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Abstract

This study is focused on the construction of long – term scenarios for the transition to renewable energy. Utilizing European and national targets, the key objective of this work is to investigate how these targets are reflected in both economic and environmental terms. The constructed model via the Long range Energy Alternatives Planning System (LEAP) software describes the impacts of energy supply and demand along with their implications for national long – term policy. Specifically, the research provides a look to the 2030 horizon in the energy and power system in Greece. Three scenarios are generated under different options, baseline (which is based on historical trends), target 2020 (which is based on the European target set in 2020) and target 2030 (which is based on the European target set in 2030). Furthermore, two additional scenarios are developed for the Greek GDP growth; the first one based on the International Monetary Fund (IMF) estimates and the second taking into account the estimates of the Organization for Economic Co-operation and Development (OECD). The results show a substantial shift in the electricity generation mix by 2030, something that has to be reversed into renewable energy solutions.

Keywords: Climate change; Renewable energy sources; Greek energy system.

JEL κωδικοί: Q20; Q40; Q41; Q42; Q54.

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Υπουργείο Παιδείας και Θρησκευμάτων
ΕΥΔΕ-ΕΤΑΚ

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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).[1] 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.[2] 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 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.

[1] For the effect of electricity consumption from renewable sources on countries′ economic growth levels see Halkos and Tzeremes (21014a).

[2] For the effect of countries compliance with the Kyoto protocol agreement (KPA) policies see Halkos and Tzeremes (2014b) and Halkos (2014).

2. Background

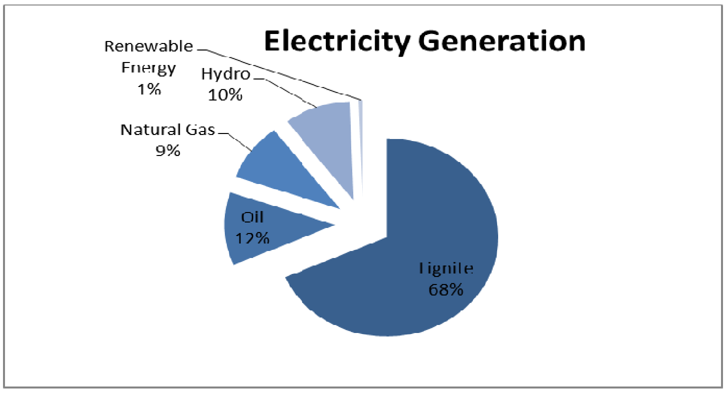
Renewable energy sources constitute a cost-effective solution for the energy sector, the society and the environment offering in terms of energy supply much more friendly solutions compared to conventional fossil fuels. Energy independence, geographical dispersion and diversity of the primary forms of 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[3] includes the decarbonisation of the Greek energy system by introducing low carbon sources or RES (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[4].

[3] For details on the hypotheses and principles on calculating abatement costs see Halkos (1992, 1993, 2010, 2014).
[4] Policies and measures are described in detail in Ministry of Environment, Energy and Climate Change (2010).

Greece as a developed country has a relatively high energy demand, considering its size, and an above the average consumption per capita. The country's population, according to the census of 2011, reached a total of 10,815,197 inhabitants, placing Greece marginally outside of the ten most populous European countries, but ahead of several major economies which affects the energy demand ranking (Hellenic Statistical Authority, 2012; Marcu, 2011). Energy production in Greece is dominated by the Public Power Corporation (PPC) which holds the biggest share in the supply of electricity. For the year 2012, Figure 1 shows that the biggest share of electricity generation by PPC came from lignite (68.4%), oil (11.9%), natural gas (9.4%), hydro (9.7%) and renewable energy (0.6%) (Public Power Corporation S.A., 2012). The category hydro represents the large scale hydropower projects while the renewable energy category includes photovoltaic, biomass, small scale hydropower projects and wind parks.[5]

Figure 1: Electricity Generation in Greece for 2012



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

[5] According to annual report of Public Power Corporation in 2012, hydropower projects can be divided into small and large scale hydropower projects. Small scale hydropower projects are referred as renewable energy resource in contrast to large-scale hydropower projects.

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).

Considering the economic part of Law 3851/2010, new electricity pricing for the main categories has been submitted and is analyzed in Table 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 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).

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).

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.

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 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 3a and 3b, 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.

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 3a and 3b, 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 5 describes in details the structure of the assumed generated capacity per RES category.

Table 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 3a: 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 3b: 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: 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 5: 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/

3.2 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[6] or from the International Monetary Fund (IMF)[7] 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 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

$$178.959 + 0.007 \times 178.959 = 180.212 \text{ δις. €},$$

[6] http://www.statistics.gr/portal/page/portal/ESYE/PAGE-themes?p_param=A0702

[7] http://www.imf.org/external/data.htm

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.[8] 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:

[8] For more information on the tests see among others Halkos (2006).

"Best Models" for «the IMF optimistic scenario»

(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.

"Best Models" for «the OECD conservative scenario»

(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.

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.

3.1.1. Structure of LEAP dataset

3.1.1.1. 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)[9], the Eurostat[10], the Bank of Greece[11], the World Bank, and the OECD[12]. The dataset depicted in Table 6 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 6: 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

[9] http://www.statistics.gr/
[10] http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/
[11] http://www.bankofgreece.gr/Pages/default.aspx
[12] http://www.oecd.org/

As it can be seen from Table 6, 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 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.

3.1.1.2. 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 7). 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 7: Fuel supply dataset of Greece

Module	Process types	Fuels	Sources
Distribution Losses	Process	Electricity, natural gas	El. Stat, Eurostat, PPC[13]
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[14], RAE[15], H.T.S.O.S.A[16]
Oil Refining	Process	Crude oil	El. Stat, Eurostat, PPC

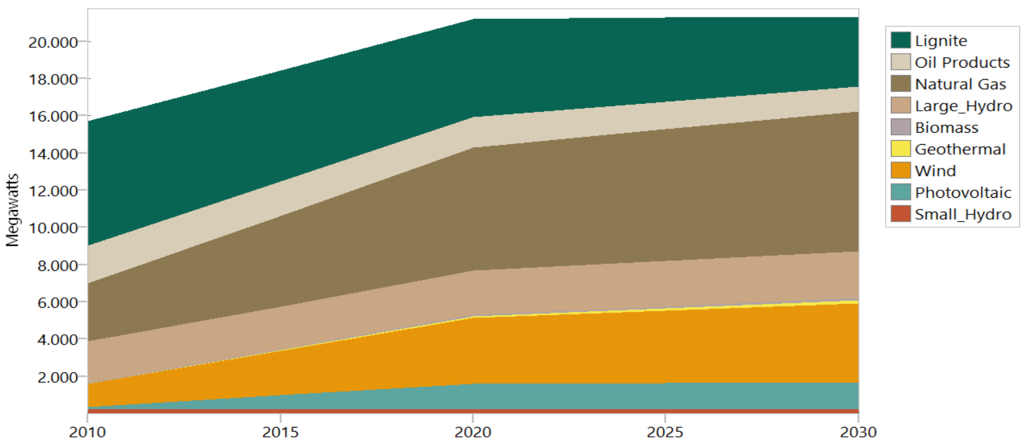
[13] http://www.dei.gr/
[14] http://www.cres.gr/kape/index.htm
[15] http://www.rae.gr/site/portal.csp
[16] http://www.desmie.gr/nc/en/home/

4. Results

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 2 presents the total installed capacity in the Electricity sector. The changes in fuel use in Figure 2 are described in details in table 8. 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).[17]

Figure 2: Capacity projection in Electricity sector (in MW)



[17] 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.

Table 8: 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

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 9. The total energy requirements by fuel source over the modeling period are shown in Figure 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 10 depicts the demand energy requirements share per fuel in details as shown graphically in Figure 3. Generally, without any environmental policy to increase the share of renewable energy sources in total energy consumption, their percentages will raise up to 7,3% in 2020 and 8% in 2030.

Table 9: 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 3: Demand Energy requirements per fuel

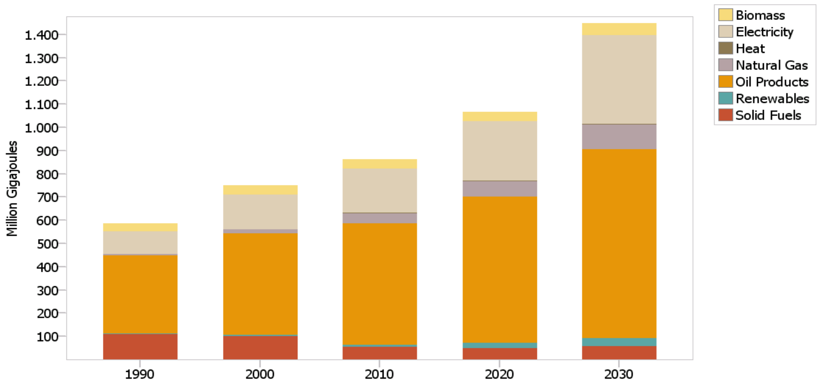


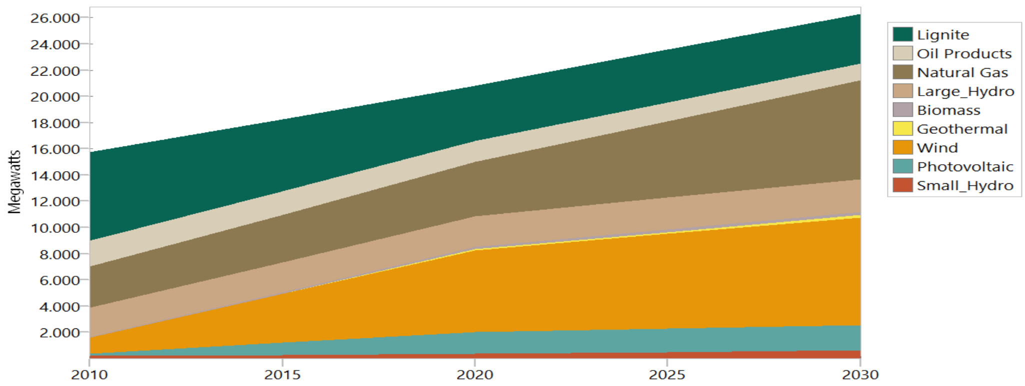
Table 10: Demand Energy requirements share per fuel

	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**

4.2 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 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: 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 11. 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 12. RES heating and cooling share (20%) and RES transport share (10%) targets are depicted in Figures 5 and 6. The primary energy requirements by fuel source over the modeling period are shown in Figure 7. Specifically, Table 13 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 11: 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 12: 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 5: Households Energy Consumption per fuel

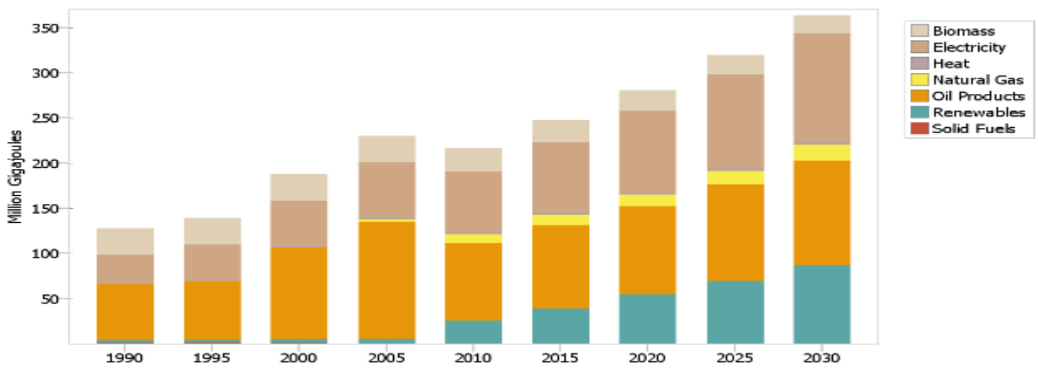


Figure 6: Transport Energy Consumption per fuel

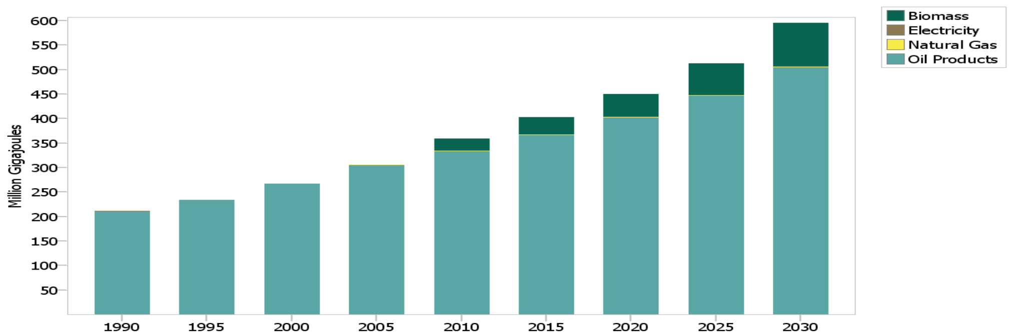


Figure 7: Total Energy Consumption per fuel

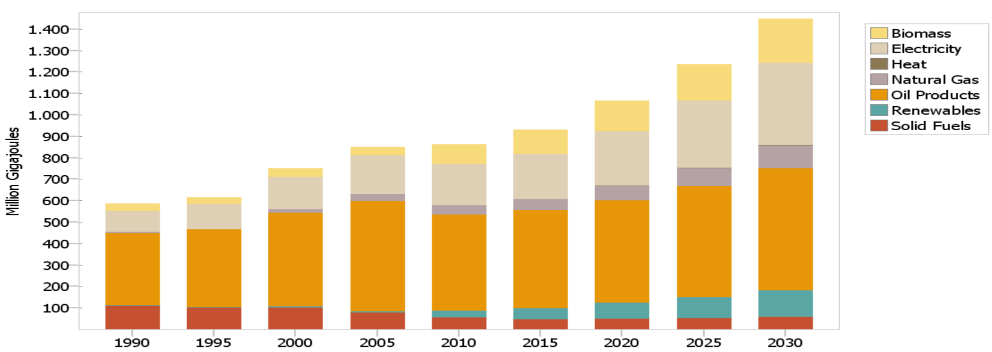


Table 13: Total Energy Consumption share per fuel (%)

	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

4.3 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 8 and table 14 depict the energy consumption per fuel in the industry sector. Figure 9 depicts the total energy consumption requirements per fuel. As it can be seen in Table 15, the total renewable share in 2030 will amount for 29%.

Figure 8: Industry's Energy Consumption per fuel

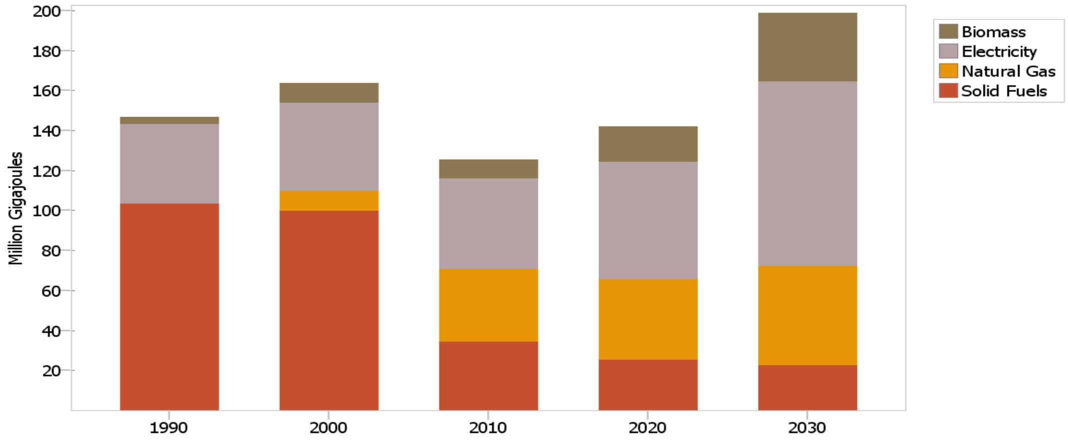


Table 14: Industry's Energy Consumption share per fuel

	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

Figure 9: Energy Consumption per fuel

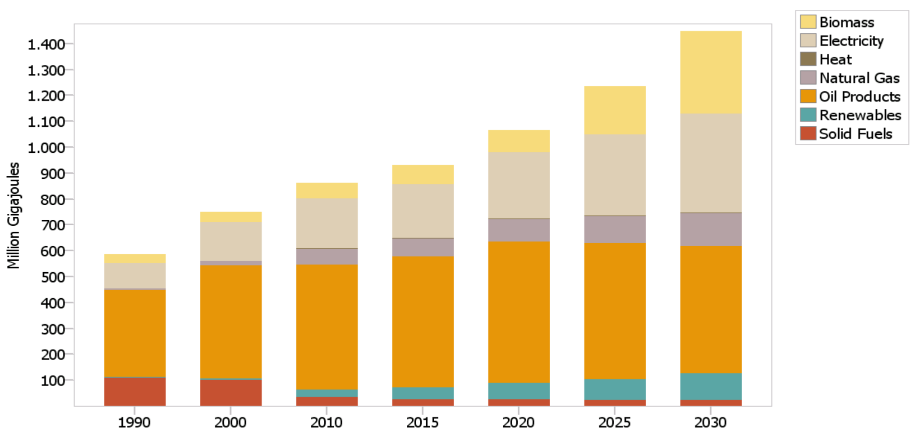


Table 15: Energy Consumption share per fuel

	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 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 10 presents the total installed capacity in the Electricity sector. The changes in fuels use in Figure 10 are described in detail in table 15. 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).[18]

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

[18] 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.

Table 16. The total energy requirements by fuel source over the modeling period are shown in Figure 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 17, depicts the demand energy requirements share per fuel in details as shown graphically in Figure 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.

Figure 9: Capacity projection in Electricity sector (in MW)

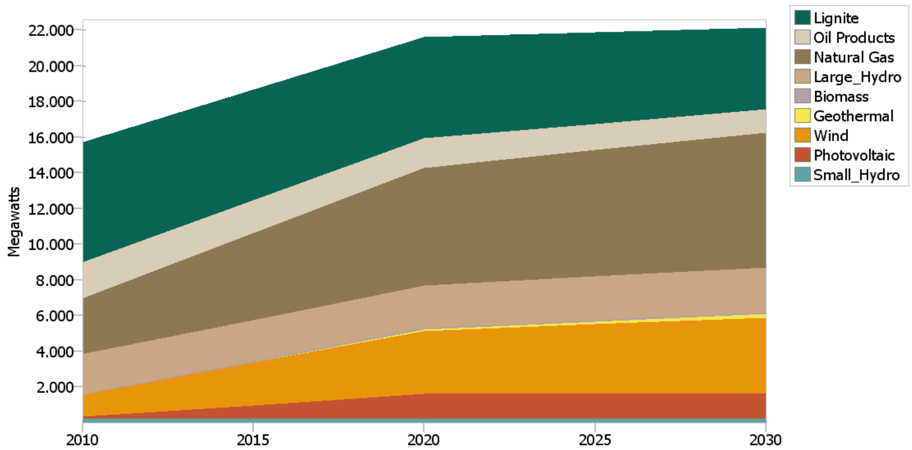


Table 15: Capacity projection in Electricity sector (in MW)

	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

Table 16: 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 10: Demand Energy requirements per fuel

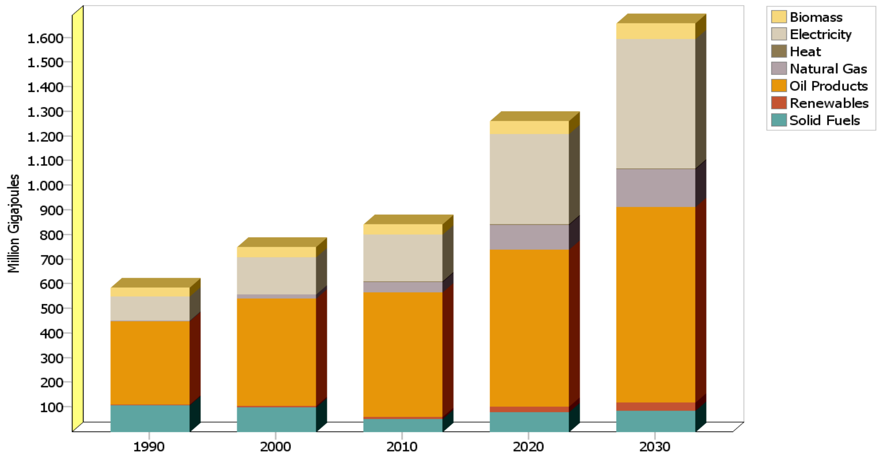


Table 17: Demand Energy requirements share per fuel

	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**

4.5 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 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.

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 18. 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 19. RES heating and cooling share (20%) and RES transport share (10%) targets are depicted in Figures 19 and 20. The primary energy requirements by fuel source over the modeling period are shown in Figure 21. Specifically, Table 20 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.

Figure 11: Capacity projection in Electricity sector (in MW)

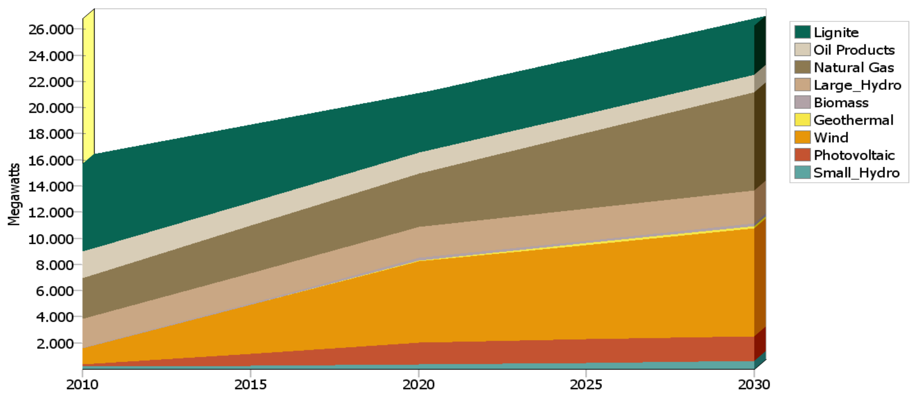


Table 18: Capacity projection in Electricity sector (in MW)

	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

Table 19: 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 19: Households Energy Consumption per fuel

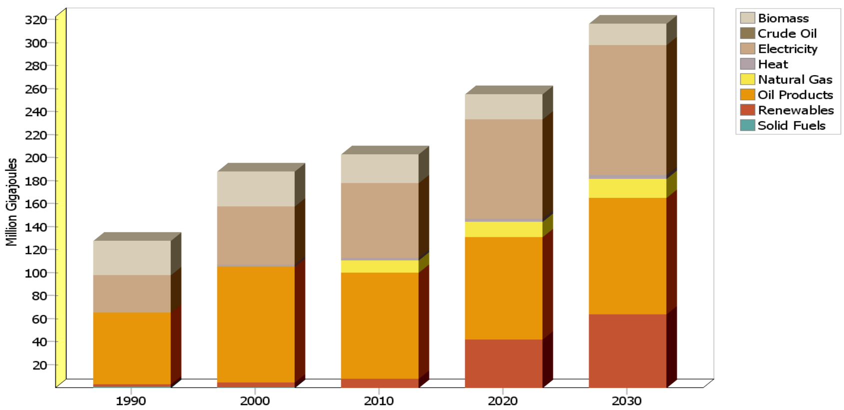


Figure 20: Transport Energy Consumption per fuel

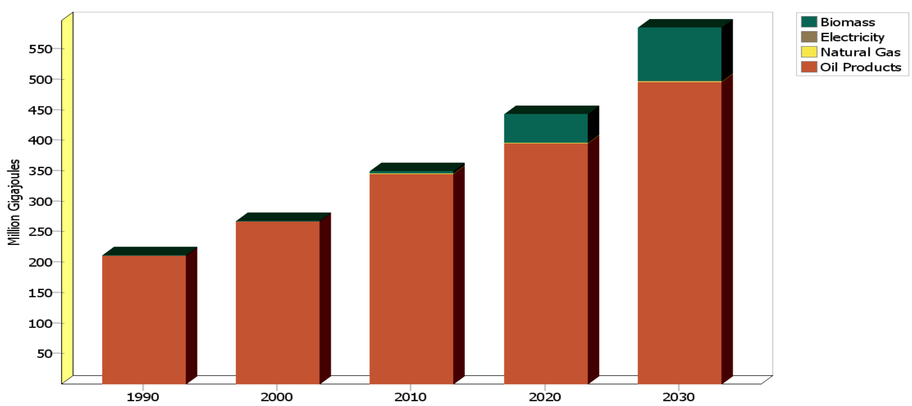


Figure 21: Total Energy Consumption per fuel

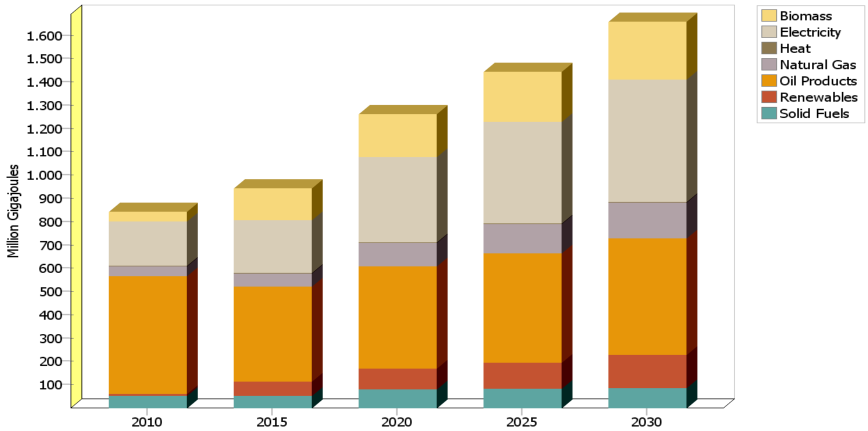


Table 20: Total Energy Consumption share per fuel (%)

	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

4.6 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 22 and table 21 depict the energy consumption per fuel in the industry sector. Figure 23 depicts the total energy consumption requirements per fuel. As it can be seen in Table 22, the total renewable in 2030 will reach 29.8%.

Figure 22: Industry's Energy Consumption per fuel

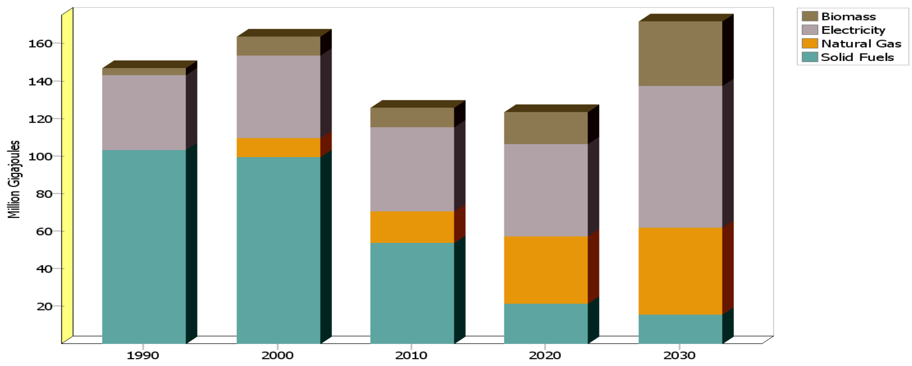


Table 21: Industry's Energy Consumption share per fuel

	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 23: Energy Consumption per fuel

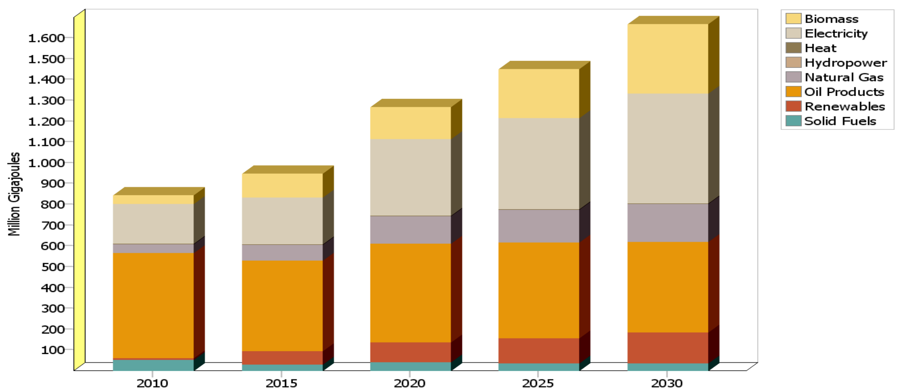


Table 22: Energy Consumption share per fuel

	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**

4.7 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 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).[19] 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 25 and Table 24, will diminish by 2030 compared to 1990 levels if the policy makers follow the Target 2030 scenario.

[19] 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).

Figure 24: Carbon intensity of Greek energy demand per scenario for the OECD conservative scenario of GDP growth

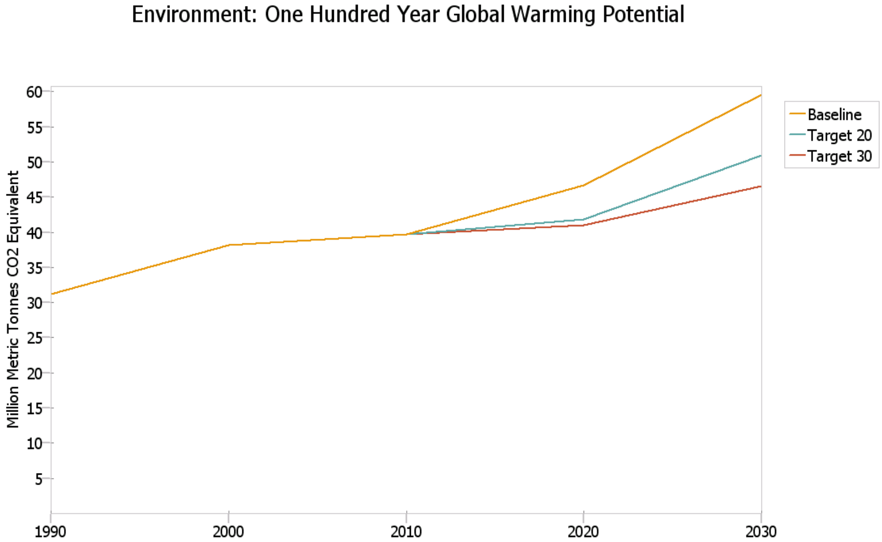
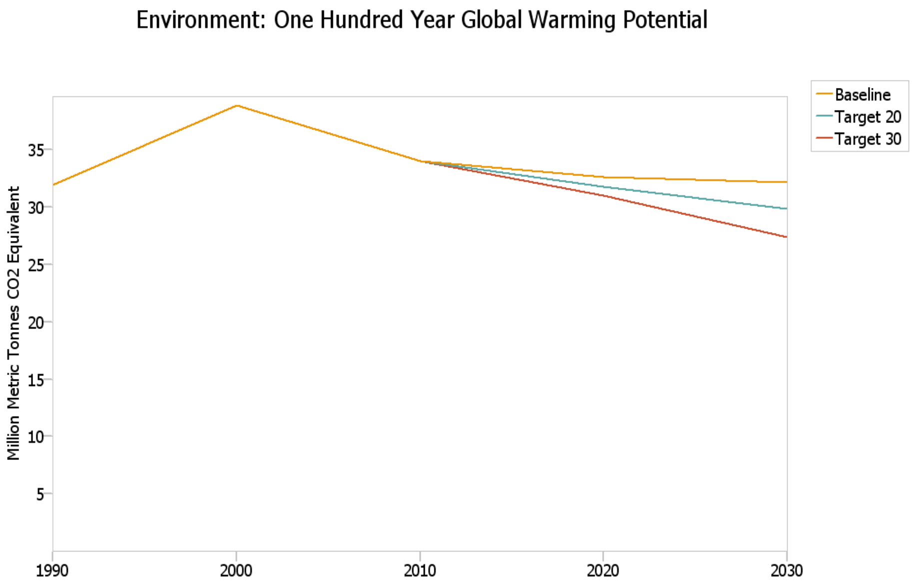


Table 23: Emissions ($MtCO_2e$) per scenario in 2020 and 2030

	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 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 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 24). 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 27 and Table 25, will slightly increase by 2030 compared to 1990 levels if the policy makers follow the Target 2030 scenario.

Figure 26: Carbon intensity of Greek energy demand per scenario for the IMF optimistic scenario of GDP growth

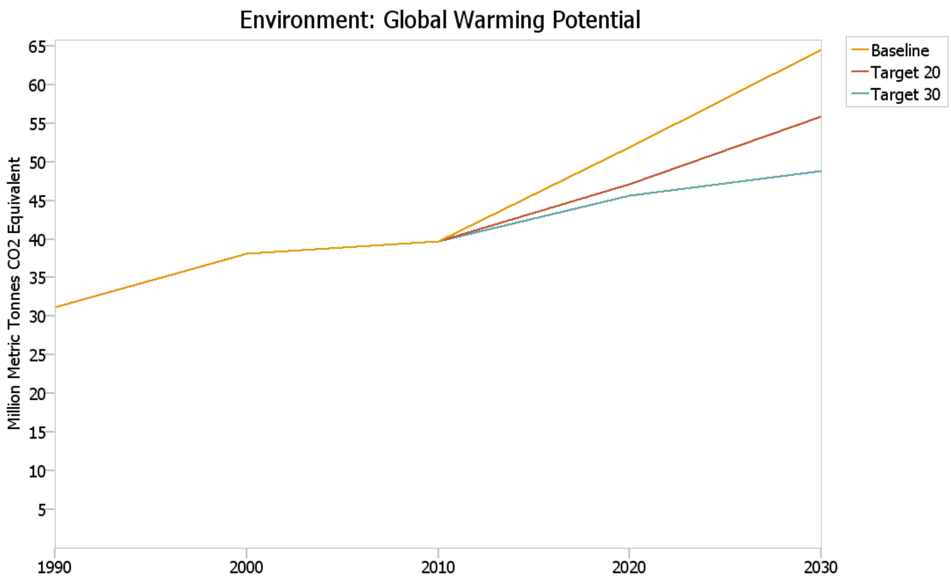


Table 24: Emissions ($MtCO_2e$) per scenario in 2020 and 2030 for the IMF optimistic scenario of GDP growth

	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 27: Carbon intensity in Greek electricity generation sector per scenario for the IMF optimistic scenario of GDP growth

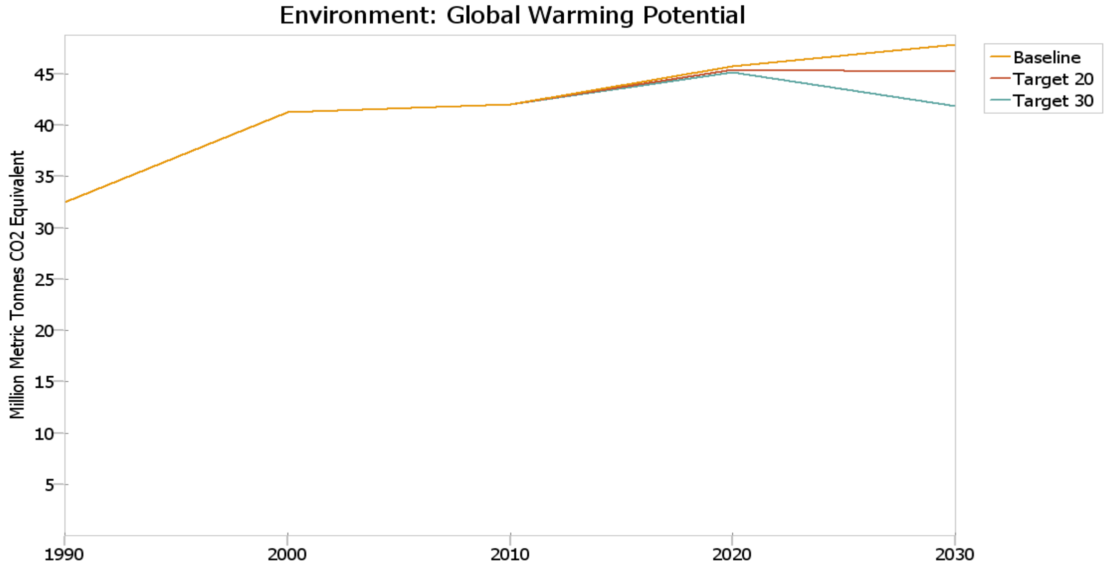


Table 25: Emissions ($MtCO_2e$) per scenario in 2020 and 2030 for the IMF optimistic scenario of GDP growth

	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**

4.8 Costs

The types of costs considered are capital costs and operating and maintenance costs as shown in Table 26. 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 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[20].

Figure 28: Total costs per scenario in 2020 and 2030

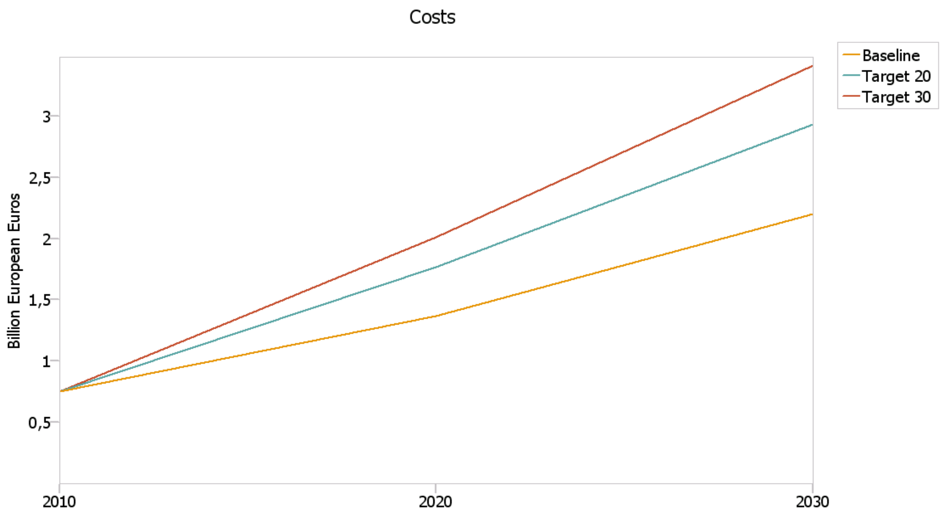


Table 26: Capital costs, fixed Operating and Maintenance (O&M) costs per scenario in 2020 and 2030 (in billion €)

	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**

[20] 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).

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»

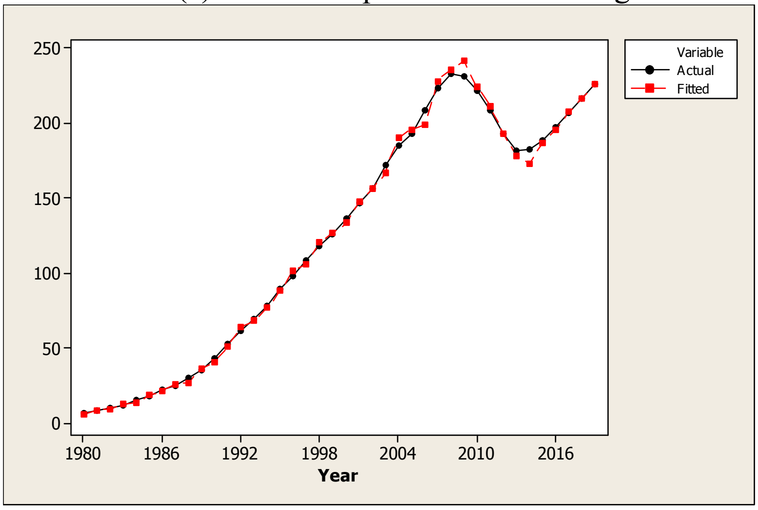
	Akaike Info	Schwarz	Hannan-Quinn	MAE	MAPE (%)
Double Exponential Smoothing				2.5386 (1)	3.0532
ARIMA with constant term					
ARIMA (1,2,0)	5.5713	5.6620	5.6018	2.6921	2.5222
ARIMA (1,2,1)	5.6174	5.7535	5.6632	2.6977	2.5086
ARIMA (0,2,1)	5.5253	5.6151	5.5559	2.6490	2.7075
ARIMA (2,2,0)	5.6570	5.7944	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»

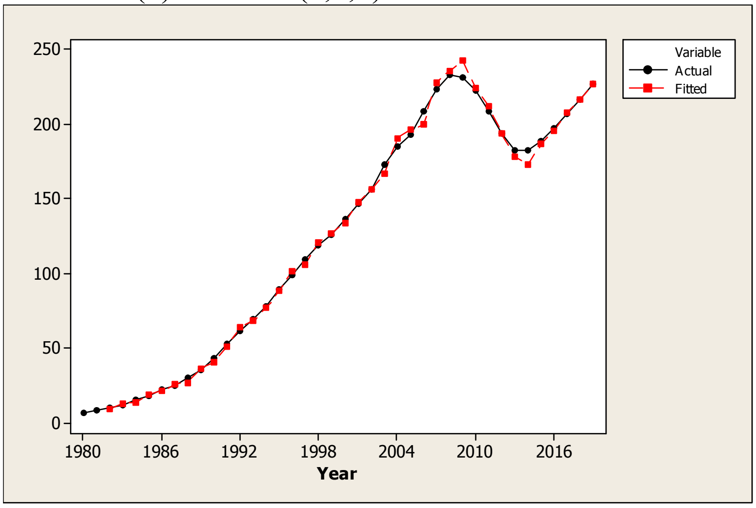
	Akaike Info	Schwarz	Hannan-Quinn	MAE	MAPE (%)
Double Exponential Smoothing				2.4407 (1)	2.8361
ARIMA with constant term					
ARIMA (1,2,0)	5.5609	5.6480	5.5916	2.5456	2.3518
ARIMA (1,2,1)	5.6040	5.7346	5.6501	2.5735	2.3895
ARIMA (0,2,1)	5.5271	5.6133	5.5578	2.5462	2.4776
ARIMA (2,2,0)	5.6357	5.7677	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

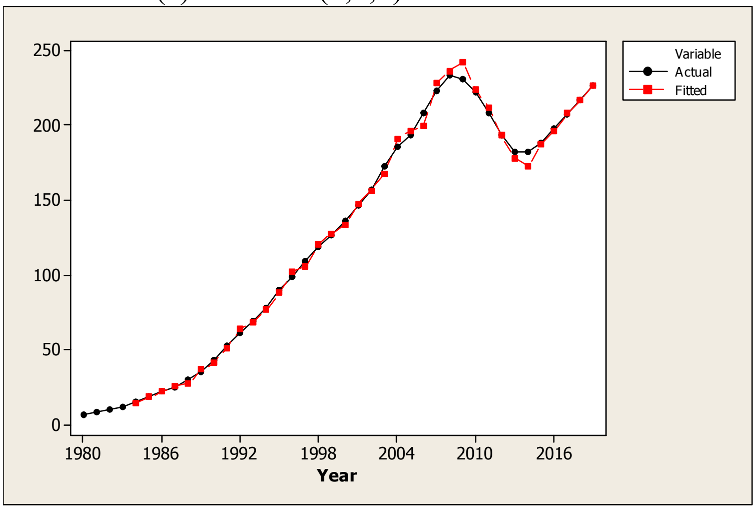
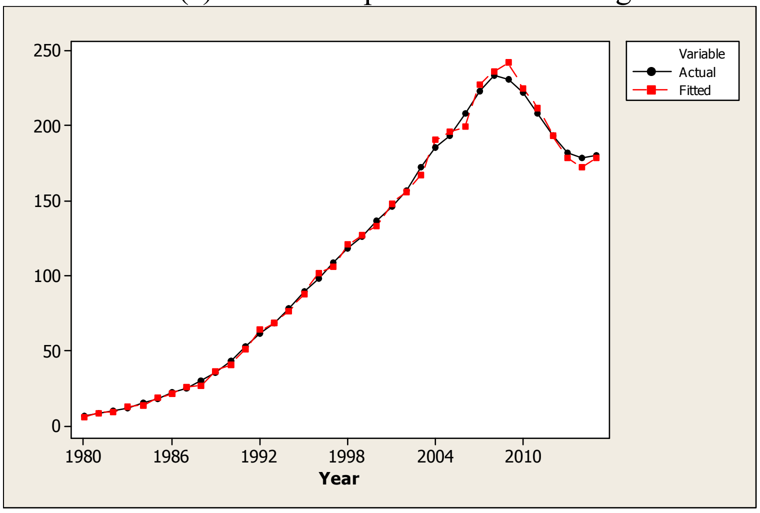
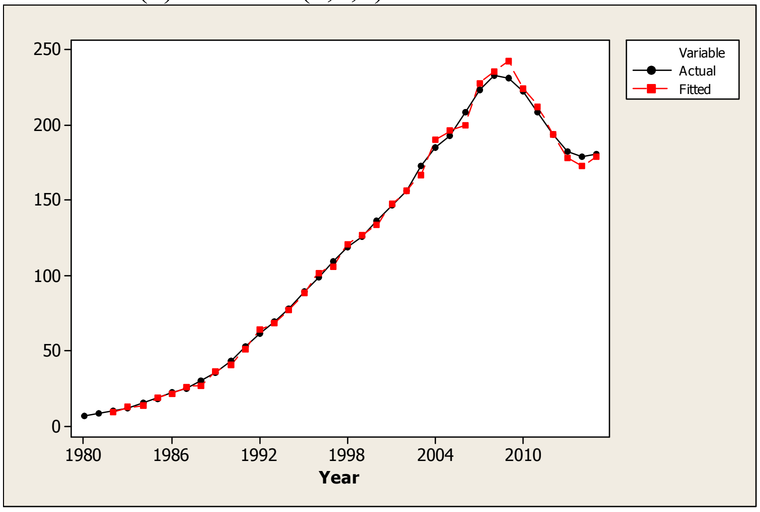


Figure A2: Actual versus fitted values for the "best" models predicting GDP under the OECD «conservative scenario»

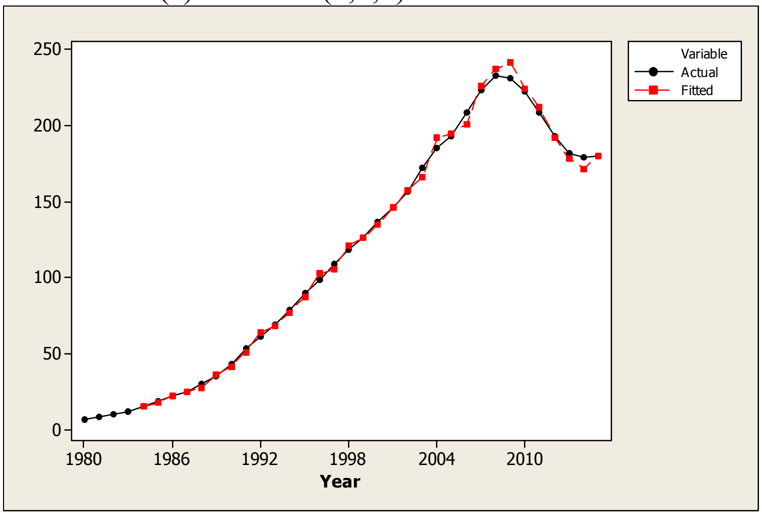
(a) Double Exponential Smoothing



(b) ARIMA (0,2,1) without constant term



(c) ARIMA (2,2,2) with constant term



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