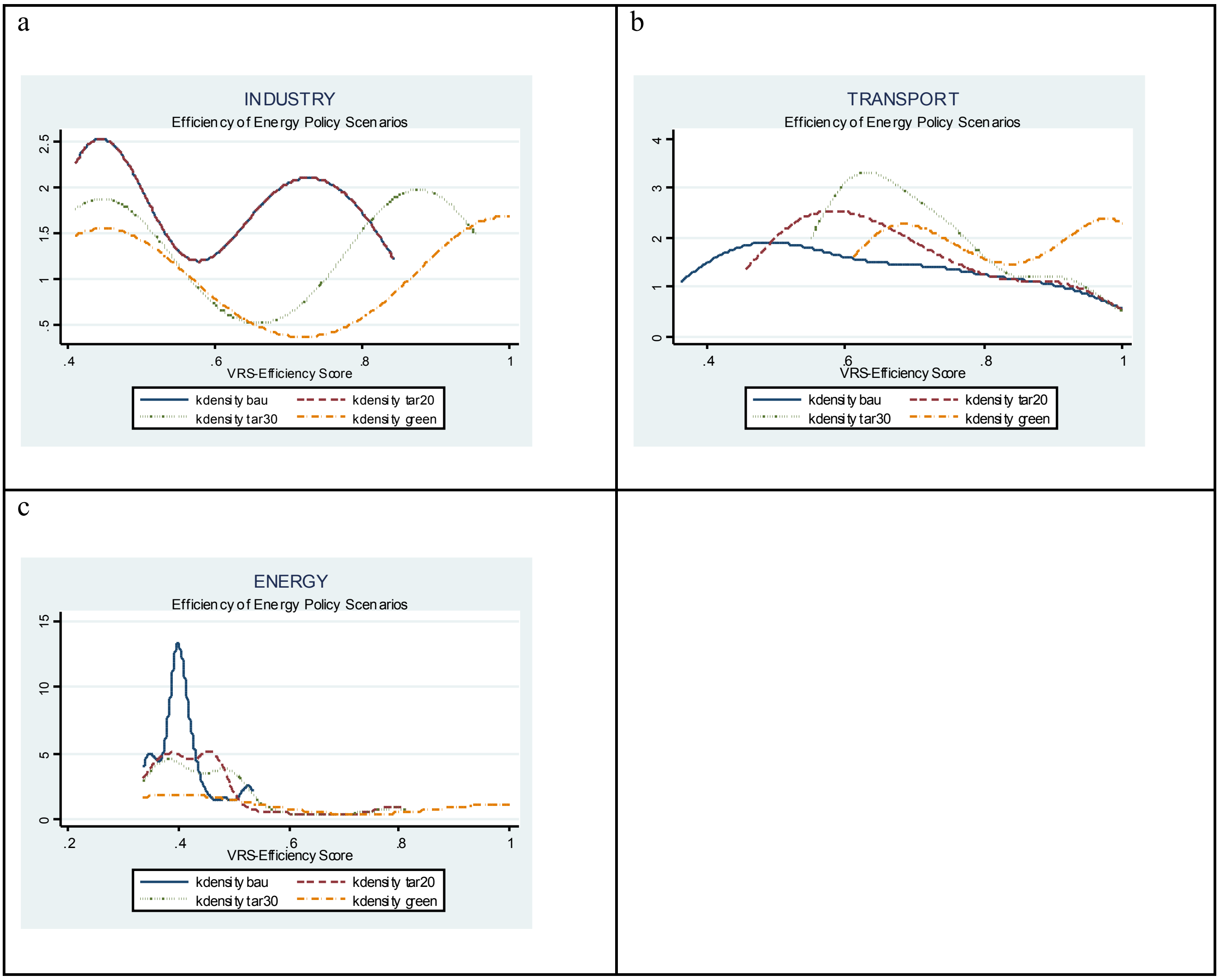
$$
\begin{aligned}
&\min_{\lambda} EREP_{\mathrm{n}} = \theta \\
&s.t. \\
&\theta U_{nm} \geq \sum_{k=1}^{N} \lambda_k Z_{km} \forall m = 1,\ldots,M \qquad (6) \\
&\mathrm{P}_n \leq \sum_{k=1}^{N} \lambda_k \mathrm{P}_k \\
&\sum_{k=1}^{N} \lambda_k = 1, \lambda_k \geq 0 \forall k = 1,\ldots,N.
\end{aligned}
$$

It must be noted that in the above linear programming we have also added an extra condition $\left(\sum_{k=1}^{N} \lambda_k = 1 \right)$ allowing therefore for variable returns to scale-VRS (Banker et al. 1984) in our measurement. Since our analysis is based over a large period of time (1990-2030) it is expected that there will be a lot of variations involved in the demand of energy from renewable sources and variations among the pollutants generated from the consumption of non-renewable energy sources. According to several authors the assumption of VRS is more suitable when investigating the impact of changing energy use over time and you expect such variations (Honma and Hu, 2013; Fang et al., 2013).

7.2.2 Analysis of the findings

As analysed previously we compared for each sector separately the EREP for each year between the four scenarios. Therefore in our case and within the framework of DEA the decision making units (DMUs) are the years of our analysis which are compared against each other and among the four scenarios presented previously. More analytically Figure 7.3 presents the kernel density plots of the estimated efficiency scores using Gaussian kernels (Silverman, 1998).

Figure 7.3: Kernel density plots of the estimated efficiency scores



For the case of industry sector (subfigure 7.3a) the results reveal that the BAU and TAR20 scenario have identical efficiency distributions[100]. Furthermore, it appears that there is a bimodal distribution of efficiencies with a first peak around the 45% level of efficiency and a second peak around the 75%. The bimodality is also reported for TAR30 and Green scenarios. Again for both scenarios there is a first peak at the 45% level of EREP whereas the second peak for the TAR30 is around the 87% and for the Green scenario is around 100%.

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[100] This is due to the fact that the Greek government under the law of L3851/2010 has decided to commit on energy investments from RES only for the sectors of transport, energy, industry and households. As a result the BAU energy scenario is identical with the TAR20.

For the case of transport (subfigure 7.4b) the twin-peak is observed only for the Green scenario with one peak around 70% of efficiency and the second peak around 100%.

Under the BAU scenario the distribution of the efficiencies of the renewable energy policies over the examined period is platykurtic. This indicates that the efficiency estimates are highly dispersed and their distribution is less clustered around the mean than in a leptokurtic distribution. Similar results can be also viewed for the efficiencies of TAR20 and TAR30. Finally, subfigure 7.4c presents the distribution of efficiency estimates for the Greek energy sector. It appears that under the BAU scenario the efficiency distribution has three peaks one around 35%, a second one around 40% and a third one around 55%. Under the TAR20 and TAR30 the distribution is bimodal with a first peak around 38% and a second peak of 45% for TAR20 and 50% for TAR30.

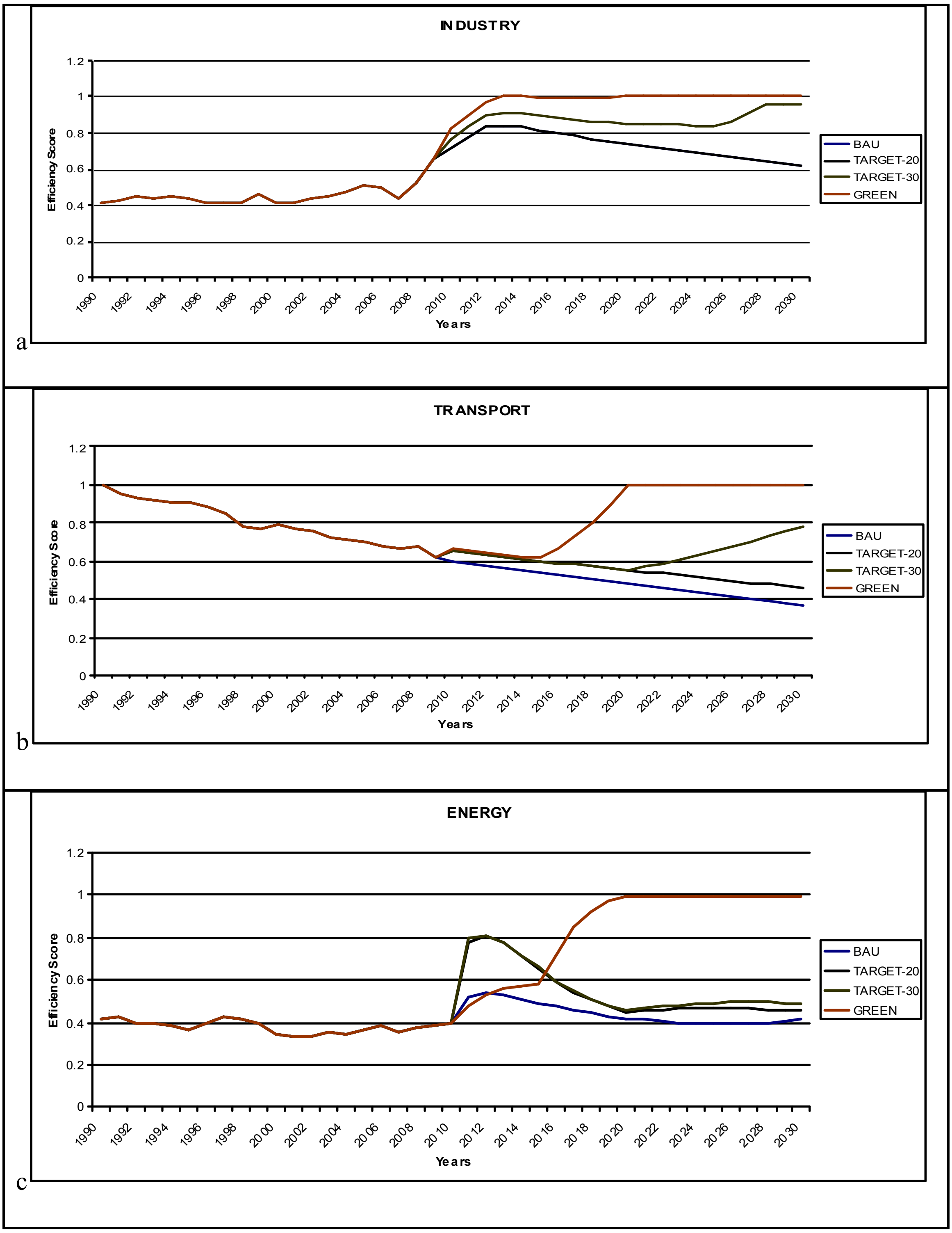
Similarly, under the Green scenario the distribution of efficiency is platykurtic. Figure 7.4 presents the efficiency estimates under the four scenarios for the three sectors under examination. When analysing the industry (subfigure 7.4a) we realise that the efficiency of the renewable energy policies adopted under the BAU and TAR 20 (same line) will decrease over the years. That is their ability to decrease GHG emissions over the examined period will be weak. As a result this indicates that the commitments made by the Greek government especially for TAR20 and BAU will be not sufficient to tackle the increased GHG emissions. Under the TAR30 it appears that the EREP will increase after 2024, whereas only under the Green scenario the efficiency of the Greek policy scenarios will be efficient on reducing the projected GHG emissions.

Moreover, subfigure 7.5b represents the efficiency levels for the Greek transport sector. It appears that under the BAU and TAR20 the EREP will decrease over the examined period indicating that under these two scenarios the Greek government will not succeed on reducing efficiently the GHG emission in the sector of transport. Under the TAR30 the efficiency will increase after 2022 whereas under the Green scenario the efficiency will increase after 2015. In these lines and for the energy sector it appears that only the Green scenario the efficiency will increase. Under the BAU scenario the efficiency will decrease whereas under theTAR20 and TAR30 the efficiencies are in similar efficiency levels.

7.2.3 Main findings

The last section of the report analyses four long term renewable energy scenarios by using LEAP software for three Greek sectors. We present the energy consumption estimates from RES and the GHG emissions generated over the period of 1990-2030 for the sectors of industry, transport and energy. In a second stage analysis we use DEA methodology in order to evaluate the efficiency of renewable energy commitments on decreasing GHG emissions. The results reveal that the efficiency of renewable energy commitments set by the Greek government under the Law 3851/2010 will not be sufficient to decrease systematically the generated GHG emissions over the examined period. In order for the Greek government to have more significant results should increase the share of energy consumption produced from renewable resources at least up to 27% by 2020 this in turn will decrease significantly more the generated GHG emissions compared to the energy policies which are based on the original commitments set by the Law 3851/2010.

Figure 7.4: Efficiency plots based on the four scenarios



7.3 Policy implications

There are various policies to cope with the problem. Planning efficient policies require the careful consideration of each sector. In power generation we may have fuel switching to less carbon-intensive fuels (like natural gas for oil), and use of nuclear and renewable energy resources like wind, solar photovoltaic, biomass co-firing, geothermal power and small hydroelectric power. In both power generation and industry we may also have energy efficiency and use of combined heat and power and carbon capture and storage. In transport we may have policies to increase vehicles' efficiencies, use of new technologies like hybrid vehicles, careful fuel switching and more effective pricing mechanisms (taxation on gasoline, charging for using the roads, etc). In households we may have higher energy efficiency (associated with human behavioral changes) leading to substantial reductions in energy consumption and pollutants' emissions. The latter may be related to buildings insulation and use of combined heat and power. Finally, planting trees and managing effectively forests are also important steps in coping with the problem.

In general we may have increasing energy efficiency per unit of output using less energy-intensive methods and demanding products with lower energy intensity or to have reductions in production of high cost carbon intensive products together with increasing sequestration through reforestation and prevention of deforestation. We may store CO_2 (or C) practicing sequestration like storing carbon in trees and plants or by using geoengineering and increasing the Earth's ability to reflect radiation. The latter may be achieved by using mirrors in space, by large balloons or by painting houses' roofs white. Oceans may play a significant role in dissolving part of CO_2 and other GHGs emissions.

Reducing GHG emissions by controlling emissions from the burning of fossil fuels may be achieved by applying abatement methods (like scrubbers) to control GHG emissions or by reducing the carbon content of the fuels used or using instead of fossil fuels various alternatives energy sources like renewables. Investments in low carbon energy may rely on RES increasing their participation in the global electricity supply. Agriculture and forestry have a great potential in reducing emissions with options related to forestry and to the international framework of Reducing Emissions from Deforestation and forest Degradation (REDD).

The latter may face institutional problems. Generally, the institutional framework is important in the imposition of appropriate policies to cope with or prevent the problem. Halkos and Tzeremes (2013) examined countries' CO_2 emissions and governance relationship using six governance measures (voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law and control of corruption) as defined in World Governance Indicators from the World Bank. They find a highly nonlinear non-monotonic relationship between CO_2 emissions and governance measures and it seems that countries' higher governance quality does not always result to lower CO_2 emissions.

As control costs of abating GHGs are not certain and may differ among countries, economic analysis may identify the appropriate policy instruments for mitigation. Different policy instruments (like carbon taxes, control subsides, quotas in emissions, performance standards, and permits) are required to cope with the problem either directly to emissions or indirectly to pollution related products (like subsidizing a control method or taxing fuels). For some countries taxes may work better compared to permits. Domestically tradable permits may be used to satisfy national targets. The Kyoto Protocol includes international policy tools like the "assigned amounts" concerning national control targets. If a system of international tradable permits is adopted this may reduce costs by 50% (Olmstead and Stavins, 2007) whereas the inclusion of developing countries could lower by half again the costs (Edmonds et al., 1994). As Olmstead and Stavins (2007) propose, for effectiveness, trading has to take place between firms and not countries with international carbon trading markets to be vulnerable to the problems faced by any other market and with serious obstacles imposed by high transaction costs or by the concentration of permits by some firms (countries). This makes initial allocation of permits quite important (Halkos, 1993).

Obviously adaptation and mitigation have to be used together and efficiently. These arguments imply that different forms of mitigation are necessary together with ways to avoid free-riding. Additionally more investments in R&D are required together with developed countries financing mitigation efforts. Measures of adaptation have to be planned in such a way that they can be modified when new information is available. Markandya (2013) incorporates this with the use of option values in CBA or cost-effectiveness analysis. Markandya (2014) claims that delivering adaptive measures requires structural steps including all actions demanding sector-wide changes (physical regulations as well as economic or fiscal incentives). Both public and private sectors have to co-finance some activities and the international community to support the development of market and institutional mechanisms for an efficient level of adaptation.

Societies have to understand the ethics of sustainability. To enhance greenhouse effect and the ethics of sustainability, Spash (2002, p. 223) identifies four rules of ethics in the case of the existing greenhouse effect: the elitist, the egalitarian, the Paretian and the neoclassical utilitarian rules. The first demands that welfare of the best-off are to be improved. The second rule opposes this requiring that the welfare of the worst-off are to increase (max-min principle). The Paretian rule in the lines of the Pareto efficiency reallocates resources in such a way as to find the point where the improvement of a generation’s welfare cannot be better off without making someone worse-off. Finally the neoclassical utilitarian rule maximizes utility for all generations by reallocating resources. We may think of the elitist rule as our generation considered as elite and us living now.

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