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LONG TERM PLAN FOR THE GREEK ENERGY SYSTEM

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SUMMARY

THE REPORT INVESTIGATES AND EVALUATES THE POTENTIAL FOR A SIGNIFICANT REDUCTION IN CO_2 EMISSIONS FROM ELECTRICITY GENERATION IN GREECE.

The 5 scenarios examined:

1. Business as Usual
2. Expansion of Lignite Use
3. Expansion of RES Use
4. Energy Efficiency
5. Efficiency and Lignite Phase-Out

Object and targets

The energy sector -the most important source of greenhouse gases both in the European Union and Greece- and particularly the electricity generation sector -the most important commercial sector- will constitute a field of strong policies in the next decades, aiming at the significant reduction of greenhouse gas emissions and the development of low carbon emission economies. There are strong concerns about the upcoming changes in the Greek energy system, particularly taking into account that these will occur in an adverse economic environment due to the economic crisis in the past few years.

WWF Greece has launched a campaign for the conversion of the Greek electricity generation model into a low CO_2 emission system. In this framework, the aim of this study is to investigate scenarios evaluating the possibilities to achieve significant reductions in CO_2 emissions in the Greek electricity generation sector, the existing technological possibilities towards this direction (large-scale RES penetration, closing down of lignite plants, etc.), as well as the financial impact (on the energy cost and the necessary investments) of such a conversion. At the same time, electricity demand is another significant factor affecting developments in electricity generation; therefore, the answer to the aforementioned questions requires an holistic examination of the energy system. This study, by analyzing and evaluating different scenarios for the evolution of the Greek energy system, investigates:

- The impact on energy cost and emissions from different shares in the energy balance of lignite electricity generation.
- The impact on energy cost and emissions from the large-scale penetration of RES technologies.
- The impact on energy cost and the electricity system structure from the emission allowance price.
- The role energy saving programs play in the final consumption sectors and how they affect the electricity generation sector structure.

The analysis is carried out using the ENPEP/Balance hybrid energy model, which is a partial balance simulation model, allowing relatively realistic representations of the behaviour of all participants (producers and consumers) in the energy market.

Scenarios

In order to examine the questions raised above, comparative alternative scenarios for the evolution of the Greek energy system until 2035 and 2050 are developed and evaluated, emphasizing on the electricity generation sector. Specifically, 5 main scenarios are developed with variations per case, 2 of which assume that lignite electricity generation will still hold a significant share in the energy balance until 2050, while the other 3 assume a large scale RES penetration and a smaller lignite share in the electricity system. Moreover, 2 of the scenarios assume that ambitious energy saving steps and policies will be adopted, in contrast with the other 3 that adopt less radical efficiency interventions. In detail, the scenarios are as follows:

- *Business as Usual Scenario (BaU)*, which prescribes the evolution of the energy system based on the already implemented and agreed upon policies, taking into account the cost saving aspect of alternative technologies, as well as the requirement for the amortization of applied or future investments within a reasonable time period. This includes the construction of the lignite unit Ptolemaida V, the environmental upgrading of Ag. Dimitrios Units I-IV, which will close down in 2030, the limited operation of Kardia and Amyntaio Power Plants, which will close down in 2023, and the closing of Megalopoli Units III and IV in 2025.
- *Expansion of Lignite Use Scenario (LIG)*, with emphasis on maintaining the lignite's significant share in the Greek electricity generation mixture, through the construction of two new lignite units (Ptolemais V and Meliti II), as well as the radical upgrading of Amyntaio I and II Units and Megalopoli IV Unit, which will continue to operate after 2023. Kardia Power Plant will close down in 2023, while Ag. Dimitrios Units I-IV will undergo an environmental upgrading and operate until 2030. Under these restrictions, the evolution of the system is prescribed taking into account the estimated energy demand, the cost saving aspect of alternative technologies, as well as the requirement for the amortization of applied or future investments within a reasonable time period. As far as the final consumption sectors are concerned, this scenario does not differ from BaU in terms of the policies applied.
- *Expansion with RES Scenario (RES)*, which assumes a limited lignite share in the electricity system and the latter's restructuring based on the estimated demand and the cost saving aspect of alternative technologies, limiting at the same time the requirements for the amortization of investments already made. Within this framework, no new lignite unit is to be constructed, while the plans for closing down the existing lignite units will proceed as prescribed in BaU. Moreover, as far as the final consumption sectors are concerned, this scenario does not differ from BaU in terms of the policies applied.
- *Energy Efficiency Scenario (EE)*, which differs from the BaU scenario by means of assuming more drastic energy saving policies in the final consumption sectors (electrification and vehicle fleet modernization in the transport sector, building stock renovation, promoting higher-efficiency equipment, etc.), while the electricity system expansion takes into account the cost saving aspect of alternative technologies by limiting the requirements for the amortization of already applied investments.
- *Efficiency and Lignite Phase-Out (LPO)*, which differs from the EE scenario in that it assumes a more ambitious policy in order to limit the lignite share in the electricity system, leading to a complete phasing out from this fuel by 2050, as well as more ambitious energy saving policies in the final consumption sectors.

A set of assumptions have been adopted which are common to all scenarios, unless otherwise specified. Specifically, the assumptions relate to the following:

- The evolution of population and number of households, based on NSSG (National Statistical Service of Greece) estimates.
- Economic growth based on estimates by the European Commission and the International Monetary Fund for the period until 2020, as well as on the estimates by the European Commission for Greece included in the report "EU Reference Scenario 2016: Energy, transport and GHG emissions Trends to 2050", for the period 2021-2050.

- The evolution of fuel prices, resulting from the New Policies Scenario in the "World Energy Outlook, 2016 Edition".
- The evolution of the emission allowance prices. Specifically, scenarios for both a conservative price evolution, which do not exceed 40 €/t CO2 in 2050, were considered as well as more ambitious scenarios such as the one adopted by the EU in its most recent Report "EU Reference Scenario 2016: Energy, transport and GHG emissions Trends to 2050".
- The investment and operation costs for various electricity generation technologies and energy storage systems.
- The investment and operation costs for anti-pollution technologies which mainly refer to the interventions required in old lignite units in order to achieve the new emission limits imposed by law.
- The development of interconnections, both cross-border and between Aegean islands and the main grid.

The scenarios developed are considered realistic approaches of the future of energy in Greece, according to the assumptions included in each one. Although even more ambitious scenarios could be formulated per case, this study does not aim at determining an "excellent" development level for the Greek energy system, but rather at evaluating comparatively different energy policies, highlighting the pros and cons, limitations and possibilities, and finally, at contributing to the dialogue on the long-term energy planning for Greece.

Evolution of primary and final energy consumption

Based on the analysis results, primary energy supply for the overall period until 2050, and for all scenarios, steadily remains below the 2015 levels (**Figure EP-1**). This is related both to the mild economic development scenario adopted, as well as to the overall improvement in the system's energy efficiency, by limiting the use of solid fuels and expanding the RES share. It is worth mentioning that the energy system's energy intensity is improved in the BaU scenario from 0.136 ktoe/M€$_{2010}$ in 2015 to 0.091 ktoe/M€$_{2010}$ in 2035 and 0.081 ktoe/M€$_{2010}$ in 2050. In the more ambitious RES, EE and LPO scenarios, the energy intensity in 2050 amounts respectively to 0.077, 0.074 and 0.065 ktoe/M€$_{2010}$, while even in the LIG scenario, it amounts to 0.084 ktoe/M€$_{2010}$.

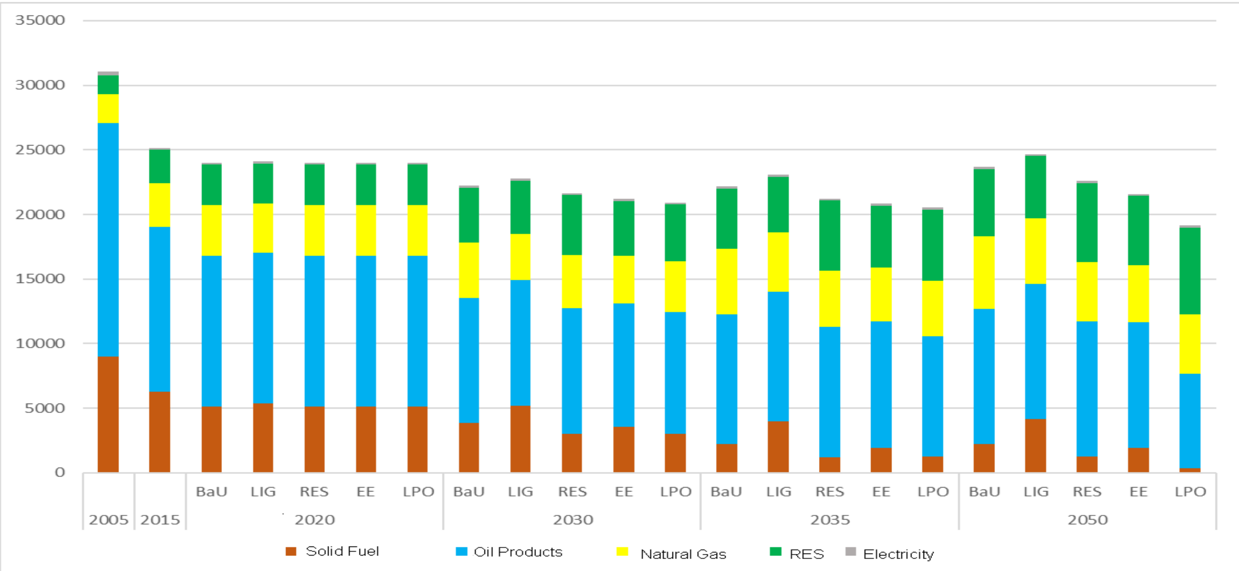


Figure EP-1: Evolution of the total primary energy supply to the Greek energy system according to the scenarios considered (in ktoe).

As far as final energy consumption is concerned, following the high decrease observed during the period 2008-2015, due to the economic crisis, the energy demand in the BaU scenario shows a slightly increasing trend, resulting from the relatively mild economic development scenario adopted. Nevertheless, consumption does not reach the 2005 levels even in 2050. The final energy demand in the LIG and RES scenarios shows very small differences compared to BaU, given that they actually integrate the same energy saving policies, and it is even lower in the EE and LPO scenarios, given that they integrate more ambitious energy saving policies.

The final electricity demand shows increasing trends and reaches 54.8 TWh in BaU and 51.3 TWh in EE and LPO in 2035, and 61.3 TWh in BaU, 58.2 TWh in EE and 57.9 TWh in LPO in 2050. However, the fact that many consumers turn to electricity both in the building and transportation sectors according to the EE and LPO scenarios, in combination with the resulting increase in demand, is mitigated by the penetration of more efficient electrical appliances, air conditioning units with a higher efficiency rate, etc.

As regards the RES share in the final energy consumption, this actually triples during the period 2005-2030 and remains stable afterwards, except in the LPO scenario where it further increases. **Figure EP-2** shows the evolution of the RES share in the gross final energy consumption. Although the target set for Greece for 2020 seems to be achieved in all scenarios, the 27% target set as a total for the EU for 2030 (and not at a national level) can be achieved by Greece only in the RES, EE and LPO scenarios. Thus, if such a national target is adopted, it will take major efforts to be achieved, either by implementing significant investments in RES (as in the RES scenario), or by combining RES investments with the implementation of ambitious energy saving measures in the final consumption sectors, as in the EE and LPO scenarios.

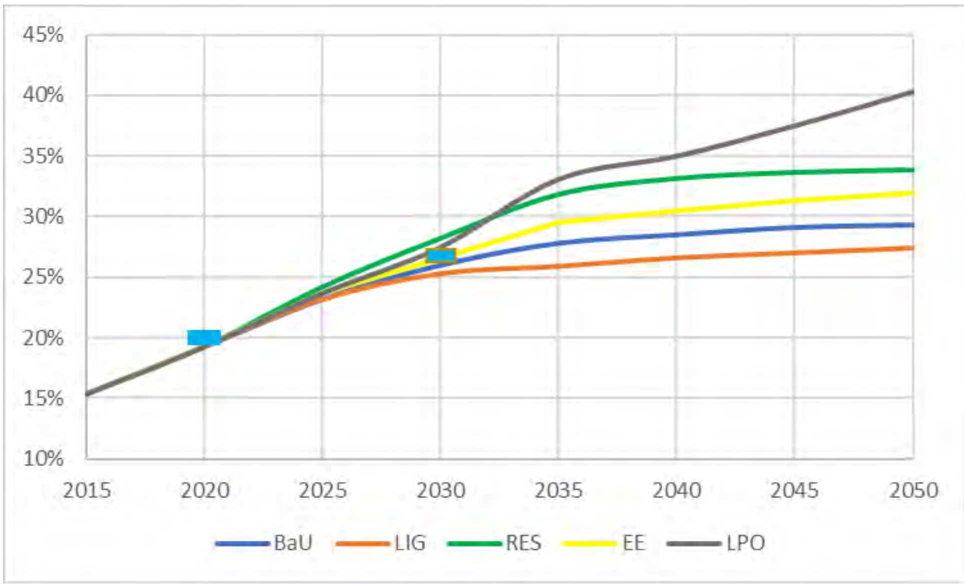


Figure EP-2: Evolution of the RES share in the gross final energy consumption based on the scenarios considered. It also includes the target for Greece for 2020 and the overall target for EU for 2030.

Electricity generation sector

Based on the analysis results, all scenarios show a decrease in lignite electricity generation, which in 2035 ranges between 3.5 (RES and LPO scenarios) and 15.2 (LIG scenario) TWh, while in 2050 it drops down to zero in the LPO scenario, ranges between 3.4 and 8 TWh in the RES, EE and BaU scenarios, and only in the LIG scenario reaches 15.7 TWh. In the scenarios promoting environmentally-friendly practices (RES, EE, LPO), the lignite electricity generation share is limited to to 6-12% in 2035 and to 0-11% in 2050. The role of oil units is also limited in the system since, following the system's interconnection with the Cyclades, Crete and most islands of the Eastern Aegean Sea and the Dodecanese by 2030, the majority of the Greek islands will thereafter be supplied by the mainland system. On the contrary, natural gas maintains a significant share during the entire reference period, since after 2030 it becomes the main conventional generation technology. The natural gas units' share in the electricity generation mixture in the various scenarios ranges between 26-33% in 2035 and 22-32% in 2050.

In all the scenarios, a significant part of electricity generation is covered by RES technologies, particularly wind and photovoltaic systems. **Figure EP-3** shows the evolution of the RES share in the gross final electricity consumption. In 2035, the RES share is estimated at 45% in the LIG scenario, 51% in BaU, 58% in EE, 62.9% in LPO and 66% in RES. In 2050, respectively, these shares are estimated at 47% in the LIG scenario, 54% in BaU, 63% in EE, 69% in LPO and 70% in RES. On a shorter-term basis, it is noted that the achievement of the 40% RES penetration target in the gross final electricity consumption by 2020 is no longer feasible.

Figure EP-3: RES share in the gross final electricity consumption. It also includes the target set for Greece for 2020.

As regards the structuring of the Greek electricity system (**Figure EP-4**), the installed power capacity of conventional units is significantly limited while, on the other hand, the installed capacity of RES technologies (mainly wind and photovoltaic systems) increases. In particular, the installed power capacity from wind systems in 2035 amounts to 5.3GW in LIG, 7 GW in BaU, 7.5in EE, 8.2 GW in LPO and 9.2 GW in RES. In 2050, their capacity amounts to 6.7 GW in LIG, 8.1 GW in BaU, 8.8 GW in EE, 9.8 GW in LPO and 10.6 GW in RES. Photovoltaic parks have even more dynamic characteristics, particularly after 2030. Thus, the installed capacity in 2035 ranges between 5.3-7 GW in all scenarios except RES where it amounts to 8.2 GW, while in 2050 it amounts to 7.1 GW in LIG, 7.7 GW in BaU, 9.3 GW in EE, 10.2 GW in LPO and 11.3 GW in RES.

The higher penetration of wind and photovoltaic technologies in the electricity system creates additional energy storage needs, due to their intermittent nature. In the scenarios considered, this storage is carried out by pumped hydroelectric storage, utilizing the existing facilities, converting existing couples of water reservoirs owned by the Public Power Corporation (PPC) into pumped storage systems and, if so required, by constructing new pumping hydroelectric power stations. The additional storage requirements by 2050 amount to 1,450 MW in LIG, 1,950 MW in BaU, 2,500 MW in EE, 3,050 MW in LPO and 3,500 MW in RES.

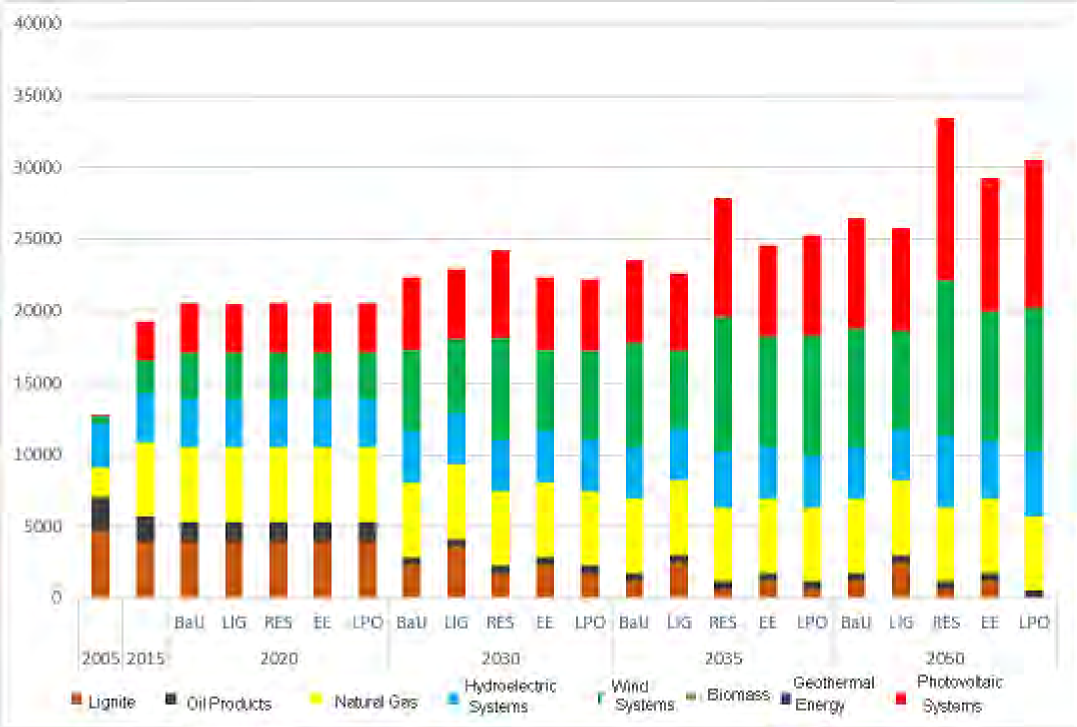


Figure EP-4: Evolution of the installed power capacity for production units in the Greek energy system per technology (in MW).

Based on the analysis carried out in each scenario, the necessary cumulative investments in the electricity system for the period 2015-2050 have been estimated. According to the calculations, they amount to 23 bil. euros in LIG, 24 bil. euros in BaU, 28 bil. euros in EE, 30 bil. euros in LPO and 33 bil. euros in RES (**Table EP-1**). The necessary investments in RES are higher by 9-10 bil. euros compared to BaU and LIG, while the implementation of EE and LPO requires significantly lower resources, approx. 5-7 bil. euros over those required in LIG and BaU.

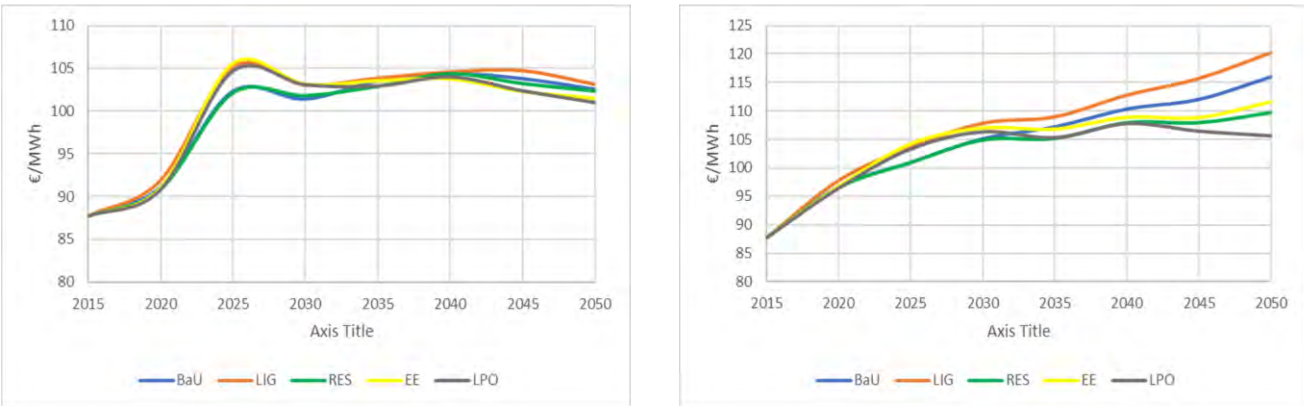
The LIG and BaU scenarios, although of lower capital intensity, do not lead to a lower electricity cost compared to the other scenarios considered, given that they also involve costs for fuels and the purchase of emission allowances. For conservative projections of the emission allowance price adopted as part of this analysis, the levelized cost of electricity shows a similar behaviour in all scenarios (since the bigger investments in the scenarios with a higher RES penetration are offset by the higher operational cost of the scenarios with larger conventional electricity generation shares), and only towards the end of the reference period do the EE and LPO scenarios lead to a slightly lower electricity generation cost (**Figure EP-5a**). Nevertheless, this picture is significantly different if the most recent scenario for the evolution of the emission allowance price as presented by the European Commission is adopted In this case the levelized cost of electricity for the RES, EE and LPO scenarios is now clearly lower than the cost for the BaU and LIG scenarios (**Figure EP-5b**).

Table EP-1: Total electricity system required investments based on the assumptions of each scenario during the period 2015-2050 (in mil. € 2015).

Technologies	BaU	LIG	RES	EE	LPO
RES	*22634*	*19873*	*33004*	*26269*	*29689*
Wind farms	12134	10298	15563	13133	14483
Industrial photovoltaic systems	5690	5147	9202	7190	8072
(Residential) photovoltaic systems	2524	2515	2524	2524	2524
Hydroelectric systems (including new pumping stations)	438	438	3734	1441	2627

Geothermal energy	32	32	32	32	32
Biomass	476	476	476	476	476
Conversion of hydroelectric systems into pumping systems	1340	968	1472	1472	1472
Conventional stations	*1664*	*3027*	*275*	*1664*	*275*
Lignite stations	1389	2431	0	1389	0
Natural gas	0	0	0	0	0
Oil	0	0	0	0	0
Upgradings	275	596	275	275	275
Total investments	***24,298***	***22,902***	***33,280***	***27,935***	***29,964***

The evolution of the emission allowance price, in combination with natural gas prices are crucial factors in order to evaluate the economic viability of new lignite units. The analysis has concluded that, when comparing conventional electricity generation alternatives, low emission allowance prices, below 30 €/t CO_2, favour the radical upgrading of existing lignite units instead of the construction of new ones, while for higher emission allowance prices, and up to a certain extent, the construction of new lignite units is more appealing from a financial point of view only when higher natural gas prices occur in the market. Wind energy seems to be competitive to lignite electricity generation for emission allowance prices in the order of 25 €/t CO_2, while if the pumped storage cost is included in the RES cost, lignite electricity generation exceeds the RES cost for emission allowance prices in the order of 50-55 €/t CO_2.



(a) (b)

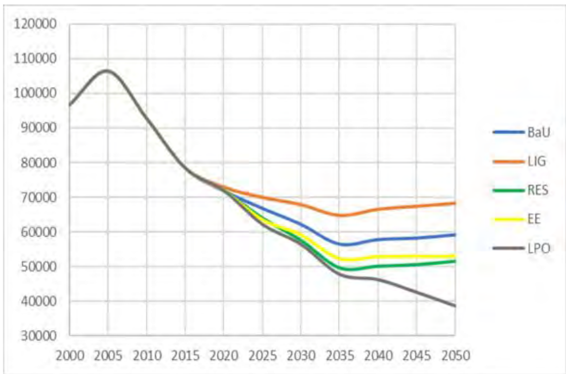
Figure EP-5: Evolution of the levelized cost of electricity in the scenarios examined (in €/MWh): (a) conservative scenario for the evolution of the emission allowance price, (b) European Commission Reference Scenario 2016 emission allowance price projections.

Greenhouse gas emissions

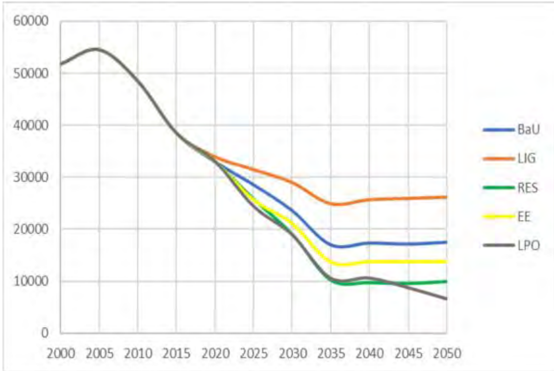
Figure EP-6a summarizes the evolution of the greenhouse gas emissions (GHG) from the energy system, while **Figure EP-6b** focuses on the evolution of the GHG emissions of the electricity generation sector.

It is obvious that the GHG emissions from the energy sector show a significant drop in all scenarios. From 106.4 Mt CO_2eq emitted in 2005, they are expected to drop down 38-68 Mt CO_2eq in 2050. By adopting one of the RES, EE and LPO scenarios, the energy system emissions will reach or fall below 50 Mt CO_2eq already by 2035, while the implementation of the LPO scenario in particular will lead to emissions of 47.8 Mt CO_2eq in 2035 and to 38.6 Mt CO_2eq in 2050, 64% lower than the 2005 levels. On the contrary, the persistence on lignite electricity generation, as expressed through the LIG scenario, leads to GHG emissions in the order of 4.7 Mt CO_2eq in 2035 and of 68.2 Mt CO_2eq in 2050 (only 36% lower than the 2005 levels).

The differences in emissions are even more impressive in the electricity generation sector, highlighting its crucial role in the development of a low carbon emissions economy. The total emissions from this sector drop down from 54.5 Mt CO_2eq in 2005 to a range of 10.5-25 Mt CO_2eq in 2035 and of 6.5-26.2 Mt CO_2eq in 2050. In 2030, both the RES and LPO scenarios lead to emissions below 20 Mt CO_2eq, while in 2050, these two scenarios lead to emissions below 10 Mt CO_2eq, and the EE scenario to emissions lower than 14 Mt CO_2eq. On the contrary, the LIG scenario leads to emissions over 25 Mt CO_2eq during the overall study period.



(a)



(b)

Figure EP-6: Evolution of greenhouse gas emissions from the energy sector (a) and from the electricity generation sector (b) per policy scenario for Greece until 2050 (in kt CO2eq).

Based on the above, and in order to reach the environmental and energy targets discussed by the EU for 2030 and 2050, significant investments in RES technologies should be expected . The promotion of energy saving policies in the final consumption sectors seems to reduce to some extent the necessity for new investments in RES. However, it should be noted that extremely strong efforts will be required in order to achieve the energy saving targets by implementing respective programs. Since the country has gone through a decade of unprecedented shrinkage in GDP and family income, it is estimated that the relative improvement of the economic conditions will bring about a strong rebound effect and, therefore, the implementation of energy saving programs and the reduction of the energy costs will contribute to the improvement in living conditions within buildings, the increase of transportation demand, etc. but the decrease in energy consumption will be smaller than the expected one. The combined promotion of RES and energy savings, along with a lignite phase out policy, pushes the Greek energy system in a direction that is characterized by not only a lower levelized cost of electricity but also by significant benefits for the protection of the environment.

1. INTRODUCTION

1.1. Climate change: european and international developments

The international community's efforts to effectively address the climate change problem were reinforced with the Paris Agreement during the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change , in December 2015. For the first time, 195 countries adopted a legally binding agreement on climate, committing to the following:

- Adopting a long-term goal for limiting the increase in the global average temperature to below 2°C compared to preindustrial levels.
- Pursuing efforts to limit the increase in the global average temperature even lower, to 1.5°C, since this will greatly reduce the risks and impact from climate change.
- The need for global greenhouse gas emissions to peak as soon as possible, acknowledging that in developing countries this may take longer to achieve.
- Implementing a fast decrease in emissions afterwards, based on scientific findings.

Within this framework, before and during the Paris Conference, the countries submitted the so-called Nationally Determined Contributions on climate, with quantitative targets for limiting their emissions. Although the limitation targets included in these Action Plans are not sufficient in order to limit the increase in the global average temperature to 2°C, they were considered as a first step in that direction.

In other important parts of the Paris Agreement, governments committed to the following:

- Every 5 years, setting more ambitious targets for limiting the emissions based on the latest scientific findings.
- Communicating the progress towards meeting their emission reduction targets .
- Monitoring the progress achieved compared to the long-term target of limiting global temperature increase to 2°C by means of an accurate, transparent and measurable system.

Moreover, with the Paris Agreement, governments have agreed to reinforce the societies' ability to address the impact of climate change and, within this framework, to provide continuous and increasing support to developing countries so that they can adapt. In addition, they acknowledge the significance of preventing, minimizing and addressing the losses and damages related to the negative impact of climate change, as well as the necessity to cooperate by developing prompt warning and risk safety systems, etc.

The Paris Agreement came in force on 4th October 2016; thus, during the 22nd Conference of the Parties to the United Nations Framework Convention on Climate Change, which took place in November 2016 in Marrakesh, the proceedings began in order to formulate the operational rules that will govern the Agreement. A strict 2-year time schedule was agreed upon for the finalization of these rules; thus, by the end of 2018, the following will have to be defined: (a) how will the Countries report their actions for emissions reduction, adaptation, funding for climate change issues, technology transfer and infrastructure development, (b) methods for monitoring these actions will be implemented as well as their progressive reinforcement, and (c) a process will be developed in order to facilitate the implementation of the Agreement's targets and to promote compliance with them. Other operational issues that will need to be defined at the same time are related to the definition of common reference periods for the established reduction targets in national emissions and to the adoption of a renewed obligation to provide economic support to developing countries on climate change issues.

Given that the national emission decrease targets presented during the Paris Conference seem to lead to an increase in the global average temperature by 2.9-3.4^{o}C in 2100 compared to preindustrial levels, it becomes apparentthat, at a global level, CO_2 emissions in 2030 will be higher than the required ones to reach the 2^{o}C target by 12-14 Gt, and by 15-17 Gt higher than the target for a 1.5^{o}C increase[1]. The Marrakesh Conference asked for the initiation of a dialogue that will set the scene for adopting more ambitious national emission limiting targets, a procedure that will start in 2018.

Also during the Marrakesh Conference, certain countries such as Canada, USA and Mexico, announced their long-term strategy for decreasing greenhouse gas emissions. Although they do not set new targets for 2050, the fact that they a discussion on the structure and characteristics of those countries' economies after 2030 has started, is encouraging. Moreover, Germany announced a long-term action plan for climate change, aiming at reducing emissions in 2050 by 95% compared to 1990, while other -developed and developing- countries, seem to be prepared to adopt relevant targets as part of the 2050 Pathways Platform adopted during the Marrakesh Conference.

During the same period in Europe, special emphasis was attributed to the amendment of the Directive on greenhouse gas emission allowances trading, which has been the main European Union (EU) policy for addressing climate change since 2005. The trading system is already going through its 3rd period of application (2013-2020), during which a linear reduction coefficient has been adopted for the overall issued allowances that equals 1.74% per year. Although it has been decided to raise this coefficient to 2.2% during the 4th trading period (2021-2030), this does not seem to be sufficient for the EU to start reducing ETS sectors' emissions by 90% in 2050, as has been prescribed in the Energy Roadmap 2050[2]. Besides, the emission allowance prices already established in the markets do not seem high enough to spurr the transition to low carbon emission economies. **Figure 1-1** shows the evolution of the emission allowance prices over time in the EU Emissions Trading System (EU ETS), in correlation with the available allowances and recorded emissions. In the market there is a surplus of available allowance that holds the prices relatively low, by not triggering radical emission decreases in the respective sectors of economic activity.

In order to address the issue of the allowance surplus, a Market Stability Reserve (MSR) mechanism was established in September 2015, which will start to operate in 2018, and the first adaptation will refer to auctions taking place after January 2019. As of May 2017, the European Commission will be issuing an annual report on the total number of allowances that was in circulation during the previous year. In case these exceed 833 Mt, 12% of the total amount will be withdrawn from the market and placed in the MSR. In reverse, if the allowances in circulation are lower than 400 Mt, 100 Mt of the additional allowances will be auctioned. The MSR also includes the 900 Mt of allowances, the auctioning of which was postponed in 2014-2016 in order to stabilize the market. Despite the limitation of the total allowances during the 4th period, the European Environment Agency, based on projections by the Member States, estimates that the allowance surplus will be absorbed by 2029, but the decrease in emissions will not reach the 43% level in 2030 compared to 2005 (the EU target for the ETS sectors)[3].

The trialogue between the European Parliament, the European Commission and the European Council for the amendment of the EU ETS is already in progress, and even more ambitious proposals than the above for the MSR operation and allowance cancellation are under discussion.

[1] UNEP 2016, The Emissions Gap Report 2016.

[2] Marcu A, Alberola E, Caneill J-Y, Mazzoni M, Schleicher S, Stoefs W and Vailles C (2017), 2017 State of the EU ETS Report.

[3] EEA 2016 Trends and projections in the EU ETS in 2016: The EU Emissions Trading System in numbers.

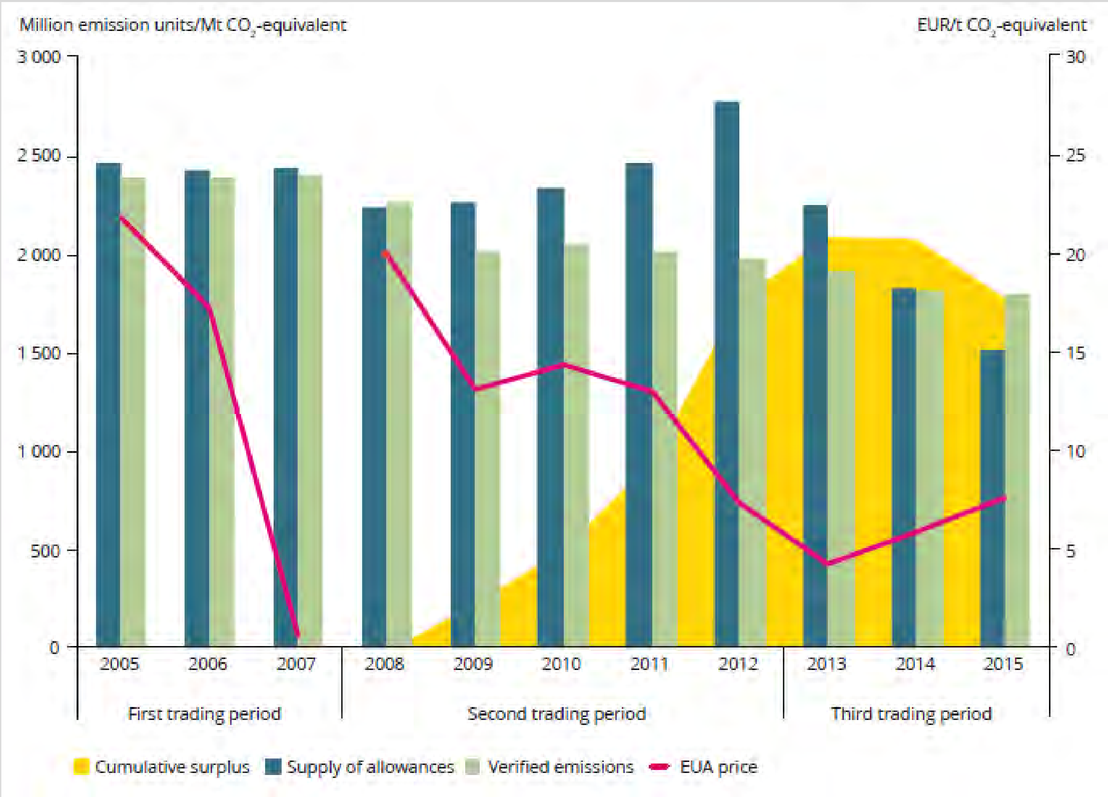


Figure 1-1: Emissions, allowances, prices and allowance surplus in the European Trading System during the period 2005-2015. Source: EEA 2016 Trends and projections in the EU ETS in 2016: The EU Emissions Trading System in numbers.

1.2. Study objective

Based on the short review of the recent developments presented above, it is obvious that the energy sector, which is the most important source of greenhouse gases in the European Union, and particularly the electricity generation sector, which is the most important EU ETS sector, will constitute a field of strong policies in the next decades, aiming at the significant reduction of greenhouse gas emissions and the development of low carbon emission economies. Especially for Greece. there are strong concerns about the upcoming changes in the energy system, taking into account that these will occur in an extremely adverse economic environment due to the economic crisis in recent years.

WWF Greece has launched a campaign for the conversion of the Greek electricity generation model into a low CO_2 emissions system. In this framework, the objective of this study is to investigate scenarios evaluating the possibilities to achieve significant reductions in CO_2 emissions in the Greek electricity generation sector, the existing technological possibilities towards this direction (large-scale RES penetration, closing down of lignite plants, etc.), as well as the financial impact (on the energy cost and the level of required investments) of such a transition. At the same time, electricity demand is another significant factor affecting developments in electricity generation; therefore, the answer to the aforementioned questions requires a holistic examination of the energy system.

Thus, as part of this study, comparative alternative scenarios for the evolution of the Greek energy system until 2035 and 2050 are developed and evaluated, emphasizing on the electricity generation sector. Specifically, 5 main scenarios are developed with variations per case, 2 of which assume that lignite electricity generation will still hold a significant share in the energy mix until 2050, while the other 3 assume a large scale RES penetration and a smaller lignite share in the electricity system. Moreover, 2 of the scenarios assume that ambitious energy saving policies will be adopted, in contrast with the other 3 that adopt less radical efficiency interventions. These scenarios were examined in order to answer to the following research questions:

- The impact on energy costs and emissions from different lignite shares in the energy mix.
- The impact on the cost of energy and emissions from the large-scale penetration of RES technologies.
- The impact on energy costs and the electricity system structure from the emission allowance price.
- The role final energy consumption saving programs play and how they affect the electricity generation sector structure.

The scenarios developed are considered realistic approaches of the future of energy in Greece, based on the assumptions included in each one. Although even more ambitious scenarios could be formulated per case, this study does not aim at determining an "ideal" development level of the Greek energy system, but rather at evaluating comparatively different energy policies, highlighting the pros and cons, limitations and possibilities, and finally, at contributing to the dialogue on the long-term energy planning of Greece.

The analysis is carried out using the ENPEP/Balance hybrid energy model, which is a partial balance simulation model, allowing to represent quite realistically the behaviour of various "players" in the energy market.

1.3. Study structure

This study is structured in 6 Chapters:

Chapter 1 briefly presents recent international developments regarding the policies for addressing climate change and defines the objective and aims of this study.

Chapter 2 elaborates on the main principles of EU policy on energy and climate during the period until 2035 and 2050, highlighting the feasibility of long-term energy planning and presenting policy directions both from other EU countries as well as from relevant, relatively recent studies carried out in Greece.

Chapter 3 presents the method for modelizing the Greek energy system in the ENPEP/Balance model that was used in this analysis.

Chapter 4 lists the main assumptions for the scenarios examined.

Chapter 5 presents a comparison of the results of the scenarios examined, the detailed results of which are included in the *Annex*.

Finally, *Chapter 6* summarizes the main conclusions of the analysis and lists some general policy directions.

2. LONG-TERM ENERGY PLANNING

2.1. The European Strategy for 2030 and 2050 (Energy Roadmap 2050)

The European Commission, after adopting the Energy and Climate Package for 2020 and the relevant Directives and Decisions, proceeded, on the 24th October 2014, to adopt a new set of important decisions aiming at a further decrease in greenhouse gas emissions and the reform of the energy sector during the period until 2030. Specifically, the following main targets are set:

- A binding target to decrease greenhouse gas emissions at EU level by at least 40% in 2030 compared to the 1990 levels. This target will be collectively achieved by the Member States (the decision does not include national targets), with further interventions both in the Emissions Trading System sectors (which are expected to reduce emissions by 43% in 2030 compared to 2005), as well as in the sectors not included in the Emissions Trading System (by aiming at a 30% decrease in emissions compared to 2005).
- A binding target for RES penetration at EU level by at least 27% in the gross final energy consumption in 2030. For the time being, there is no target per Member State, although there are relevant consultations in progress, and this is expected to take place in the near future.
- An indicative target for the improvement of the energy efficiency at EU level by at least 27% in 2030 compared to a reference scenario. This target can be increased to 30% during the ongoing Efficiency Directive reform process.

A set of decisions and directive amendments are planned in order to achieve the targets, so as to define in greater detail the changes that will have to be made in the various sectors of the energy system economy towards this direction.

Specifically, as regards the Emissions Trading System, the proposal to amend the Directive includes the following:

- A 2.2% decrease in the maximum number of emission allowances that can be issued on an annual basis as of 2021 and 1.74% afterwards, in accordance with the 3rd period of the EU Emissions Trading System, until 2020.
- A reform of the rules for addressing the problem of carbon leakage. Specifically, the following measures are prescribed: focusing on the free distribution of emission allowances in the sectors with the highest risk of relocating their production outside the EU, granting a significant number of free allowances to new and developing facilities, improving the correlation between the freely distributed emission allowances and the production levels, as well as updating the benchmarks in order to take into account the technological innovations of the past decade.
- The adoption of supporting mechanisms so that the industry and electricity generation sectors can proceed to the necessary innovations and investments for the transition to a low carbon emission economy. Within this framework, two new funding mechanisms are proposed: (a) the innovation fund, with approximately 400 mil. for allowances, in order to demonstrate innovative technologies in the industry (this includes RES and carbon capture and storage), and (b) the modernization fund, with approximately 310 mil. allowances, in order to facilitate the modernization of the electricity generation sector and, in general, energy systems, as well as the promotion of energy efficiency in the 10 poorest EU Member States (for the time being, these do not include Greece).

These changes should also include the operation, as of January 2019, of the Market Stability Reserve mechanism, which will be used to monitor the allowance surplus in the market and to make the necessary adjustments in terms of the allowance amount to be auctioned in order to protect the market from extreme fluctuations.

As regards the greenhouse gas emissions in the sectors outside the EU ETS (buildings, transportation, waste, agriculture, etc.), the European Commission proposed specific targets per Member State, as part of formulating the relevant Regulation[4]. For Greece, there is a requirement for a mere 16% decrease in 2030 compared to the 2005 levels.

As far as the RES targets are concerned, Directive 2009/28/EC is under revision. The achievement of the 27% RES penetration in the gross final energy consumption of EU in 2030 is expected to lead to a 50% RES penetration in electricity generation. No targets have been set per Member State. However, the Staff Working Document[5] of the European Commission contains indicative targets per Member State and for various scenarios/criteria for the necessary effort sharing. According to these, the RES penetration in the gross final energy consumption for Greece in 2030 ranges between 26% and 34%, amounting to 30% in the reference scenario. According to Article 3 of the draft Directive, Member States will commit to specific targets through the Integrated Energy and Climate Action Plans that they will submit to the European Commission, with the latter retaining the right to intervene in case it is concluded that EU as a total does not achieve the 27% target.

Particular emphasis is attributed to the promotion of RES in the heating/cooling sectors, to the promotion of next generation biofuels, electricity, hydrogen and renewable synthetic fuel in transportation, the limitation of the role played by traditional biofuels that compete in terms of food availability, as well as to the promotion of self-generation.

Moreover, there is an intention to fully integrate the internal energy market by facilitating the construction of interconnection projects, particularly in energy isolated areas, such as Greece, Cyprus and Malta. The target for 2030 is a 15% electrical interconnection between Member States.

Finally, as far as energy efficiency is concerned, in November 2016, the European Commission proposed the adoption of a binding target for improving the energy efficiency at EU level by 30% by 2030. This new target is part of a proposal by the European Commission to amend the Directive on energy efficiency. Specifically, the proposed policies to achieve the target include the following:

- An annual decrease in energy sales at a national level by 1.5%.
- Energy renovations carried out by the Member States in at least 3% of the buildings owned and used by the central government.
- Compulsory use of an energy efficiency certificate during building selling and renting.
- Development of National Energy Efficiency Plans every 3 years.
- Installation of 200 mil. smart electricity meters and 45 mil. of smart gas meters.
- Energy inspection of large enterprises every 4 years.
- Protection of consumers' rights for easy and free access to current and past energy consumption data.

All the aforementioned targets for 2030 are integrated in the Roadmap adopted by the EU for the development of a low carbon emission economy by 2050. In particular, the EU Roadmap aims at decreasing the greenhouse gas emissions in 2050 by 80% compared to the 1990 levels, through the exclusive implementation of national actions and without the utilization of international coal markets. For this reason, it will be necessary to apply suitable policies and measures in all Member States and in all sectors. **Figure 2-1** presents the decreases in emissions that will be necessary per sector, also based on the available technological and financial potential. Specifically:

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[4]REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 for a resilient Energy Union and to meet commitments under the Paris Agreement and amending Regulation No 525/2013 of the European Parliament and the Council on a mechanism for monitoring and reporting greenhouse gas emissions and other information relevant to climate change
http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52016PC0482&from=EN

[5] Staff Working Document (2016) 418 Final.

- In the electricity generation sector, a very large potential of decreasing emissions is detected, through the promotion of RES, other low emission technologies, including carbon capture and storage technologies and smart networks. The emissions from the sector may be eliminated by 2050, despite the requirement to cover additional energy loads in transportation and heating.
- In the transportation sector, emissions will have to be decreased in 2050 by over 60% compared to 1990. The main interventions are penetration of energy-efficient vehicles and biofuels, as well as the partial electrification of the sector.
- In the building sector, the decrease in emissions will have to reach a 90% level through the construction of passive house standrad buildings, the renovation of the existing building stock and the integration of RES technologies into them.
- Decreases in emissions in the order of 80% will also be required by energy intensive industries through the application of more efficient and cleaner technologies.

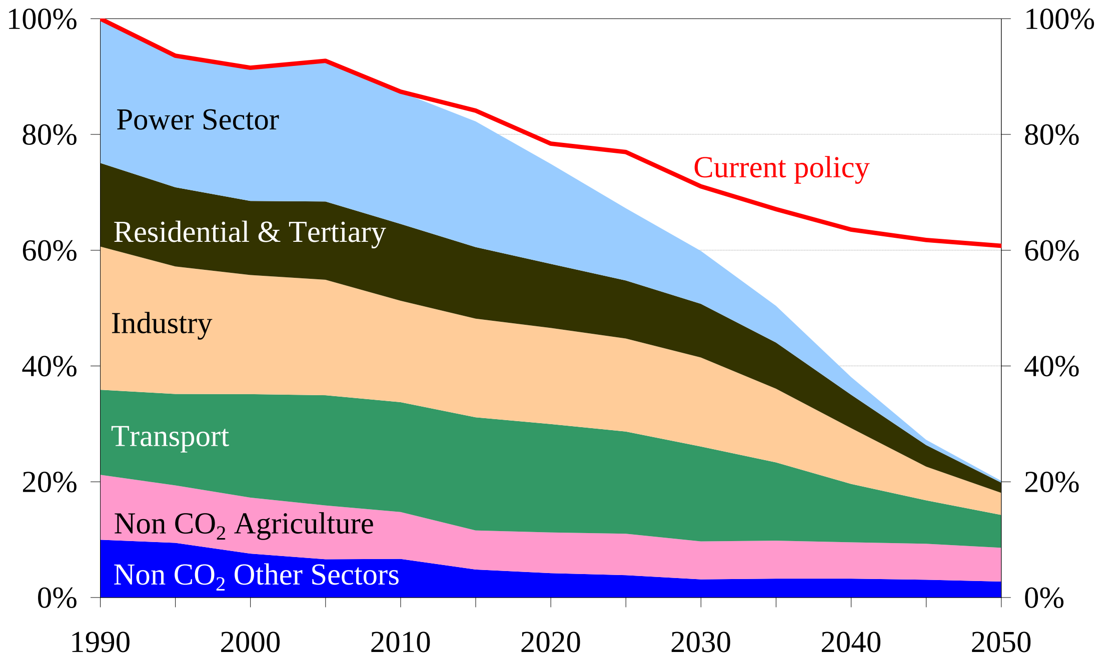


Figure 2-1: Evolution of greenhouse gas emissions in the EU with a 80% decrease target by 2050 (100% =1990).[6]

2.2. Review of national long-term planning in Europe

In addition to the Roadmap 2050, several European countries have proceeded to the formulation of national long-term strategies for energy and climate. This section attempts to present a brief review of this planning for selected EU countries, especially as regards the quantitative targets they set for the decrease in the greenhouse gas emissions, the decrease in the primary energy consumption and the RES promotion in electricity generation during the period until 2030-2035 and 2050. It is not easy to make a comparative analysis of these plans, given that:

[6] *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Roadmap for moving to a competitive low carbon economy in 2050*

- They have not been developed during the same period and, therefore, they do not necessarily integrate the same energy/climate policies or the same assumptions in relation to the evolution of socio-economic aspects.
- The ambition level for the decrease in emissions during the period until 2030-2035 and/or 2050 may vary from one country to another.
- They are based on the analysis of different models.
- The potential to decrease emissions, utilize RES, etc., may vary significantly from one country to another.

Table 2-1 summarizes the targets set by 10 European countries and compares them to the respective targets set as part of the European energy map. These targets are included in official documents and/or studies carried out under the coordination of the competent ministries and authorities in each country. This does not include targets and estimates resulting from modelization studies carried out by universities, research centres, consulting companies, etc. It is noted that, to date, not all EU countries have developed a 2050 Roadmap regarding energy and/or climate. It is mainly the Northern European countries and the oldest EU Member States that have developed such plans which, in general, have the strongest policies for the RES promotion and the decrease in greenhouse gas emissions. As a rule, these countries adopt more ambitious targets than the overall target set by the EU. On the contrary, Hungary, which is a recent EU Member State, adopts more conservative targets. The majority of the countries that have developed a long-term Roadmap for energy and climate set targets for the decrease in the greenhouse gas emissions, while relatively fewer countries specialize these targets in relation to the RES penetration in electricity generation, a decrease in energy demand, etc.

Table 2-1: Targets adopted by various EU countries as part of a long-term Roadmap for energy and climate[7]

Countries	2030			2050		
	Decrease in GHG compared to 1990 (%)	*Decrease in Primary Energy (%)*	*RES in electricity generation (%)*	*Decrease in GHG compared to 1990 (%)*	*Decrease in Primary Energy (%)*	*RES in electricity generation (%)*
Belgium				80-95	37-54 (2010)	79-100
France	40		40	75	50 (2005)	
Germany	55		50	80-95	50 (2008)	80
Denmark			100	80-95		100
United Kingdom	50			80		
Italy				75	17-26 (2010)	85-90
Netherlands				80-95		
Hungary		-2 - 8 (2008)	15-20			20-35
Finland				80-95		
Sweden				100		
EU	40	16-20 (2005)	51-60	80	32-42 (2005)	59-86

[7] Sources: (1) van Sluisveld M, Hof A, van Vuuren D, 2016. Long-term perspectives beyond 2020: a meta-analysis on European and national climate and energy roadmaps, Pathways Project, Exploring transition pathways to sustainable, low carbon societies, Grant Agreement number 603942. (2) Ministry of Employment and the Economy Energy and Climate of Finland, 2014. Roadmap 2050. Report of the Parliamentary Committee on Energy and Climate Issues on 16 October 2014. (3) Ministry of National Development Hungary, 2012. National Energy Strategy 2030, ISBN 978-963-89328-3-9. (4) Ministry of Economy of Italy, 2013. Italy's National Energy Strategy: For a more competitive and sustainable energy. (5) Climate Change Section of the Federal Public Service Health, Food Chain Safety and Environment, 2013. Scenarios for a Low Carbon Belgium by 2050. Climact and Vito.

2.3. Greek long-term energy planning

2.3.1. The need for long-term energy planning

Energy is a main production factor in each economic activity developed as part of an economy; therefore, the way of structuring, organizing and developing the energy system has multiple impacts on economic development and the inhabitants' quality of life. The main objectives are:

- The sustainable management of natural resources and a decrease in environmental loads/consequences from energy generation and consumption.
- Development of energy product prices that amount to tolerable levels for industries, enterprises and households.
- Energy security and unrestricted access to energy resources for potential consumers.
- Decrease in energy dependence and exploitation of domestic energy resources.

The achievement of these targets in energy efficiency terms raises a series of energy policy problems for policy-makers in relation to the following:

- The mix of energy technologies that will have to be used both in energy generation and in the final consumption sectors, given their special technical and financial characteristics. In recent years, the commercial maturity of a series of RES technologies has enhanced potential choices, while the progress of electricity storage technologies offers integrated solutions concerning the intermittent nature of key technologies, such as wind and photovoltaic systems, thus ensuring the security of energy supply.
- The extent of interventions at the level of energy supply and demand. The application of energy saving programs in the final consumption sectors reduces energy and fuel demand, thus facilitating the utilization of the most effective technologies. On the other hand, the application of measures in the demand sector requires the involvement of a large number of users which, in several cases, makes the application of planned interventions ineffective. Energy policies on the supply side concern a smaller number of participants; therefore, this allows a better coordination, but reasonable questions are still raised regarding the possibilities and cost of an energy system that is called upon to cover a constantly rising demand.
- Energy costs. Several technologies using fossil fuels were until recently characterized by a lower cost, but without taking into account their critical impact on the environment and public health which, in turn, constitute the so-called external cost. The stricter European environmental legislation has led to regulatory (e.g. setting strict emission limits that require the installation of expensive anti-pollution technologies) and economic (e.g. Emissions Trading System) policies, which gradually lead to internalizing part of this external cost, resulting in a higher cost of electricity generated from fossil fuel.

Taking into account that, in most cases, energy investments are capital intensive and their life span extends over decades, it is obvious that the above issues must be the object of diligent investigation and exhaustive consultation between the government, regulatory energy authorities and participants in the energy market. The elaboration of a long-term energy plan, which will be regularly assessed and updated, is a necessary condition in order to ensure Greece's sustainable economic development.

2.3.2. The Greek energy system

The Greek energy system is relatively isolated compared to the EU Member States' energy systems, has a large number of autonomous island systems, has demonstrated high rates of increase in energy demand until the beginning of the economic crisis and is highly dependent on conventional fuel imports (higher than the EU average). Lignite is actually the main fossil fuel produced in Greece which is almost exclusively used for electricity generation.

Gross energy consumption in Greece (**Figure 2-2**) increased by 42.5% during the period 1990–2008, with 2008 being the year with the highest consumption (31.8 Mtoe). Then, as a result of the economic crisis, consumption started to drop and in 2015 it amounted to 24.4 Mtoe (namely at the levels of the 5-year period 1995–2000). In terms of the structure of the gross energy consumption per energy form, the most important change that took place is the introduction of natural gas in the Greek energy system in 1996, initially for electricity generation and then in the final consumption sectors. As a result of introducing natural gas, the oil products' share in the gross energy consumption has decreased (from 58% of the consumption in 1990 to 51% in 2015). Nevertheless, these oil products are still the main energy form in the Greek energy balance, mainly due to the domination of oil in the transportation and heating sectors. Similarly the solid fuel's share (mainly lignite for electricity generation) decreased from 36% in 1990 to 23% in 2015. The RES share remained at 5% until 2005 consisting largely of biomass and hydropower (over 85%). Later on, the introduction initially of wind and then photovoltaic energy in the energy mix starts to become significant; as a result, in 2015, the RES share in gross energy consumption in Greece was 11%.

Final energy consumption (including the consumption of the energy sector) in 2015 amounted to 18.6 Mtoe (**Figure 2-3**), showing a 11% decrease compared to 2010 and a 18% decrease compared to 2005. In proportion to the gross energy consumption, the final consumption had shown high increase rates until 2005. The average annual increase rate of final consumption was 3.4% for the 5-year period 1995–2000 and 2.3% for the subsequent 5-year period. Liquid fuels and electricity are the main forms of energy consumed (60% and 26% respectively for 2015), while the RES share in 2015 is limited to 8% (the RES share in the final energy consumption is in the order of 6%-8% during the period 1990–2015).

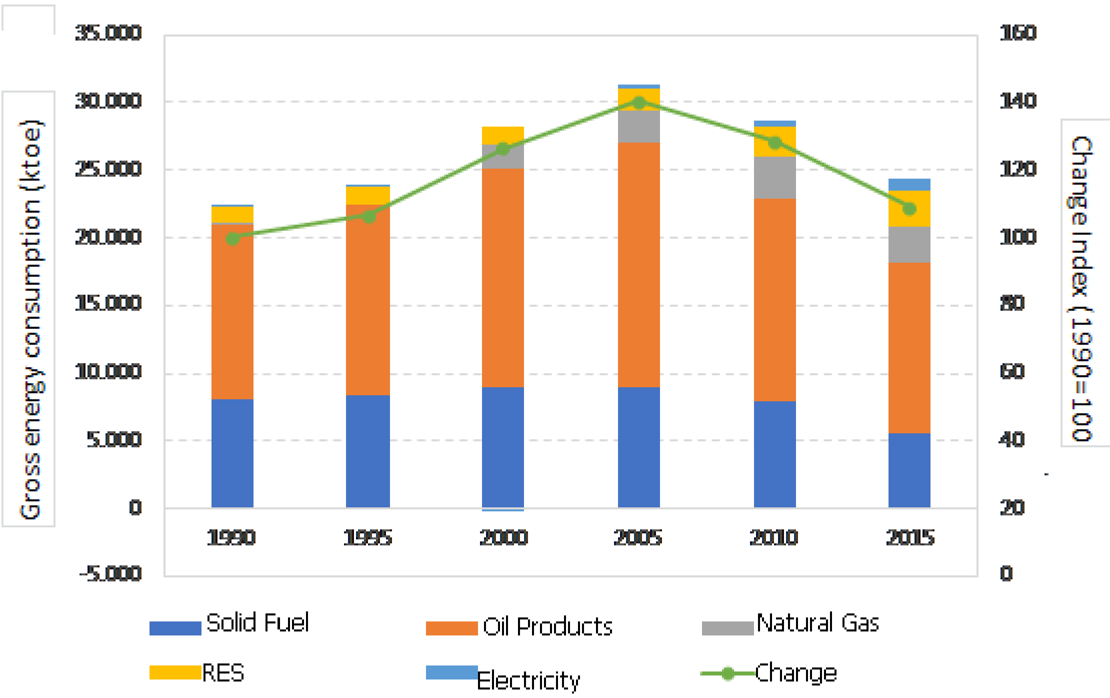


Figure 2-2: Evolution of the gross energy consumption (in ktoe) in Greece for the period 1990–2015. Source: EUROSTAT

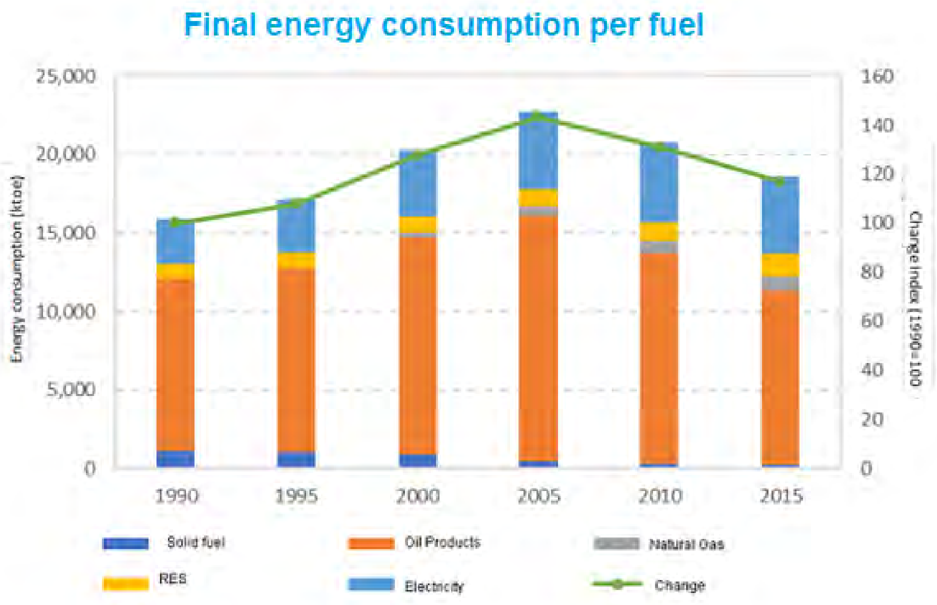
The changes in final energy consumption (and gross consumption), in terms of both absolute prices and their structure per fuel and sector (Figure 2-3), are affected by the overall socio-economic conditions.

(a) As a result of the gradual shift of the Greek economy towards the service sector, the industry share in the final energy consumption drops from 25% in 1990 to 18% in 2005 and then to 16% in 2015, mainly due to the economic crisis and the resulting decrease in industrial activity.

(b) The decrease in the industry share in final energy consumption and the gradual substitution of solid fuel (mainly in the cement production industries), initially from oil products and then from natural gas, resulted in limiting the solid fuel share in the final energy consumption to 1% in 2015 (from 7% in 1990 and 4% in 2000).

(c) The tertiary sector share in the final energy consumption in 2015 was in the order of 10% (from 4% in 1990 and 6% in 2000), while during the 5-year period 2010–2015 the energy consumption in the sector decreased by 4%.

(d) The transportation sector share is higher than 35% during the whole period 1990–2015 (share percentage in 2015, which is the lowest in this timeframe); in addition, during the past 5-year period, the energy consumption in the sector decreased by 20% (from 8.2 Mtoe in 2010 to 6.6 Mtoe in 2015).



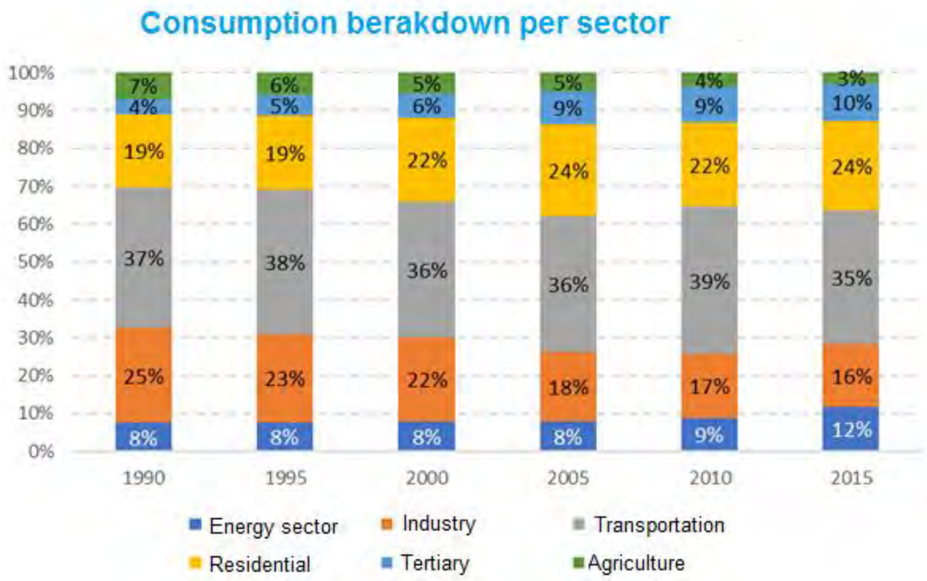


Figure 2-3: Evolution of the final energy consumption (in ktoe) in Greece for the period 1990–2015. Source: EUROSTAT

(e) The shift of economic activity towards the service sector and the improvement of living standards (until 2008) resulted in a significant increase in electricity consumption (by 50% during the period 1990–2000 and by 30% during the period 2000–2008). In 2015, electricity consumption (4.9 Mtoe) had decreased by 10% compared to 2008, the year with the highest value in electricity consumption for the period 1990 – 2015.

(f) The primary sector share in the final energy consumption was low during the overall period. In 2015, it only amounted to 3%.

(g) Energy consumption in the residential sector in 2015 (4.4 Mtoe) amounts to 24% of the final energy consumption. The sector share is in the order of 22%-24% for the period from 2000 and onwards but, in absolute prices, consumption has dropped by 20% during the last decade, since the increase in the heating oil price has led to a significant decrease in energy consumption for space heating.

The Greek energy system's efficiency, in terms of energy intensity (defined as the gross energy consumption divided by the GDP in 2010 prices), showed a significant improvement during the period 1995–2010), was comparable to the energy intensity of the Eurozone and lower than the energy intensity at EU level (**Figure 2-4**). The shift of economic activity from processing to the service sector, the gradual introduction of natural gas in the Greek energy system and the renewal of equipment, cars, etc. as a result of economic development are some of the parameters that have led to this improvement. An increasing trend is observed afterwards (2010 – 2015), with the energy intensity values now higher than those in the Eurozone and the EU. This trend in energy intensity is mainly due to the fact that the energy consumption decrease rate, owing to the limitation of the economic activity and the available income, was lower than the respective GDP decrease rate during the same period.

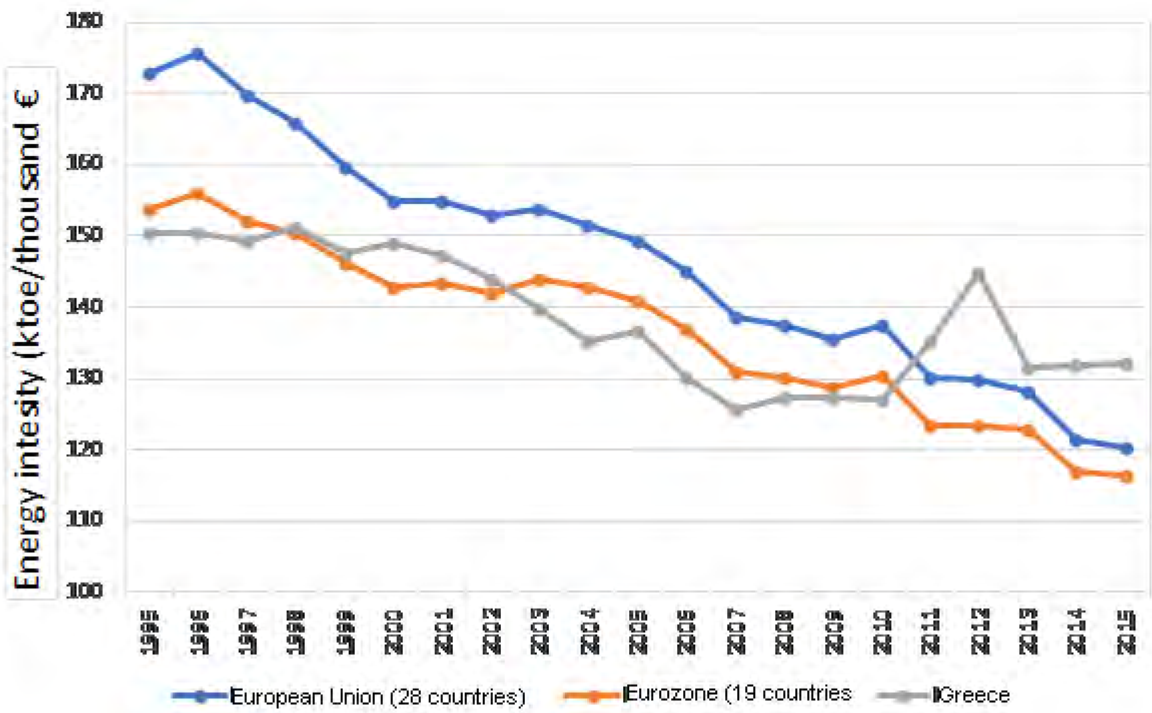


Figure 2-4: Evolution of energy intensity of gross energy consumption (in ktoe per thousand €, 2010 prices) in the European Union, the Eurozone and Greece for the period 1990 – 2015. Source: EUROSTAT

The energy sector (energy generation and consumption) is the main source of **greenhouse gas emissions (GHG)**, since the average emissions from this sector amount to 75% of the total national emissions. Specifically, the emissions from electricity generation amount to approximately 50% of the emissions in the energy sector and 37.5% of the total emissions

(**Figure 2-5**). Consequently, the changes in the GHG emissions depend on the changes in generation/ consumption and the parameters leading to these changes.

- In 2015, the total national GHG emissions amounted to 97.7 Mt CO_2eq, lower by 6.6% compared to the 1990 emissions, according to the most recent inventory of GHG emissions submitted by Greece to the UNFCCC Secretariat (April 2017). According to the Eurostat data[8] and despite the continuing economic crisis, Greece still has one of the lowest climatic performances in the EU. It holds the 7th lowest performance in the EU-28, while the average decrease in the GHG emissions in 2015 was 22.12% compared to the 1990 levels.
- As part of the Kyoto Protocol, Greece aimed at limiting the increase in the GHG emissions during the 2008 – 2012 period to 25% compared to the baseline emissions, the second less ambitious target among the EU Member States at the time, when the overall target for EU was to achieve a net decrease of 8% for the same period. Finally, the increase in emissions was limited to 12% compared to the baseline levels, namely complying with the target set.

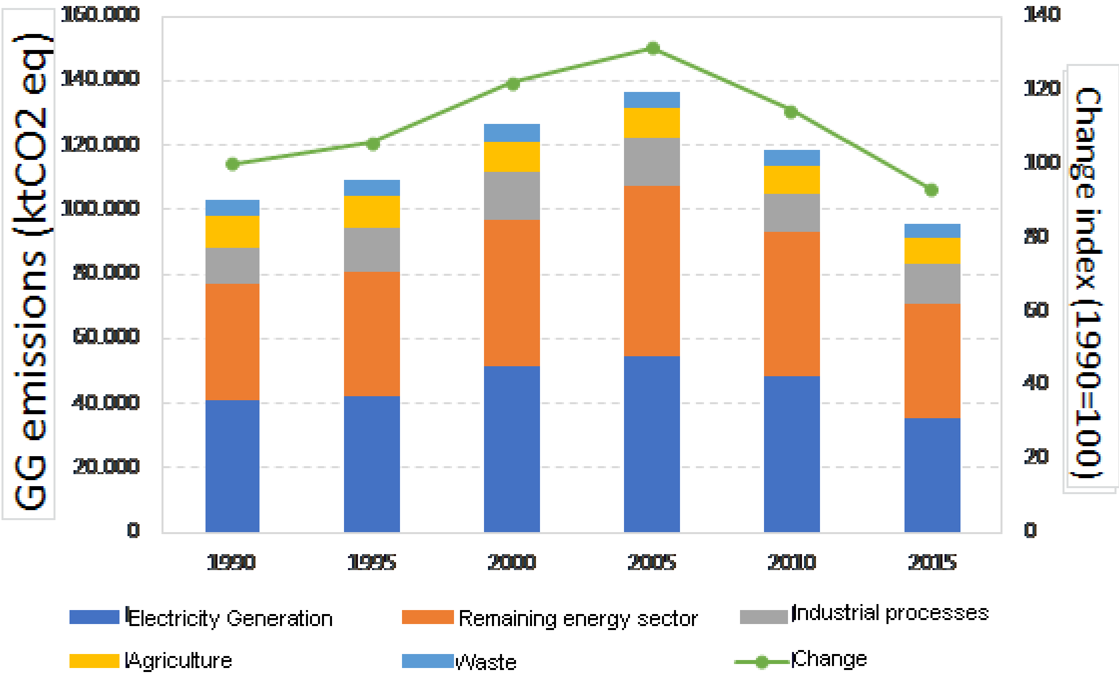


Figure 2-5: Evolution of the greenhouse gas emissions (in kt CO2 eq) in Greece for the period 1990 – 2015.[9]

2.3.3. Assessing the progress towards the national targets

The European Union set as a target (in 2008) the decrease in greenhouse gas emissions by 20%, until 2020. In order to achieve this target, binding targets have been set (for 2020) aiming at (a) a RES penetration (20% of the gross final energy consumption) and (b) the improvement of energy efficiency (20% improvement compared to the reference scenario). These overall targets have been specialized and broken down among the Member States through relevant decisions adopted afterwards. Particularly for Greece, the targets prescribed as part of the climate–energy set of measures for 2020 are as follows:

[8] Eurostat database.

[9] *Source: YPEN (MINISTRY OF ENVIRONMENT & ENERGY) (2017): Annual inventory submission of Greece under the Convention Kyoto Protocol for greenhouse and other gases for the years 1990-2015*

- In accordance with Decision No 406/2009/EC (*on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020*), by 2020, Greece will have to reduce the non-ETS emissions by 4% compared to the 2005 emissions.
- Directive 2009/28/EC (*on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC*) prescribes that the RES share in the final gross energy consumption in 2020 will have to amount to 18% for Greece. The same Directive prescribes that "*Each Member State shall ensure that the share of energy from renewable sources in all forms of transport in 2020 is at least 10% of the final consumption of energy in transport in that Member State*".
- In accordance with Directive 2012/27/EU (*on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC*), Greece set a target for energy consumption in 2020 not to exceed 24.7 Mtoe (primary energy consumption) or 18.4 Mtoe (final energy consumption).

Law 3851/2010, with which Greece integrates Directive 2009/28/EC into the national legislation, sets the following national targets for RES penetration (Article 1, paragraph 3):

- 20% share of energy generated by RES in the gross final energy consumption. This is a more ambitious target compared to the provisions of Directive 2009/28/EC (18% RES share).
- At least 40% share of electricity generated by RES in the gross energy consumption.
- At least 20% share of energy generated by RES in the final energy consumption used for heating and cooling.
- At least 10% share of energy generated by RES in the final energy consumption in the transportation sector (adopting the relevant target of Directive 2009/28/EC).

Table 2-2 shows the achievement rates of the aforementioned national targets.

Table 2-2: Progress towards meeting of national targets for 2020 (2005 – 2015) regarding RES penetration and the limitation of greenhouse gas emissions.[10]

Year	RES share				Primary energy consumption	GHG emissions outside the ETS
	Gross final consumption	Transportation	Heating & Cooling	Electricity generation		
	(%)	(%)	(%)	(%)	(Mtoe)	(Mt CO_2 eq)
2005	7.04	0.05	12.80	8.21	30.6	61.78
2006	7.20	0.73	12.46	8.92	30.7	59.32
2007	8.15	1.26	14.42	9.33	30.7	59.37
2008	8.01	1.05	14.26	9.65	30.9	58.63
2009	8.48	1.10	16.52	11.02	29.6	58.36
2010	9.81	1.91	17.91	12.31	27.6	56.06
2011	10.88	0.59	19.44	13.81	26.9	54.16
2012	13.45	0.89	23.41	16.36	26.8	48.25
2013	14.99	0.96	26.47	21.24	23.6	44.18
2014	15.32	1.30	26.85	21.92	23.7	44.41
2015	15.44	1.43	25.90	22.09	23.7	44.52

[10] Source: EUROSTAT

Target (2020)	**18.00 (20% from 3851/2010)**	**10.00**	**20.00**	**40.00**	**24.7**	**61.24**

The following conclusions are drawn from Table 2-2

(a) It appears that, as of 2015, the targets for the limitation of the greenhouse gas emissions outside the ETS and for the RES contribution in meeting the heating and cooling needs have been achieved. However, it is noted that the evolution presented in the table above should mainly be attributed to the decrease in economic activity and consumption for heating places rather than to policy measures.

(b) The achievement of the targets concerning the RES share in transportation and electricity generation is no longer feasible as a result of the economic crisis and specific political choices that have restrained the RES potential in the electricity generation sector, at the same time supporting fossil fuel.

(c) The achievement of the energy saving target (see column Primary energy consumption in Table 2-2) may be proved marginal, since the available increase margin until 2020 amounts to 4%.

(d) The national target for a 20% RES share in the gross final consumption should be considered not feasible, while it is not at all obvious that the respective 18% target included in Directive 2009/28/EC will be achieved, despite the fact that the progress of implementation so far is deemed satisfactory since the intermediate targets have been achieved, as well as the intermediate target for 2017/2018 (2011/2012: 9.1%, 2013/2014: 10.2%, 2015/2016: 11.9%, 2017/2018: 14.1%). It is noted that, despite the investments made in RES units in recent years (see **Figure 2-6** for the net power of the Greek electricity generation system in 2015), there is a direct need for additional investments even in case the energy demand remains at the low levels of the last few years.

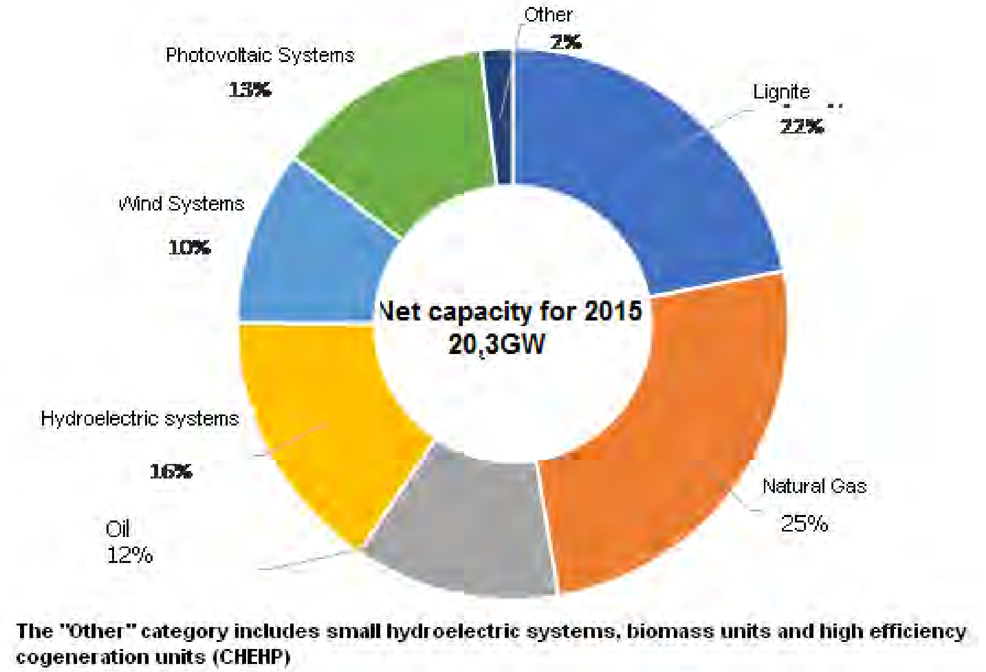


Figure 2-6: Net power of the Greek electricity generation system in 2015. Sources: (1) LAGIE (Operator of Electricity Market): Monthly newsletter for DAS (Day ahead Scheduling) (December 2015), (2) HEDNO (Hellenic Electricity Distribution Network Operator): Information Newsletter for generation in non-interconnected islands for December 2015

2.3.4. Data from the Roadmap 2050

At this stage, no long-term energy planning for Greece has been officially adopted. The last attempt to elaborate a long-term plan dates back to 2012, when there was a public consultation on the Roadmap 2050 by the then Ministry of Environment, Energy and Climate Change (YPEKA)[11]. Although this plan was never officially adopted by the Greek state, it still includes a set of scenarios for the evolution of the Greek energy system during the period until 2050, which are briefly listed in this section.

Roadmap 2050 integrates the National Action Plans for Renewable Energy Sources and Energy Efficiency, which for the period until 2020 aimed at a 20% RES penetration in the gross final energy consumption and a 4% decrease in the non-ETS greenhouse gas emissions compared to 2005. Besides the future evolution of the energy system, Roadmap 2050 also presents the evolution of the greenhouse gas emissions until 2050.

3 main groups of scenarios for the evolution of the energy system have been developed:

- The *"Existing Policies"* Scenario (EP Scenario) assumes a conservative policy implementation for energy and the environment. It foresees a medium limitation of greenhouse gas emissions until 2050 by at least 40% compared to 2005. It also foresees a medium level of RES technology penetration and energy savings as a result of its conservative implementation policies.
- The "*RES Maximization Measures*" Scenario (RESMM Scenario) assumes RES maximum penetration at a 100% level in electricity generation and at a much larger scale overall, aiming at reducing the greenhouse gas emissions by 60%-70%, with high energy savings in buildings and transportation. The same scenario is examined in combination with electricity imports that will result in a cost decrease in the electricity sector due to the lower investments and purchase of electricity at lower prices (RESMM-a Scenario).
- The "*Minimum Cost Environmental Measures*" Scenario (MCEM Scenario), where the energy technologies' mix is selected based on the minimum cost policy for a 60-70% decrease in the greenhouse gas emissions, combined with high energy savings in buildings and transportation. The RES penetration level is quite high but does not exceed 85% in electricity generation due to a limitation in the required storage units. Based on the assumptions formed for the MCEM Scenario , an alternative scenario is also examined (MCEM-a Scenario), which assumes that, during the period 2035-2040, the carbon capture and storage technology (CCS) is integrated in two of the existing (and newest) steam-electric power stations using lignite (1.1GW power). This alternative scenario actually examines the possibility of extending the presence of domestic solid fuels in the electricity generation system.

Figure 2-7 presents the estimated evolution of CO_2 emissions from the Greek energy system based on the groups of scenarios listed above. Moreover, **Figure 2-8** presents the evolution of the RES share in the gross final energy consumption. The quantitative analysis of the energy system was based on the MARKAL-TIMES energy model.

[11] Ministry of Energy, Environment and Climate Change (2012), National Energy Plan, Roadmap 2050. Available here: http://www.ypeka.gr/LinkClick.aspx?fileticket=Xm5Lg9NOeKg%3D&tabid=367&

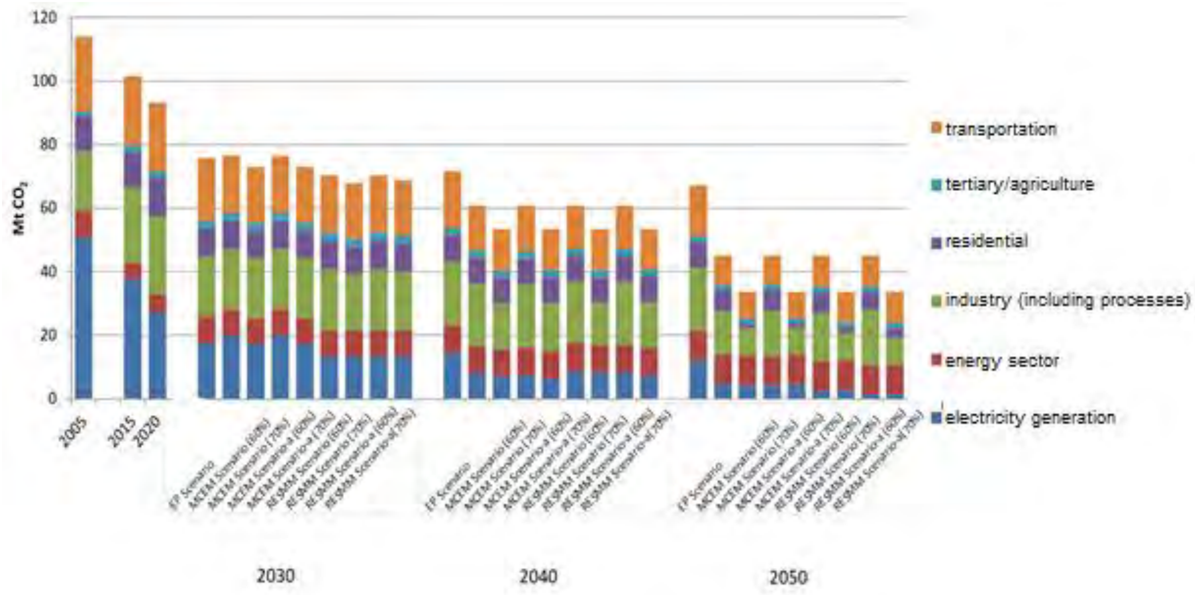


Figure 2-7: Evolution of CO_2 emissions in the Greek energy sector per policy scenario until 2050.[12]

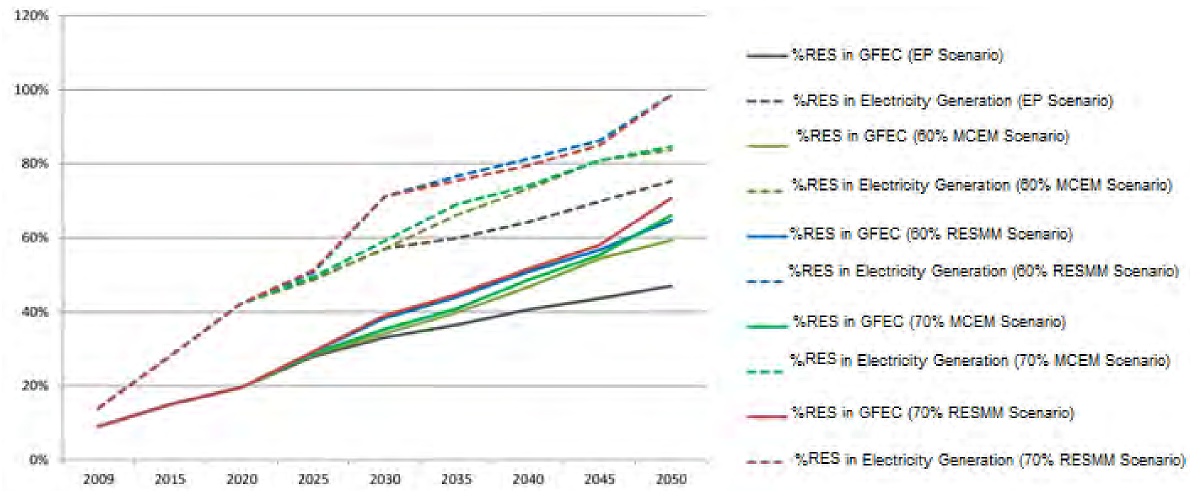
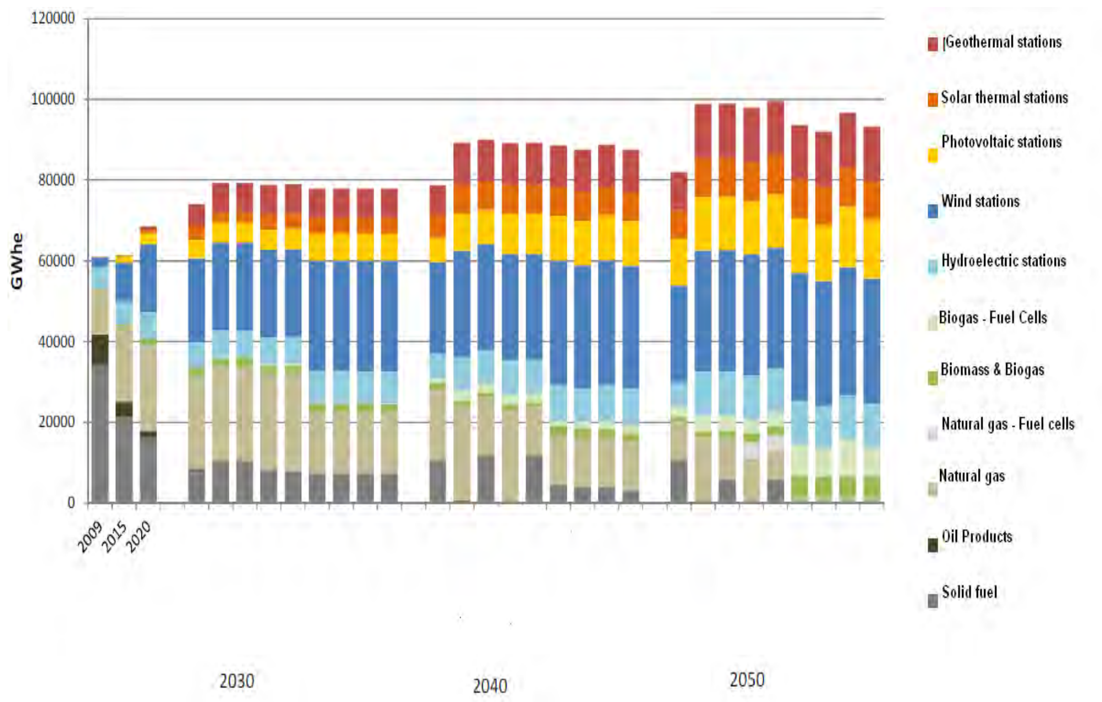


Figure 2-8: Evolution of RES share in the gross final energy consumption and in electricity generation per policy scenario included in the Roadmap 2050 study.[13]

All scenarios prescribe a radical restructuring of the electricity generation sector. **Figure 2-9** presents the share of the various electricity generation technologies both in electricity generation as well as in the installed power capacity. The cumulative cost of the required energy investments to be differs depending on the scenario examined. The necessary investments for the MCEM Scenarios are estimated at approximately 62 bil. €, while the estimated investments for the RESMM Scenarios amount to approximately 72-77 bil. €. However, even the EP Scenario will require the implementation of energy investments in the order of 50 bil. €.

[12] Source: YPEKA (2012): Long-term Energy Planning, Roadmap 2050.
[13] Source: YPEKA, same as above



120000
100000
80000
60000
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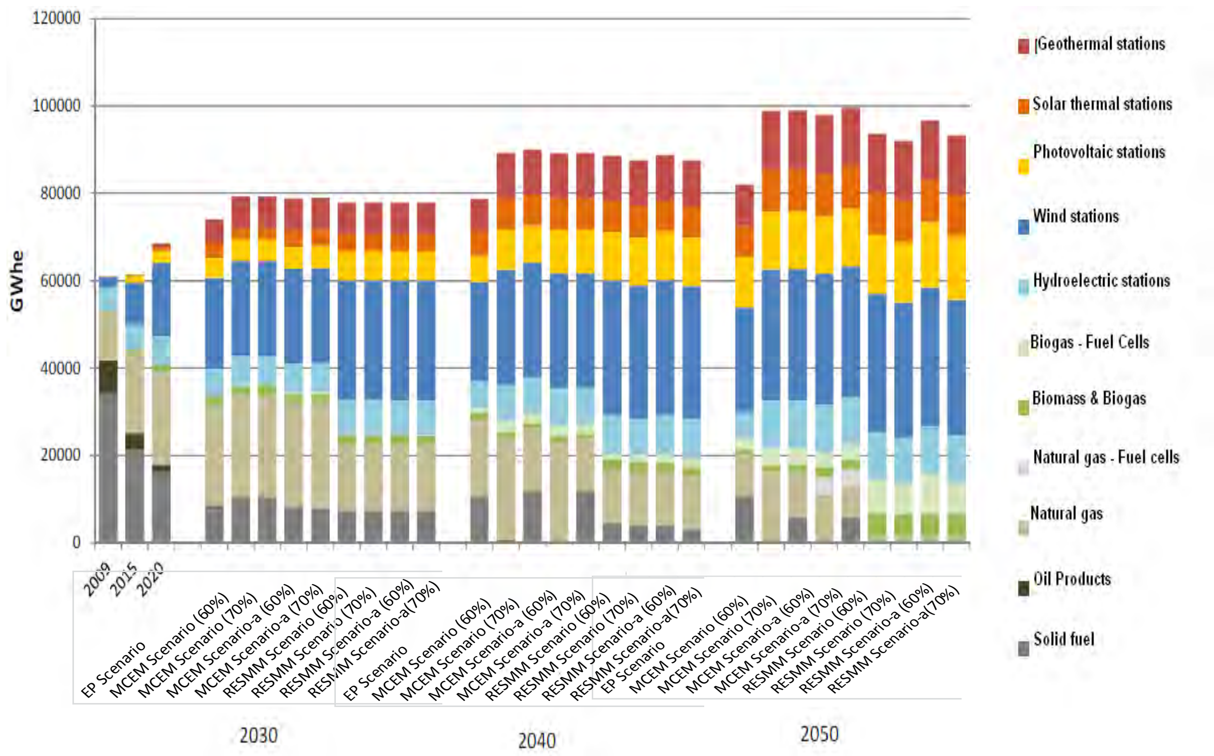
0
GWhe
2009
2015
2020
2030
2040
2050
|Geothermal stations
Solar thermal stations
Photovoltaic stations
Wind stations
Hydroelectric stations
Biogas - Fuel Cells
Biomass & Biogas
Natural gas - Fuel cells
Natural gas
Oil Products
Solid fuel



120000
100000
80000
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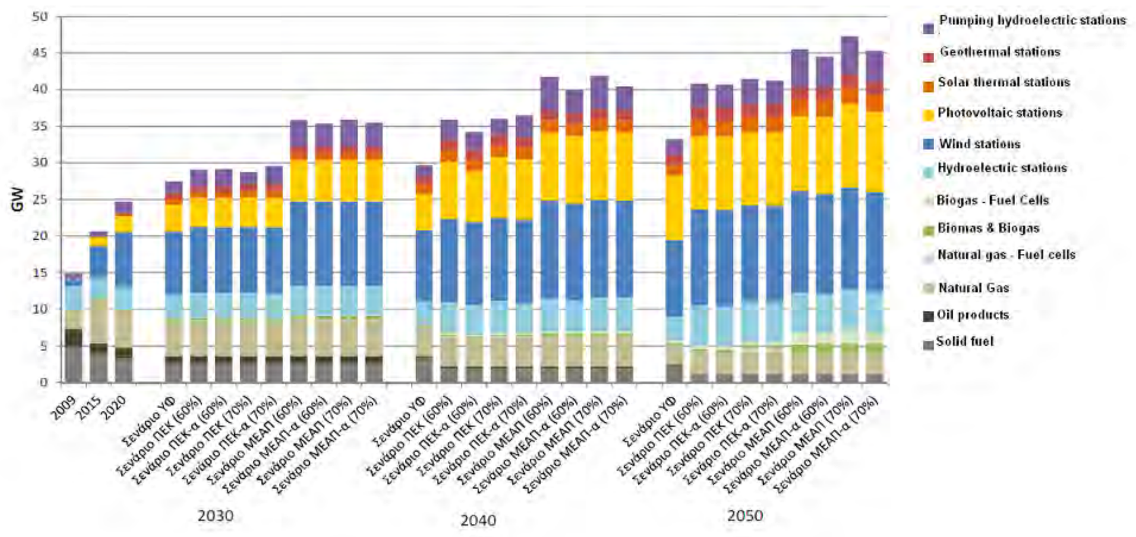
GWhe
2009
2015
2020
EP Scenario
MCEM Scenario (60%)
MCEM Scenario (70%)
MCEM Scenario-a (60%)
MCEM Scenario-a (70%)
RESMM Scenario (60%)
RESMM Scenario (70%)
RESMM Scenario-a (60%)
RESMM Scenario-a(70%)
2030
2040
2050
|Geothermal stations
Solar thermal stations
Photovoltaic stations
Wind stations
Hydroelectric stations
Biogas - Fuel Cells
Biomass & Biogas
Natural gas - Fuel cells
Natural gas
Oil Products
Solid fuel

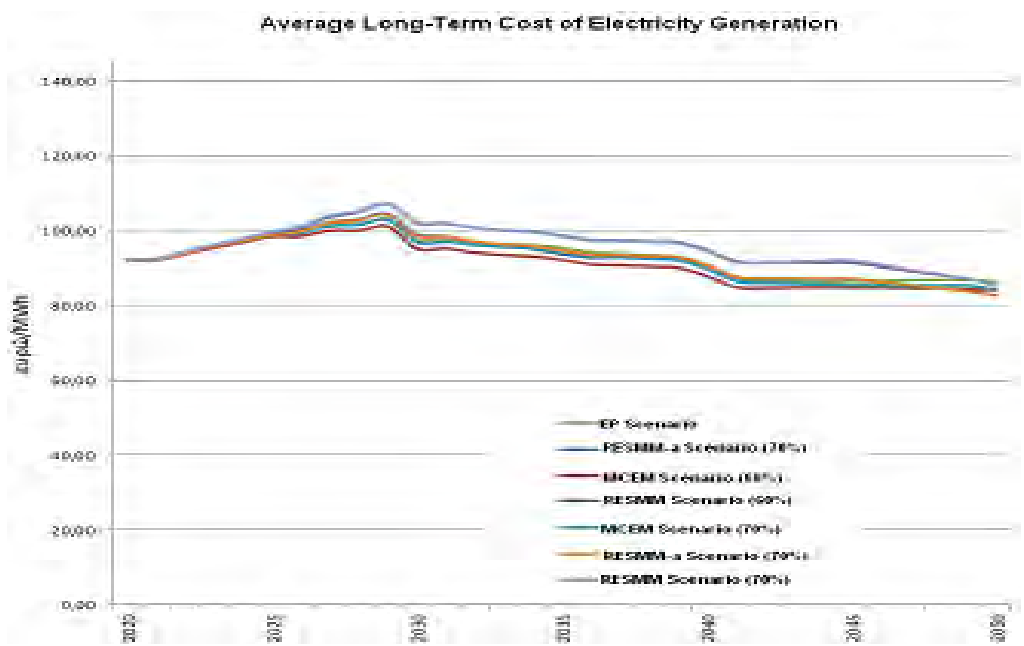
(a)



(b)

Figure 2-9: Shares of electricity generation technologies in (a) the electricity generated and (b) in the installed power capacity.[14]

An interesting aspect is the continuous increase of electricity shares in the final consumption for all the scenarios examined. This penetration is more intense in the scenarios involving decreasing emissions, exceeding 7000 ktoe for the period until 2050, compared to the EP Scenario where it falls below 6000 ktoe for the same period. Finally, **Figure 2-10** presents the evolution of the long-term electricity generation cost, which does not show significant differences between the scenarios examined.



[14] Source: YPEKA, same as above

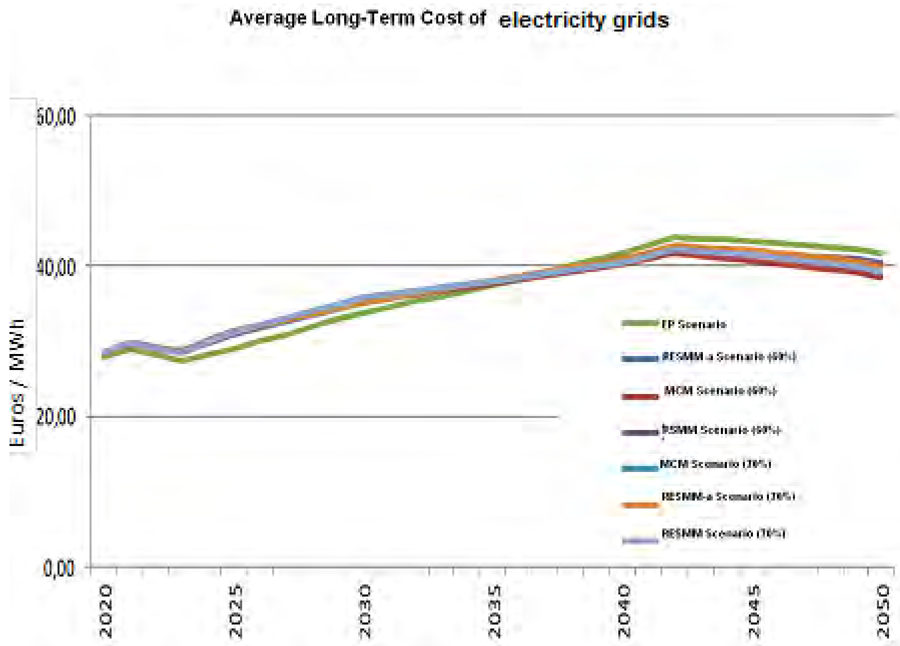


Figure 2-10: Evolution of long-term electricity generation cost.[15]

2.4. Evaluation of long-term energy planning scenarios by other institutions

This section contains a brief presentation and commentary on the long-term energy planning scenarios elaborated quite recently for the Greek energy system by various instituions and bodies.

2.4.1. Planing the energy future: study by the Hellenic Association of Photovoltaic Companies for the period 2015-2030

In 2014, the Hellenic Association of Photovoltaic Companies (HELAPCO) proceeded to the elaboration of a study[16] in order to examine the impact from various RES penetration scenarios until 2030. The study was elaborated by the School of Electrical and Computer Engineering, Power Systems Laboratory (SECE PSL) of the Aristotle University of Thessaloniki.

The study makes a simulation of the Greek Wholesale Electricity Market (GWEM) for the time period 2015-2030, taking into account the changes expected in the market after 2017 with the operation of the Energy Stock Market (ESM). Specifically, it investigates the following:

- the evolution of the System Marginal Price (SMP) and the Weighted Average Variable Cost of Conventional Thermal Units (WAVCCTU) on an hourly basis,
- the forecast for the annual electricity generation per unit technology,
- the evolution of CO_2 emissions, and

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[15] Source, YPEKA, same as above

[16] Kapellos S. (2014), Planning the energy future: study by the Hellenic Association of Photovoltaic Companies for the period 2015-2030. Published on the "Hellenic Economy" Review – special "Energy" issue by the Economic Studies and Planning Centre.

- the compensation for RES technologies based on the applicable feed-in-tariff and the necessary level of the Special Duty of Greenhouse Gas Emissions ReductionETMEAR, for the aforementioned time period.

The study examined a conservative RES penetration scenario for the time period until 2030, in relation to two main scenarios for the evolution of electricity demand (low and medium/realistic).

One of the most interesting results of the study is that the energy system can support a significant RES penetration with only marginal aid and interventions. The medium demand scenario requires the addition of a new combined cycle unit in 2025, while extra needs can be covered by increasing the use of the existing pumped storage units. The low demand scenario requires a further increase in the storage potential. In general, storage needs drop as demands increases, and they mainly appear after 2027.

Moreover, according to the study findings, the economic crisis in combination with the policies adopted to date, lead to the non-achievement of the targets set for the RES share in the gross electricity consumption (at least 40% in 2020). Instead, in the main versions of the scenario examined, a RES share of about 35% is achieved in 2020 and 45% in 2030. The installed power capacity of RES in 2030 was estimated at 6.5 GW for photovoltaic systems, 6 GW for wind farms, 0.45 GW for small hydroelectric plants and 0.50 GW for biomass units. The implementation of the growth scenario will require investments in the order of 15 bil € until 2030.

In addition, the study highlights the contribution of photovoltaic systems to maintaining a low SMP. But in order to achieve this, it will be necessary for new investments on photovoltaic systems to be sustainable, a fact that is not guaranteed by the applicable legislation for estimating the compensation for photovoltaic generation. As a result, it is proposed that the compensation for big photovoltaic systems follows a linear annual decrease from 90 €/MWh for the year 2015 to 70 €/MWh for the year 2030, while small and medium systems will be exclusively supported by net-metering. These scenarios impose a cost on the ETMEAR less than 1 €/MWh, in relation to the applicable legislation, and lead to a smaller total charge for the consumers – the sum of the SMP and the ETMEAR remains at 75 €/MWh in 2030, while without the new photovoltaic systems it shoots up to 81 €/MWh.

2.4.2. EU Energy Reference Scenario 2016

In 2016, the European Commission published a reference scenario[17] for the evolution of the EU energy system, which integrates the existing and planned policies in the various energy sectors. The analysis was carried out using various energy models, including PRIMES, PROMETHEUS, GEM-E3, etc., while it presents in detail the results of the energy system evolution both for the whole EU and per Member State. **Tables 2-3** and **2-4** summarize the main results for Greece.

Some main conclusions of the analysis are as follows:

- The penetration of wind and photovoltaic energy in the electricity system amount to 6 and 5.6 GW respectively in 2030, and to 7.9 and 8.9 GW in 2050.
- The installed power capacity of natural gas falls as of 2020 onwards, and ranges between 3.8 and 4.9 GW during the whole period 2030-2050.
- The installed power capacity of lignite units is limited to 2.8 GW in 2030 and to 0.8 GW in 2050.
- The RES share in electricity generation amounts to 57.5% in 2030 and to 78.4% in 2050.
- The average cost of electricity generation amounts to 100 €/MWh in 2030 and to 64 €/MWh in 2050.

[17] EU Reference Scenario 2016: Energy, transport and GHG emissions Trends to 2050

- The scenario integrates important energy saving measures in final consumption. Thus, the final energy consumption remains stable at 15.6 Mtoe during the period 2030-2050, compared to 17.5 Mtoe in 2015 and 19.2 Mtoe in 2020.
- The energy intensity shows a 48% improvement during the period 2010-2050, accompanied, respectively, by a 57% decrease in CO_2 emissions.

Table 2-3: Evolution of the Greek energy system during the period 2015-2050.[18]

	2015	2020	2025	2030	2035	2040	2045	2050
Gross Electricity Generation per energy source (1) (GWh$_e$)	***54082***	***58052***	***57523***	***54970***	***58077***	***57279***	***57025***	***58595***
Nuclear energy	0	0	0	0	0	0	0	0
Solid fuel	26751	22885	19611	11963	12644	9364	1821	0
Oil products (including refinery gas)	4847	5122	2384	131	123	126	57	59
Natural gas	8817	13840	11444	11286	11389	11642	12620	12576
Biomass-waste	195	382	660	812	1091	1061	1781	1784
Hydroelectric systems (except for pumping)	5880	5901	5552	5578	5631	5618	5609	5607
Wind systems	3834	5207	10434	15949	16021	17857	21281	22200
Solar systems	3757	4715	7438	9252	11177	11611	13856	16368
Geothermal energy and other RES	0	0	0	0	0	0	0	0
Other fuel (hydrogen, methanol)	0	0	0	0	0	0	0	0
Net Installed Power Capacity for Electricity Generation (MW$_e$)	***19208***	***19703***	***22088***	***23780***	***24196***	***24086***	***25436***	***26514***
Nuclear energy	0	0	0	0	0	0	0	0
RES	8146	9363	12651	15233	16105	16768	18962	20371
Hydroelectric systems (except for pumping)	3389	3579	3579	3579	3579	3579	3579	3579
Wind systems	2152	2637	4306	6038	6038	6567	7600	7884
Solar systems	2605	3147	4766	5616	6488	6622	7783	8908
Other RES	0	0	0	0	0	0	0	0
Thermal stations	11062	10340	9437	8548	8092	7318	6474	6143
out of which cogeneration	284	309	316	341	390	446	576	535
out of which CCS units	0	0	0	0	0	0	0	0
Solid fuel	3923	3030	3100	2845	2834	2834	1405	833
Natural gas	5062	5306	5272	4738	4418	3827	4416	4897
Oil products	2022	1824	834	733	595	409	378	153
Biomass-waste	55	180	230	232	245	249	275	260
Hydrogen	0	0	0	0	0	0	0	0
Geothermal energy	0	0	0	0	0	0	0	0
Indexes								
Average Load Index for net installed power capacity (%)	29.6	31.4	28.2	25.5	26.5	26.4	25.3	25.1
Gross efficiency rate for fossil fuel units (%)	38.6	41.4	42.7	43.2	43.0	43.7	54.8	58.5
% of gross production by CHP units	3.0	3.4	2.9	3.1	3.9	4.3	4.5	6.6
% of production by CCS units	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% of gross production by units without CO_2 emissions (RES, nuclear energy)	25.3	27.9	41.9	57.5	58.4	63.1	74.6	78.4
Average cost of gross electricity generation (€'13/MWh)	85	97	99	100	92	87	72	64

[18] Source: EU28: Reference Scenario (REF2016), Summary Report PRIMES ver. 4 Energy Model.

Table 2-4: Evolution of the Greek energy system during the period 2015-2050.[19]

	2015	2020	2025	2030	2035	2040	2045	2050
Final Energy Consumption (ktoe)	***17486***	***17105***	***16398***	***15635***	***15677***	***15739***	***15720***	***15657***
per sector								
Industry	3224	3313	3193	2900	2917	2964	2975	2875
Energy intensive industries	2157	2198	2094	1821	1873	1877	1879	1776
Other industrial sectors	1067	1115	1099	1079	1045	1087	1096	1100
Residential sector	4351	4275	4084	3941	3852	3761	3661	3625
Tertiary sector	2426	2247	2133	2051	2113	2191	2238	2298
Transportation	7484	7271	6989	6743	6795	6823	6845	6859
per fuel								
Solid fuel	208	195	175	126	99	77	56	39
Oil products	10307	9478	8892	8267	7961	7680	7487	7343
Natural gas	1018	1029	996	939	1033	1142	1190	1173
Electricity	4397	4583	4472	4342	4547	4670	4744	4849
Heat (from CHP and teleheating)	44	51	60	71	90	100	97	99
RES	1510	1762	1793	1873	1929	2043	2107	2099
Other	2	7	11	15	19	27	39	55
Indexes								
Gross Domestic Consumption/GNP (toe/M€13)	130	121	108	93	86	77	68	64
Greenhouse gas emissions (Mt of CO2 eq.)	105.7	96.6	85.1	71.7	70.9	66.7	55.9	52.6
out of which in sectors in the trading system (2013)	57.3	52.9	44.6	34.4	34.6	30.9	21.0	18.3
out of which in sectors outside the trading system (2013)	48.4	43.7	40.5	37.3	36.3	35.8	34.9	34.3
Total greenhouse gas emissions (outside LULUCF [Land Use, Land-Use Change and Forestry]) Index (1990=100)	**98.4**	**89.9**	**79.2**	**66.7**	**66.0**	**62.1**	**52.0**	**49.0**
RES in the Gross Final Energy Consumption (%)	**14.4**	**18.4**	**23.6**	**29.6**	**31.4**	**33.5**	**37.8**	**40.0**
RES - heating & cooling	24.8	29.9	32.6	36.8	39.7	42.9	45.0	46.5
RES - electricity	22.4	25.8	39.9	55.0	56.6	59.2	69.9	74.0
RES - transportation (based on ILUC [Indirect Land Use Change])	1.4	10.2	11.4	14.2	15.9	17.7	21.0	23.2

2.4.3. Energy scenarios by CRES (Centre for Renewable Energy Sources and Saving)

The CRES Division for Energy Policy and Planning systematically analyzes long-term energy planning scenarios for Greece, which are used in various reports submitted by the Ministry of Environment and Energy to the EU and other international organizations. Energy scenarios are analyzed using the MARKAL-TIMES optimization energy model, as well as other specialized energy models in order to check critical parameters of the energy system. The most recent results were presented to the Greek Parliament in November 2016, and some main conclusions are summarized below.

Three main scenarios for the future evolution of the energy system are analyzed below:

- Natural Gas Low Price Scenario (NGLPS).
- Natural Gas High Price Scenario (NGHPS).
- 40% RES penetration scenario in electricity generation already in 2020 (S40).

The target for all scenarios is for RES penetration to reach 30% of gross final energy consumption and 50% of electricity generation in 2030.

[19] Same as above

Table 2-5 presents the evolution of the installed power capacity in the electricity system per technology. In 2030, the installed power capacity amounts to 8.7 GW for wind systems and to 4.4 MW for photovoltaic systems. The installed power capacity of lignite units is limited by approximately 1.9 GW during the 15-year period 2015-2030, while the installation of natural gas units amounting to 0.5 GW and of hydroelectric pumping units amounting to 0.8 GW is required during the same period. The respective shares of electricity generation technologies are presented in **Table 2-6**.

It is noted that all the scenarios examined foresee an increase of oilo-fired power plants to 2.1 GW, while oil continues to be the main fuel in the non-interconnected network until 2030 with a 2.5 TWh contribution. The drop from the current 4.3 TWh levels is attributed to the implementation of the interconnection of Crete and part of the Cyclades to the mainland grid.

RES generation will amount to 31 TWh in 2030, 2/3 of which are covered by wind systems. The average long-term electricity cost in the interconnected system will range between 114 and 134 €/MWh in 2020, with the low cost referring to the NGLPS scenario and the high cost referring to the S40 scenario.

Table 2-5: Evolution of the installed power capacity for the Greek energy system (GW).[20]

	2015	2020			2030	
		NGLPS	NGHPS	S40	NGLPS	NGHPS
Lignite stations	3.9	4.5	4.5	4.5	2	2
Oil fired stations	1.9	2.1	2.1	2.1	2.1	2.1
Natural Gas	4.8	5.2	5.2	5.2	5.3	5.3
Fuel Cells Natural Gas	0	0	0	0	0.1	0.1
Biomass & Biogas	0.05	0.1	0.1	0.1	0.3	0.3
Hydroelectric systems	2.7	2.9	2.9	3	3.1	3.1
Pumping hydroelectric systems	0.7	0.7	0.7	0.7	1.5	1.5
Wind systems	2.1	3.62	3.65	5.1	8.7	8.7
Photovoltaic systems	2.6	3.82	3.82	4.04	4.4	4.3
CSP	0	0	0	0	0	0
Geothermal energy	0	0.04	0.04	0	0.2	0.2
Fuel Cells H2	0	0	0	0	0	0
Total	***18.7***	***23***	***23***	***24.8***	***27.3***	***27.3***

Table 2-6: Evolution of the electricity generation in the Greek electricity system (TWh).

	2015	2020			2030	
		NGLPS	NGHPS	S40	NGLPS	NGHPS
Lignite stations	19.4	14.1	18.3	14.0	8.6	7.9
Oil fired stations	4.6	4.3	4.3	4.3	2.5	2.5
Natural Gas	8.5	13.4	9.1	9.2	12.9	13.4
Fuel Cells Natural	0.0	0.0	0.0	0.0	0.4	0.5

[20] Source: CRES, presentation to the Greek Parliament 22/11/2016.

Gas						
Biomass & Biogas	0.0	0.3	0.3	0.5	1.1	1.1
Hydroelectric systems	4.7	5.6	5.7	5.9	6.1	6.1
Wind systems	4.8	8.4	8.5	11.6	20.2	20.3
Photovoltaic systems	3.8	5.6	5.6	6.0	6.5	6.5
CSP	0.0	0.0	0.0	0.0	0	0
Geothermal energy	0.0	0.3	0.3	0.3	1.4	1.4
Total	***45.9***	***52.0***	***52.1***	***51.8***	***59.3***	***59.3***

Table 2.7 presents the evolution of the total energy demand per sector and fuel, while **Table 2-8** presents the evolution of characteristic indexes in the energy system.

Table 2-7: Evolution of the final energy consumption in the Greek energy system (ktoe).

		NGLPS		**NGHPS**	
	2014	2020	2030	2020	2030
Total	15850	17152	18230	17150	18220
Per sector					
Industry	3134	3552	4286	3554	4278
Residential sector	3813	3948	4046	3945	4044
Tertiary/Agricultural sector	2558	2964	3598	2964	3597
Transportation	6344	6688	6300	6688	6300
Per fuel					
Solid fuel	244	246	248	246	246
Oil systems	8917	9215	8526	9230	8528
Natural Gas	886	1272	1745	1274	1748
Electricity	4291	4597	5108	4595	5107
Heat	39	38	95	38	95
RES	1473	1784	2507	1767	2496

Table 2-8: Evolution of Greek energy system.indicators

	2014	2020			2030	
		NGLPS	NGHPS	S40	NGLPS	NGHPS
Emissions (Mt CO_2eq)	101	80	84	78	65	64
Emissions in ETS (Mt CO_2eq)	55	37	42	36	25	24
Emissions outside ETS (Mt CO2eq)	46	42	42	42	40	40
Decrease in ETS (% compared to 2005)	30	47	41	50	64	66
Decrease outside ETS (% compared to 2005)	33	34	34	34	38	38
RES % in GFEC (gross final energy consumption)	15	20	20	22	30	30
RES % in electricity generation	24	37	37	45	57	57
RES % in final thermal consumption	27	27	27	25	33	33
RES % in gross electricity consumption	22	33	33	40	52	52
Biomass % in transportation according to RED	1.3	4	4	7	7.80	7.80

2.4.4. Power system adequacy report for the period 2017 – 2027 by IPTO (Independent Power Transmission Operator)

Pursuant to Law 4001/2011, the Hellenic Transmission System Operator (HTSO) elaborated a special study on the electrical power adequacy and the sufficient margins of power reserves, each time taking into account the approved 10-year Development Program of the Electricity Transmission System, as well as the Greek long-term energy planning. The most recent power adequacy study was published in May 2017 and covers the period 2017 – 2027.

The sufficiency of the electricity generation system is expressed through the LOLE (Loss of Load Expectation) and EUE (Expected Unserved Energy) indexes, which are calculated using a probabilistic simulation with the PROSIM model developed by the NTUA's (National Technical University of Athens) Power Systems Laboratory.

- The LOLE index expresses the hours of the year during which an electricity generation system cannot fully meet demand. As part of this particular study, values less than 3 hours per year are considered satisfactory index values. The operation of the electricity generation system is simulated, taking into account the successive integration of thermal power in steps of 50 MW in order to achieve the reliability criterion for each year.
- The EUE index expresses the energy needs, on an annual basis, which an electricity generation system is not expected to cover.

The parameters determining the electricity generation system's adequacy in order to meet demand (energy and peak) in a reliable way, which are examined as part of the study, are as follows: (a) evolution of demand for power and energy, (b) availability of production stations , (c) hydraulicity conditions, (d) power availability for imports from interconnections and (e) RES penetration rate.

As part of the power adequacy study, 3 scenarios have been examined (reference scenario, low demand scenario and high demand scenario) regarding the evolution of energy demand and peak load, according to the most recent projections by IPTO (**Table 2-9**). It is noted that the projections concern the Electricity Transmission System, also taking into account the interconnections of island systems which are expected to be completed during the reference period, and not the entire country. This also includes the estimated demand of the Cyclades complex (expected to be interconnected by 2017), part of Crete's demand as of 2020 (to be serviced by the Crete – Peloponnese line) and the total demand for Crete as of 2025 through the Crete – Attica line. As far as the foreseen energy demand levels are concerned, all IPTO scenarios present significantly higher increase rates of energy demand compared to the EU energy reference scenario 2016 (see par. 2.4.2) and the CRES scenarios (see par. 2.4.3); as of 2020, demand has been restored to the 2008 levels.

Table 2-9: Evolution of energy demand (in GWh) and peak load (in MW) for the period 2017 – 2027 according to the IPTO forecasts.[21]

	Low demand scenario		Reference Scenario		High demand scenario	
	Energy (GWh)	Peak load (MW)	Energy (GWh)	Peak load (MW)	Energy (GWh)	Peak load (MW)
2017	52440	9840	52600	9868	52770	9900
2018	53360	10010	53720	10079	54070	10140
2019	54130	10150	54700	10260	55280	10370
2020	56310	10450	57110	10590	57920	10740
2021	56670	10510	57690	10700	58730	10890
2022	56800	10540	58050	10770	59320	11010
2023	56940	10565	58420	10840	59920	11120
2024	57080	10590	58780	10900	60530	11240
2025	59080	11150	61010	11510	63100	11900
2026	59270	11180	61440	11590	63790	12040
2027	59460	11230	61840	11670	64430	12170

The availability of thermal power stations is simulated through the *Equivalent Demand Forced Outage Rate* ($EFOR_D$) index. The values used per existing production unit originate from the data published by IPTO, while typical values were used for the new units depending on the unit type.

In order to integrate the hydraulicity parameter, three scenarios were developed (dry, average and humid year), which were determined through the statistical processing of historical data; according to these, the annual production amounts to 2200 GWh, 4200 GWh and 5500 GWh, respectively.

For the purposes of the power sufficiency study, the contribution of the interconnections is examined through three equivalent thermal units of 500 MW, the availabilities of which are determined based on the historical data of cross-border interconnections for the past three years (97.3%, 88.9% and 55.8% respectively).

Figure 2-11 presents the net installed power capacity adopted in the power adequacy study for the reference scenario. The total system power drops from 17.5 GW (01.01.2017) to 17.1 GW in 2020 and then rises to 20.2 GW in 2025 and to 20,5 GW in 2027. During this period, lignite units of 1.9 GW will close down, while the thermal stations and hydroelectric systems to be integrated include the following:

- The PPC combined cycle unit in Megalopolis, with a capacity of 811 MW,
- The PPC lignite power station, with a capacity of 660 MW, in Ptolemais
- The PPC hydroelectric station "Ilarion EGS" [Electricity Generation Substation] in Aliakmon, with a capacity of 153 MW.

The study assumed that, due to the overall economic situation, conventional and hydroelectric stations with connection offers are not expected to be constructed, at least during the time period of the study, so they have not been taken into account.

The installed power capacity of RES and CHEHP (Cogeneration of High Efficiency Heat and Power) units in the system increases from 4.8 GW in 2016 to 6.5 GW in 2020 and to 9.5 GW in 2027, with more than 90% of the power originating from photovoltaic and wind systems.

[21] Source: IPTO, Power sufficiency study for the period 2017 – 2027, Athens, May 2017.

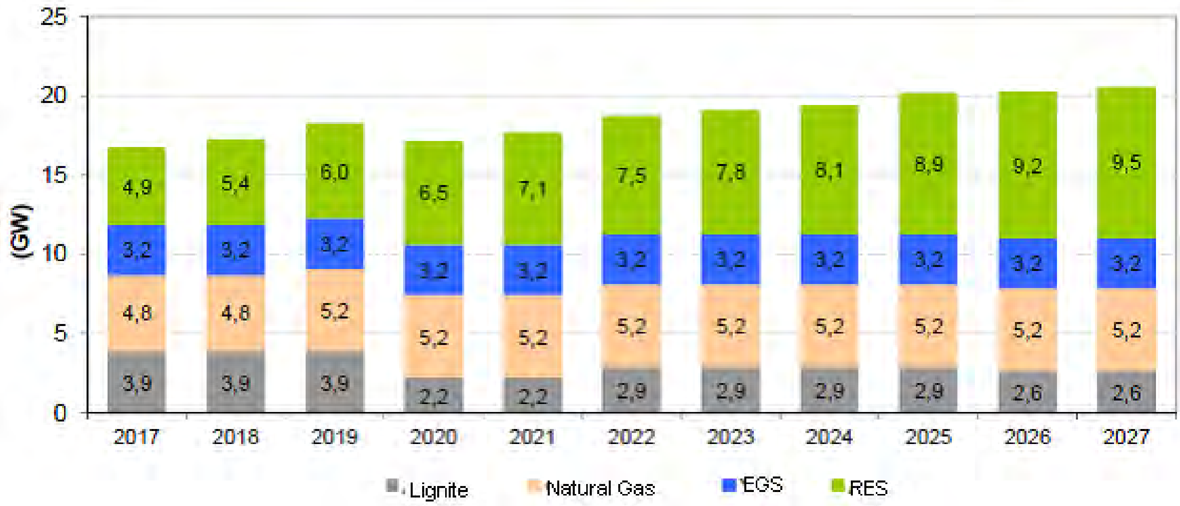


Figure 2-11: Evolution of the system's net installed power capacity in the reference scenario.[22]

The study results for the reference scenario and for an average hydraulicity year and all the aforementioned assumptions are summarized as follows:

- The international HTS interconnections largely affect the adequacy of the electricity generation system during the time period of the study. If imports remain at the same levels as in previous years, the apparent result in most cases is that the system will be able to sufficiently meet the demand requirements (**Figure 2-12**). On the contrary, under conditions of autonomous operation, the system reliability is considered insufficient in the majority of cases.

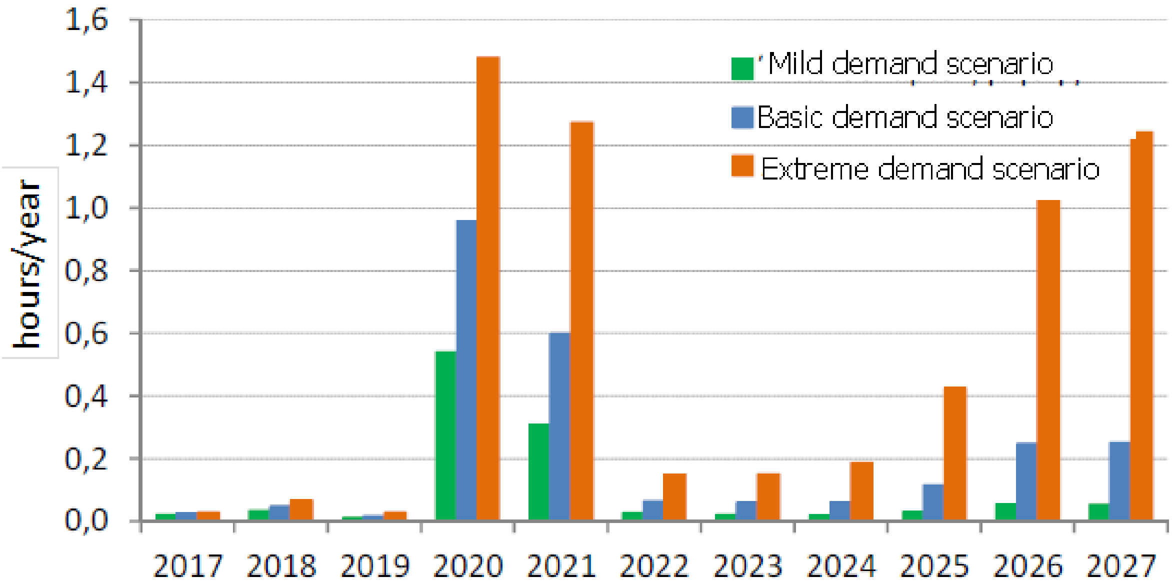


Figure 2-12: Evolution of the LOLE index for the Reference Scenario with interconnections, assuming an average hydraulic year.[23]

- Adopting a reduced availability scenario for lignite units results in higher LOLE index values, but without substantially differentiating the analysis conclusions.
- The simultaneous closing down of the SEPS (steam-electric power stations) in Kardia and Amyntaio results in an increase in the LOLE index values during the two-year period

[22] Same as above

[23] Source: IPTO, Power sufficiency study for the period 2017 – 2027, Athens, May 2017

2020-2021 compared to previous years. However, assuming a dry year, the index values exceed the annual 3-hour limit and the reliability of the electricity generation system can be characterized as insufficient according to the relevant definition in the IPTO study, despite the contribution of interconnections.

- The expected integration of the new Ptolemais V unit in early 2022 improves the LOLE index values and maintains them at a low level until 2025. Otherwise, the high values during the two-year period 2020 – 2021 will be maintained until its integration.
- Undertaking the total demand of Crete in early 2025 and closing down the Megalopolis III unit in late 2025 will result in a new increase in the LOLE index values, which however are still lower than the 3 hours per year. This does not apply to the case of a dry hydraulic year.

3. MODELIZATION IN ENPEP/BALANCE

3.1. General

The analysis of energy systems, as well as the forecast of future energy balances and the resulting gas emissions is a relatively complex procedure, affected by many parameters and policies. Thus, the inherent uncertainty involved in forecast problems is higher in this case, due to the assumptions for technological developments in the various sectors of economic activity, the cost of alternative technologies as well as the evolution of energy prices, the requirements for environmental protection, the general regulatory framework, the deregulation of energy markets, etc. It is therefore obvious that the integrated energy analysis which will take into account all the aforementioned parameters requires complex calculating tools and a very detailed representation of the energy system.

As part of this analysis, the attempted simulation of the future evolution for the Greek energy system was carried out using the ENPEP/Balance energy model. ENPEP/Balance, developed in the Argonne National Laboratory[24], is actually a "hybrid type" model, having being developed from an energy model of the "top-down" type in its initial design and allowing the full energy analysis/simulation of the energy/electricity system, at the same time quantifying its environmental and social consequences. A more detailed description of the model is contained in Annex A.

The main objective of the initial modelization for the Greek energy system in ENPEP was to clearly determine the main sources of greenhouse gas emissions, as well as to allow for the assessment of policies and measures that contribute to significant drops in the energy sources consumed and the resulting emissions. In subsequent applications, all the necessary transformations took place in order to analyze in greater detail the main issues of energy policy related to RES promotion and energy saving. The network representation is quite detailed and allows for predicting detailed energy balances and assessing a large range of energy saving policies and measures, RES promotion and reducing polluting gas emissions.

The necessary data for the network description, as well as for the forecast of future energy needs, are classified in the following categories:

- Macroeconomic data referring to demographic data, as well as economic activity and income data.
- Energy consumption data for the baseline year and data referring to the determining parameters of various activities (industrial production, residences, passenger-kilometers, etc.).
- Technico-economic data for the available technologies (e.g. investment cost, maintenance and operational cost, life cycle, etc.).

The Greek energy system is represented in ENPEP/Balance with sectors and fields covering the main economic and energy activities. Specifically, the network developed includes the sectors of energy supply, energy conversions (oil refineries, electricity generation), energy sources transportation/distribution and final energy consumption, which analyzed in greater detail below. In particular, it is possible to also simulate the electricity generation sector in the ENPEP/WASP model, so that future expansions of the electricity system can be determined more accurately. The ENPEP/Balance and ENPEP/WASP models are cross-fed with the data through a repetitive process until they converge to one feasible solution. Below there is a more detailed presentation of the sectors and fields in the Greek energy system as developed in ENPEP/Balance.

[24] Argonne National Laboratory (ANL), 2000. Description of BALANCE model. Technical Report.

3.2. Energy supply sector

The energy supply sector includes the fields of solid fuel, imported liquid fuel, domestic produced crude oil, natural gas and renewable sources of energy (RES). In particular, the solid fuel sector includes coal and lignite, which are used both in electricity generation and the fields of final energy demand. The two liquid fuel fields include crude oil (imported and domestic) and the remaining raw materials for supply and additives, which are refined in the four Greek refineries. Moreover, the network comprises the imported quantities of various oil products, including diesel, petrol, fuel oil, LPG, kerosene, naphtha, petcoke and other petroleum products. The natural gas field includes the quantities of gas imported in the Greek energy system both through pipes (from Russia or other sources) as well as in the form of liquefied natural gas (from Algeria, etc.). Finally, the RES sector comprises biomass (including biofuel), geothermal energy, various solar energy technologies (all the aforementioned energy forms are used either in electricity generation or in final demand), as well as the hydraulic and wind energy mainly utilized in electricity generation.

The sector has evolved in such a way as to:

- meet the energy demand by connecting the various sectors of the system's economic activity,
- determine the shares in the energy balance for domestic and imported energy sources,
- apply potential restrictions in the energy supply system, and
- determine the prices of primary energy forms.

3.3. Energy conversion sector

The energy conversion sector comprises the fields of refineries and electricity generation.

The ***refineries field*** was designed based on the total refinery capacity of the existing production units in the four Greek refineries. According to **Figure 3-1**, the refinery node is supplied with domestic crude oil (as a first priority, also due to the small production), imported crude oil and other raw materials for refineries (feedstocks). The links exiting the refinery node represent the production of various products (petrol, diesel, etc.), each of which ends at a decision node. Other links ending at decision nodes are those used for the direct import of the respective oil products, as well as links connected to storage nodes, in case the refinery production exceeds demand and the agreed quantities of products intended for export. The refinery field has been designed so as to meet the demand for a specific fuel, giving priority to the refinery production. Only if the refinery production cannot meet the total demand are additional quantities of the specific fuel imported through the respective link.

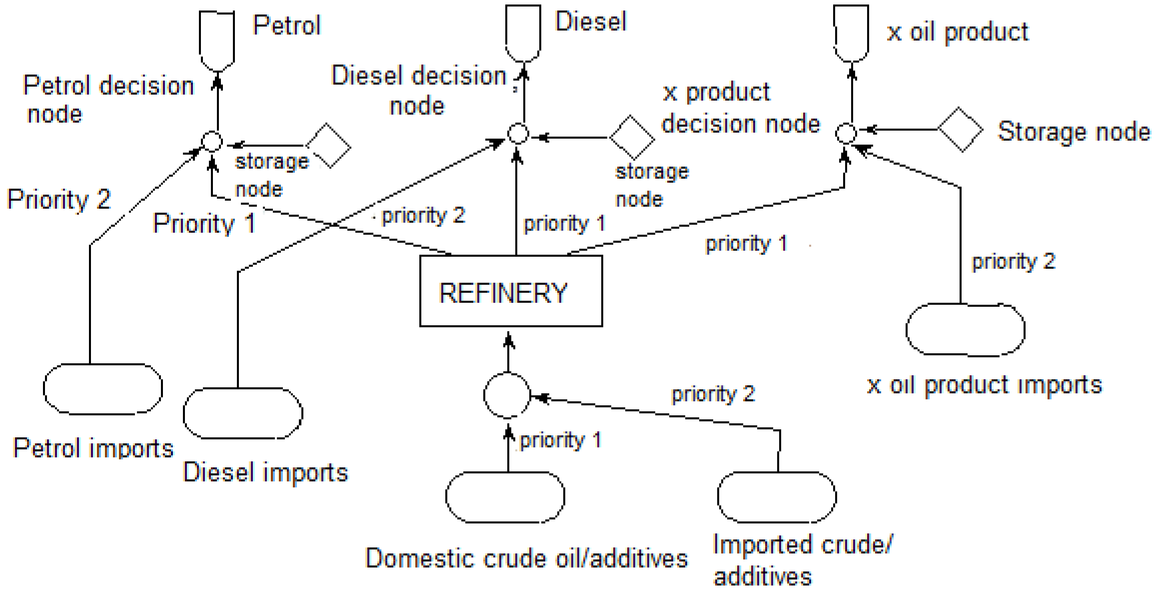


Figure 3-1: The refinery field of the Greek energy system as represented in ENPEP.

For the ***electricity generation field***, the network has evolved in such a way as to comply with all the particularities of the Greek system and the recent developments after the market deregulation. Besides, it should be noted that electricity generation is the biggest domestic source of greenhouse gas emissions. Thus, as seen in **Figure 3-2**, the modelization of the electricity generation field takes into account that Greece possesses a main interconnected system but also a significant number of autonomous stations and systems, as well as that this particular electricity grid is also connected with other grids in neighbouring countries.

The deregulation of the electricity market is represented with the integration of various categories of power producers, which are differentiated in terms of their economic aspects and the needs they meet:

- large electricity generation enterprises;
- small electricity generation enterprises and applications (mainly RES) which contribute to the distributed electricity generation;
- industrial self-producers;
- independent producers in the industrial sector, who meet their needs for heat and electricity through cogeneration;
- independent producers in the tertiary sector, who meet their needs for heat and electricity through cogeneration.

This tool comprises a large number of electricity generation technologies which fall under one of the following categories: (a) existing thermal stations, whose capacities and operational characteristics are known, (b) new thermal stations, which are eligible for integration in the system, (c) existing hydroelectric stations, which can operate either as baseline units or peak units, (d) new hydroelectric units, eligible for integration, (e) RES units, existing and eligible for integration. Depending on the forecast for the evolution of the electricity demand, the integration of new units in the system is determined by the basic Balance model, in combination with the WASP model (which includes ENPEP and simulates in greater detail the electricity system), while each of these units' load degree is calculated by ENPEP/Balance, again taking into account the economic, technical, environmental and regulatory restrictions.

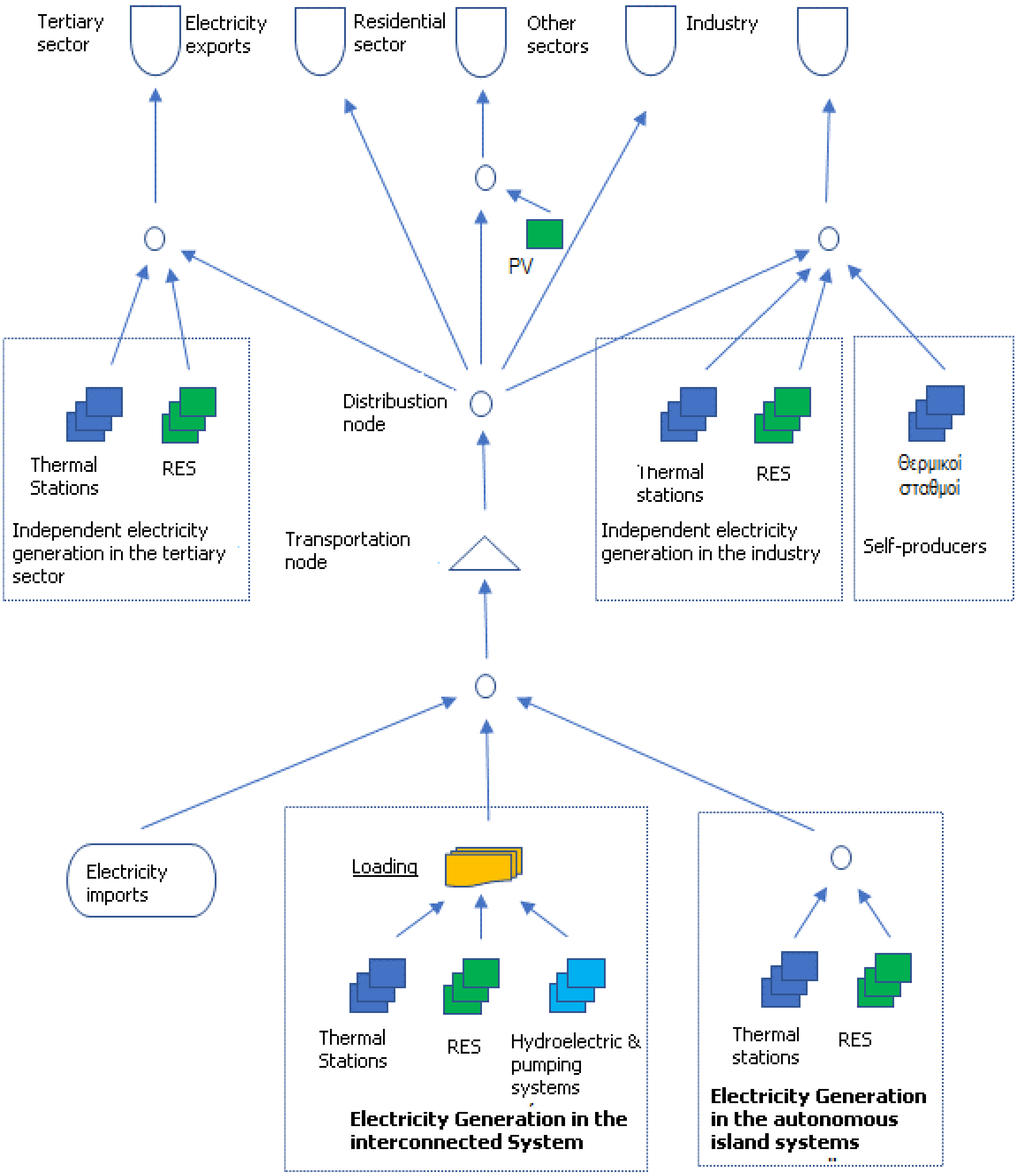


Figure 3-2: The electricity generation sector of the Greek energy system as represented in ENPEP.

3.4. Transportation/distribution sector

The transportation/distribution sector represents the transportation of primary and secondary energy sources through the distribution networks to the final consumers. In this sector, the following are achieved, among other things:

- the modelization of potential energy losses during transportation and distribution,
- the integration of the existing or planned taxation and economic policies, which affect the final energy prices, and
- the connection between energy supply and energy conversion sectors and the final consumption sector.

3.5. Final energy consumption sector

The final consumption sector includes the fields of industry, transportation, agriculture, residence and services. For each of these sectors, specific energy uses have been determined (e.g. heating for residences, steam generation, etc.), while a significant number of alternative technologies and/or fuels can be applied to each use in order to meet demand in each case. At the present stage of the grid development, it includes more than 70 different energy uses and 300 technologies overall, which can be used to meet the respective needs. The grid evelopment per field of final consumption has taken place in such a way as to include the most important energy uses, the most widespread technologies, the potential energy savings, the potential restrictions (technological, regulatory and others), etc. The future penetration of the various alternative technologies / fuels per use is estimated based on their cost saving aspect, the restrictions imposed by the existing infrastructure and the social criteria related to the degree of acceptance of these technologies, the degree of the consumers' adaptation to technological developments, etc.

The ***industry field*** has been simulated in such a way as to represent, simultaneously and distinctly, the following elements in the energy network:

- The most energy intensive industrial sub-fields, including the sub-fields which are subject to the EU ETS Directive.
- The most important industrial energy uses per sub-field.
- The technologies and fuels that are or can be applied to these uses.
- The possibility to meet part of each sub-field's needs through electricity self-production and/or cogeneration, based on the new regulatory framework for the deregulated market.
- The possibilities for energy savings.
- The existing restrictions due to the structure and technological situation in each sub-field.

The model assesses and determines the potential for the penetration of new technologies in the energy system, based on three distinct mechanisms that take into account the financial attractiveness, restrictions due to the existing capacity, and the gradual penetration/acceptance of the available technologies and techniques. The evolution of each sub-field in the model is determined based on the useful energy demand, which is defined externally, as a function of industrial production and the total Gross Added Value per sub-field.

The ***transportation sector*** in the energy system includes urban passenger transportation, non-passenger transportation, freight transportation and international transportation. The transportation load demand for each of these categories can be met by various transportation means (road, railway, maritime, air transport), while there are also several technologies determined at various levels of energy consumption and/or alternative fuels.

The transportation load demand is expressed either in the form of passenger-kilometres (for passenger transportation) or tonne-kilometres (for freight transportation), and it is externally integrated in the model, as a function of income, economic development and the population. The shares of alternative transportation means/technologies are determined by the model based on their cost, which is internally calculated by the model, as well as by social behaviour parameters (**Figure 3-3**). The cost of alternative transportation means is calculated based on the definition of generalized transportation cost and includes the following:

- Vehicle cost;
- Fuel cost;
- Vehicle maintenance cost;
- The cost of time, given that in order to cover a specific route, the use of alternative transportation means results in time delays.

The ***agriculture sector*** is divided in two main sub-fields (greenhouses and agricultural machinery), each of which includes various energy uses (heating, pumping, etc.), while the energy needs can be met through alternative energy technologies and fuels. The evolution of the agricultural sector is defined based on the demand for useful energy, which is externally determined as a function of the total Gross Added Value of the field as well as industrialization indexes for agricultural production.

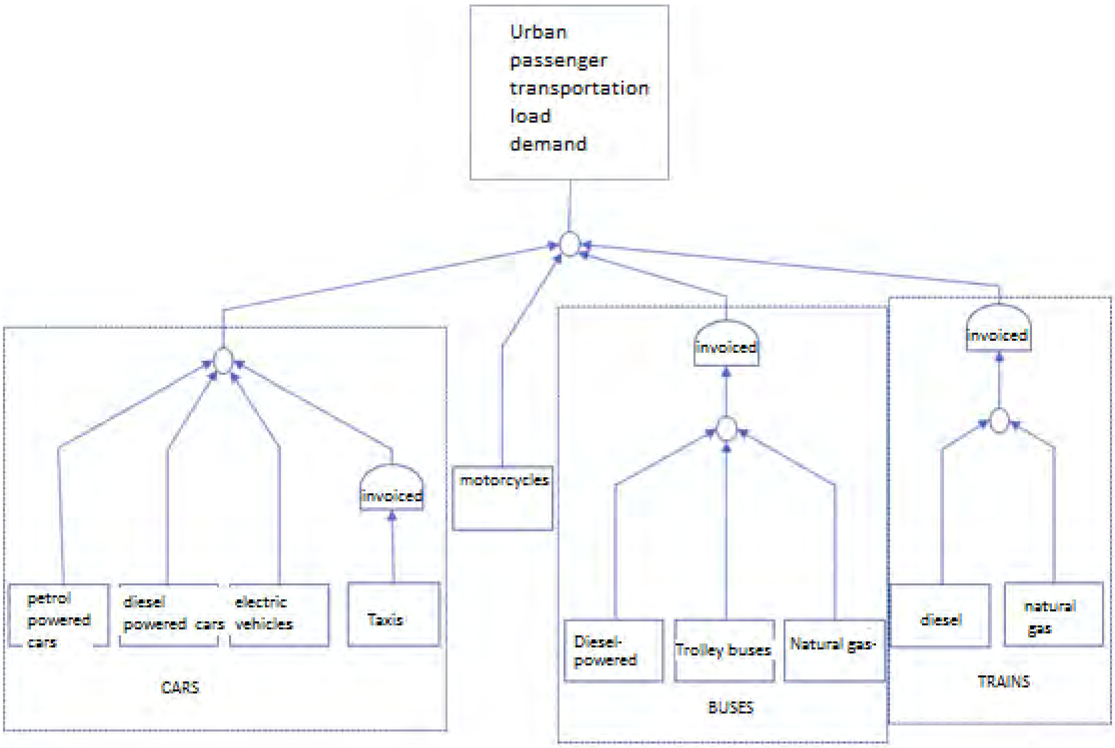


Figure 3-3: Simplified structure of the urban passenger transportation network in ENPEP/Balance.

The ***services sector*** is further divided in the sub-fields of offices, commerce, hotels and public services. At sub-field level, the energy network includes a set of energy uses (space heating, lighting, cooling, etc.) for each of which the energy demand is possible to be met through alternative technologies and fuels. The building stock is divided in two main categories: (a) all buildings erected after 1979 (when the Thermal Insulation Regulation came in force) which are considered insulated, and (b) buildings erected before 1979, which are considered non-insulated but with the technological possibility to install some kind of insulation in the future.

The energy network of the services field has evolved in such a way as to represent at the same time:

- The broad range of the existing energy uses.
- The multiple possibilities regarding the use of alternative technologies and fuels, including renewable energy sources.
- The possibility to meet part of the sector's needs through cogeneration and/or teleheating networks.
- The possibilities for energy saving.
- The existing restrictions due to the structure and technological situation of the field.

The evolution of the services field is defined based on the useful energy demand, which is externally determined as a function of the total Gross Added Value or the employment per sub-field and the infrastructure improvement indexes in the services sector.

The ***residential sector*** is divided in two main types of households depending on whether a central heating system is used. Besides space heating, all other energy uses (hot water, cooking, air conditioning, etc.) are addressed in the same way regardless of the household type. The same as in the case of the services sector, the building stock is divided in two main categories, assuming that all buildings erected after 1979 are insulated and older ones non-insulated (still with the possibility to apply insulation interventions). The reasoning used for the evolution of the energy network in ENPEP/Balance is similar to that of the services field, while the evolution of the sector is defined based on the useful energy demand and the degree of electrical appliances penetration, which are externally determined, as a function of the number of households, private consumption and economic development.

The main advantage of this approach is that is allows to investigate the interconnections between the energy system sectors. Determining the equilibrium point based on the market mechanisms, in combination with the detailed technical description of the energy sectors and uses, allows for the realistic representation of the energy system, as well as the modelization of the various policy tools. However, it should be noted that the solution achieved each time is closely related to the degree of detail in which the energy network is represented on the tool.

4. MAIN SCENARIO ASSUMPTIONS

This chapter summarizes the main assumptions adopted as part of this analysis in order to formulate both the Business as Usual Scenario (BaU) of the Greek energy system as well as the other policy scenarios examined. BaU determines the future evolution of the Greek energy system under the existing policies and consumers' behaviours, taking into account the expected future trends. The policy scenarios integrate additional policies that affect the evolution of the energy system and are specialized in Chapter 5. The assumptions presented below all refer to the scenarios examined, unless otherwise mentioned.

4.1. Demographic characteristics

The main assumptions for the population evolution have been taken into account by the Hellenic Statistical Authority and are presented in detail in **Table 4-1** and **Figure 4-1**. As far as the average household is concerned, it is assumed that the trends of the 2001-2011 decade will continue and this estimate is used to calculate the number of households.

Table 4-1: Evolution of population and number of households in Greece.

	Population	Average household size	Households
2000	10,903,757	3.09	3,533,292
2005	10,969,912	2.91	3,769,217
2010	11,119,289	2.72	4,086,180
2015	10,858,018	2.63	4,133,453
2020	10,964,916	2.55	4,298,995
2025	11,018,069	2.48	4,449,040
2030	11,041,194	2.40	4,591,727
2035	11,040,445	2.33	4,728,744
2040	11,018,034	2.27	4,860,294
2045	10,962,879	2.20	4,980,607
2050	10,853,021	2.14	5,078,173

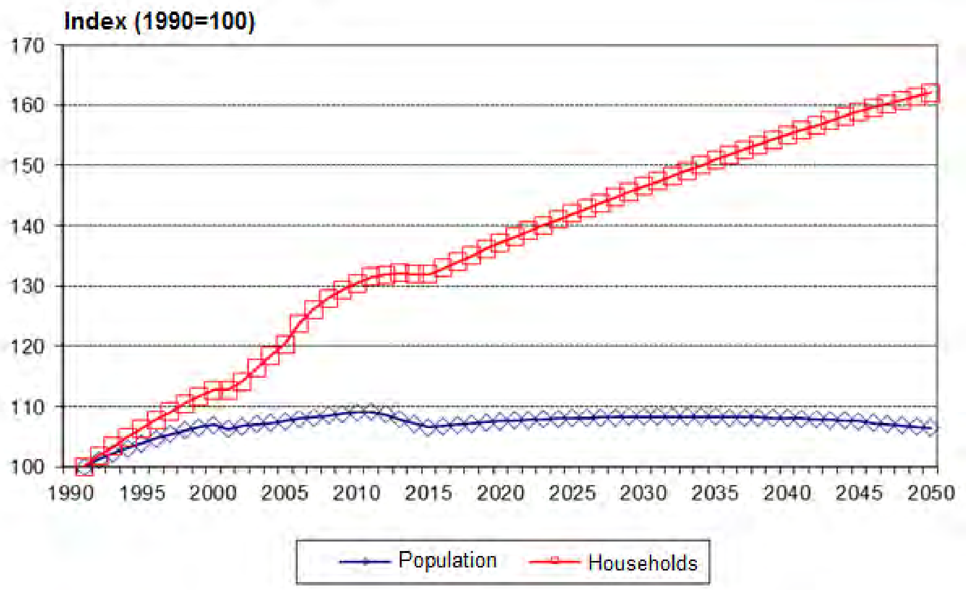


Figure 4-1: Demographic evolution indexes in Greece during the period 1990-2050.

4.2. Macroeconomic parameters

The evolution of energy demand in a system largely depends on the progress of the sectors of economic activity covered, but also on the way in which this evolution is spread among the population and the resulting impact on their living standards. Thus, the scenarios developed in this analysis take into account forecasts for the evolution of the economic activity as far as they are available by official bodies, such as the Greek government, the European Commission or the International Monetary Fund. Specifically, the forecast for the evolution of the GDP is based on the following sources:

- Forecasts by the European Commission for the period 2016-2018 (AMECO financial database).
- Forecasts by the International Monetary Fund for the period 2019-2020.
- Forecasts by the European Commission for Greece included in the "*EU Reference Scenario 2016: Energy, transport and GHG emissions Trends to 2050*" report, for the period 2021-2050.

Figure 4-2 shows the evolution of the Greek economy GDP for the overall period 2015-2050. The Gross Added Value (GAV) and the Consumers Expense are assumed to follow relevant trends and they are presented in**Table 4-2**.

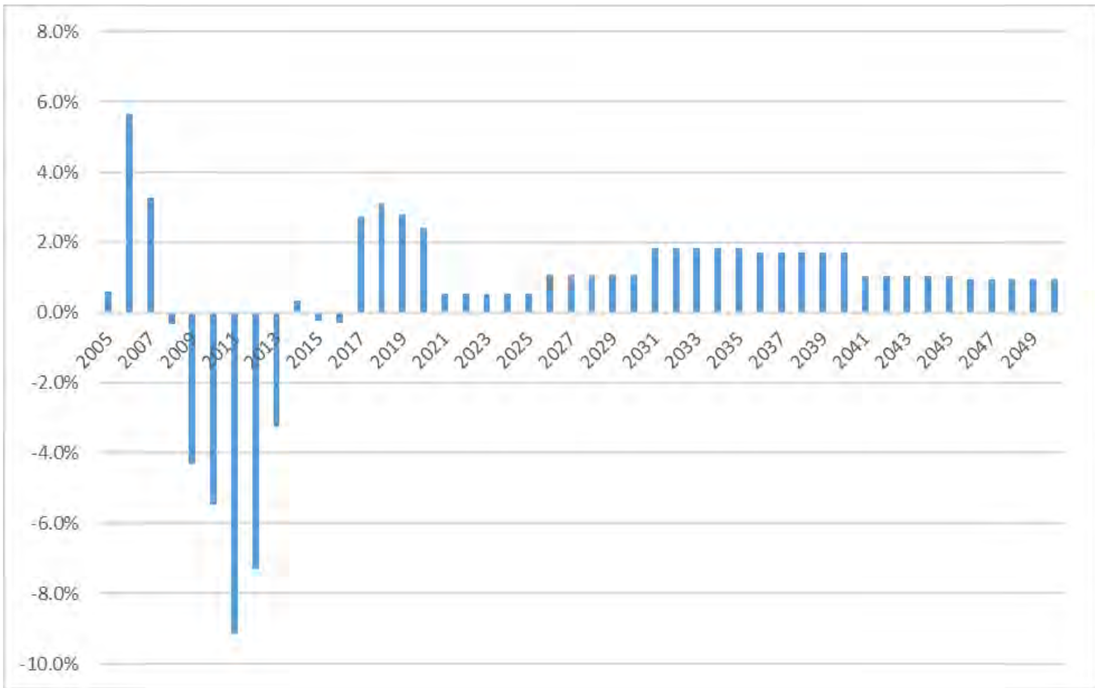


Figure 4-2: Evolution of the Greek economy GDP during the period 2005-2050.

Table 4-2: Evolution of the main economic indexes in the energy scenarios examined.

	GDP (bil. €2010)	Gross Added Value (bil. €2010)	Private Consumption (bil. €2010)	Average annual rate change of the GDP during the past 5 years (%)
2015	184.5	164.9	127.1	
2020	205.1	182.4	137.2	2.1%
2025	210.6	187.3	140.9	0.5%
2030	222.2	197.6	148.6	1.1%
2035	243.5	216.5	162.9	1.9%
2040	264.9	235.6	177.2	1.7%
2045	279.2	248.2	186.7	1.1%
2050	292.8	260.4	1959	1.0%

As far as the structure of the Greek economy is concerned, the following assumptions are made:

- The shares of GAV in the main economic sectors, such as agriculture, processing, construction, services, evolve during the overall period 2015-2050 based on the forecasts contained in the "*EU Reference Scenario 2016: Energy, transport and GHG emissions Trends to 2050*" Report (**Table 4-3**).
- In the cement industry: the clinker production dropped from its historical peak of 12,442 kt in 2005 down to 4,569 kt in 2011, and eventually amounted to 7,234 kt in 2014. We assume that production will gradually increase further, amounting to 10,000 kt in 2030 and 12,500 kt in 2050.
- In the ceramic industry, which during the decade 2005-2014 showed a 95% drop in economic activity, we assume that there will be a relative upturn, amounting in 2050 to approximately 50% of the maximum production achieved in 2005.

- In the aluminium, ferro-nickel and refineries industries, it is assumed that production during the overall study period reaches the 2014 levels, a year during which the production capacity of the existing facilities was utilized to a very high degree.
- In the steel industry, steel production amounted to 2,555 kt in 2007 and, eventually, to 1,022 kt in 2014. We believe that during the period until 2030 it will amount to 1,500 kt and in 2050 to 2,000 kt.
- The remaining fields follow the general evolution trends of the economy.

Table 4-3: Evolution of the Gross Added Value for the main economy fields in the energy scenarios examined (in mil. €2010).

	Offices	Commerce	Public Sector	Hotels	Agriculture	Industry
2015	72630	15187	34536	11209	6658	18592
2020	79176	23619	32629	12219	6110	17619
2025	82131	24514	33222	12675	5936	17969
2030	87522	26136	34749	13507	5907	18827
2035	96558	28950	37774	14901	6139	20440
2040	105728	31824	40752	16316	6313	22025
2045	112283	33908	42136	17328	6243	23110
2050	118694	35958	43353	18317	6119	24137

4.3. Fuel Prices / Taxation

The level of energy prices affects both the future total energy demand of the energy system as well as the shares of the various energy sources/technologies in meeting this demand. Both these factors affect in turn the level of the greenhouse gas emissions that originate from the energy sector. The forecast of the medium- or long-term evolution of the fuel prices presents major methodological problems and uncertainties, and it depends on the conditions in the international oil, natural gas and coal markets, as well as on the national pricing policy adopted.

It is underlined that, as part of the energy systems analysis, we are not so interested in the short-term energy price fluctuations, which may be particularly important and extremely uncertain, but mainly in the long-term trends that are determined by the total energy supply and demand. Besides, the long-term trends in price fluctuations are those that finally lead the consumers and the participants in the energy market to take specific decisions to undertake initiatives for energy saving, investments, etc.

Therefore, the analysis used the international fuel prices originating from the New Policies Scenario of the “World Energy Outlook, 2016 Edition”, which was published by the International Energy Agency (IEA). The prices are presented in **Table 4-4**. The report presents the prices of energy products until 2040. We believe that during the decade 2040-2050 these prices will eventually reach the 2040 levels. Moreover, **Figure 4-3** presents the price variation of the energy products in Greece before imposing taxation on the final consumers.

Table 4-4: International fuel prices[25]

		2015	2020	2030	2040	2050
Coal	$_{2015}$/ton	62	63	74	77	77
Natural gas	$_{2015}$/MBtu	7.0	7.1	10.3	11.5	11.5
Crude oil	$_{2015}$/bbl	49.3	79	111	124	124

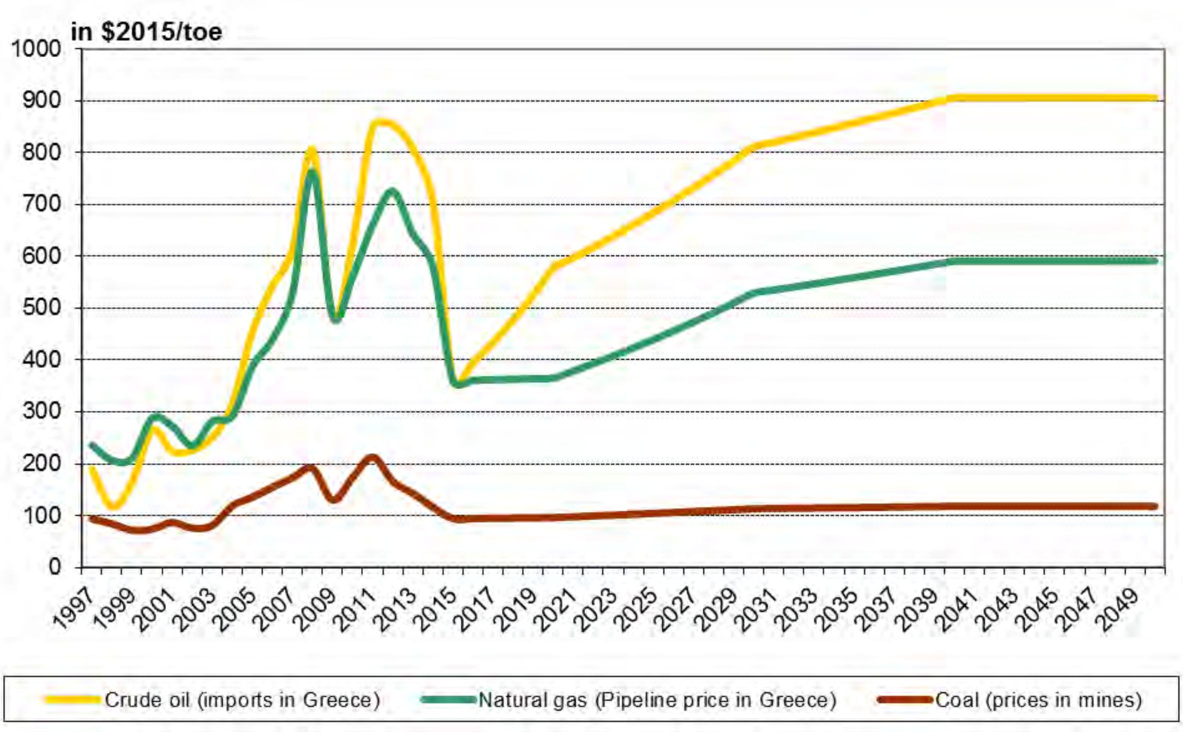


Figure 4-3: Evolution of energy product prices in Greece

Moreover, it has been assumed that the main characteristics of the existing (2015) tax policy for fuels will not be modified and there will be no coal tax imposed on fuel prices during the time period examined. However, the sectors included in the emissions trading system will have to undertake an extra cost for purchasing carbon dioxide emission allowances, which will be higher for the electricity generation sector (given that as of 2013 this sector was not granted free emissions allowances) and relatively lower for the other sectors which are subject to the trading system, since they will be granted part of the necessary allowance for free. For the remaining duration of the 3rd phase of the EU ETS (2013-2020), the average of the estimates by 8 different analysts was used[26]. Particularly for 2018 and 2019, a price of 10.55 €/t and 7.12 €/t, respectively, is foreseen. This analysis does not contain an estimate for 2020.

For the 4th phase of the EU ETS (2021-2030), it was assumed that the allowance price will amount to 25 €$_{2015}$/t CO_2 according to the European Commission forecast during the submission of its proposal to amend Directive 2003/87/EC (15 July 2015), which followed the decision to establish the Market Stability Reserve and to increase the linear reduction factor to 2.2%[27].

[25] World Energy Outlook, 2016 Edition, International Energy Agency

[26] Reuters. 12.1.2016. "Analysts cut EU CO2 price forecasts on lower coal, higher gas use", http://uk.reuters.com/article/eu-carbon-idUKL8N14V3JF20160112

[27] A) May 2015: Informal agreement between the European Parliament (ENVI Committee) and the Council of Ministers http://goo.gl/ovzX5n
B) July 2015: Endorsement of the agreement between the European Council and the European Parliament by the European Parliament's Plenary Session http://www.europarl.europa.eu/news/en/news-room/content/20150703IPR73913/html/Parliament-adopts-CO2-market-stability-reserve

Specifically, the European Commission, in its questions and replies[28], estimates that the sale of 400 mil. of allowances available in the innovation fund will generate revenues amounting to 10 bil €, which means that the Commission estimates that during the decade 2021-2030 the average price of the CO_2 allowance will amount to 25 €/t. This EU estimate is also consistent with the projection by Point Carbon Thompson Reuters for a CO_2 allowance price in the order of 30 €/t in 2030[29]. Finally, the position paper by Eurelectric[30] foresees even higher prices for the allowances during the 4th phase of the EU ETS.

Based on the above, the emission allowance prices during the period 2021-2030 are expected to range between 15 and 35 €/t CO_2, while the price of 25 €/t CO_2 is used as the baseline price in our analysis. For the period after 2030, we make the moderate assumption that the allowance prices will be in the order of 30 and 40 €/t CO_2 for the periods 2031-2040 and 2041-2050 respectively. It is noted that the European Commission's forecasts adopted in its most recent energy reference[31] are far higher during the period after 2030. Specifically, in this scenario, the emission allowance prices amount to 15 €/t CO_2 in 2020, 22.5 €/t CO_2 in 2025, 33.5 €/t CO_2 in 2030, 42 €/t CO_2 in 2035, 50 €/t CO_2 in 2040, 69 €/t CO_2 in 2045 and 88 €/t CO_2 in 2050. A sensitivity analysis was also elaborated as part of this study, in terms of the financial cost of the energy scenarios examined, using these forecasts by the European Commission.

At this point, it should be stressed that the elasticity of the energy demand in the various consumption sectors of the Greek energy system in terms of the international oil/natural gas prices is low; therefore, only relatively small variations are expected in energy consumption and the total greenhouse gas emissions even in case of significant short-term fluctuations in the prices of these fuels. On the contrary, the total greenhouse gas emissions greatly vary in case the price fluctuations lead to a change in the cost saving relationship between oil/natural gas and solid fuels (e.g. by imposing an environmental tax or developing high prices for emission allowances).

4.4. Discount rate

The discount rate used to assess alternative energy technologies varies based on the special characteristics of the decision-makers involved in the energy sectors under consideration. Specifically in the residential sector, the consumers usually prefer investments with a short repayment period; therefore, a significantly higher discount rate than the one expected in the banking market was adopted, in the order of 14%. On the other hand, industries, public utilities, refineries, etc., usually plan their investment policy on a long-term basis; for this reason, a discount rate in the order of 6% was considered the most suitable. Finally, in the tertiary sector, which by presumption comprises smaller enterprises, an intermediate 9% discount rate was adopted.

4.5. Interconnections

The Greek electricity system is interconnected with those of Turkey, Albania, FYROM, Italy and Bulgaria, allowing electricity imports and exports in order to cover loads with a relatively lower cost and to dispose of the generation surplus. In the longterm the further reinforcement of Greece's interconnections with other systems, mainly that with Bulgaria, is under consideration[32]. The quantities of electricity transported through the interconnections depend both on domestic demand, availability of generation units and cost of electricity generation, as

[28] FleishmanHillard. 2015. "Reforming the EU Emissions Trading System. Outcomes & Analysis". http://goo.gl/W8cLsg page 6
[29] http://goo.gl/EUoZxw
[30] http://www.eurelectric.org/media/295167/20161130_recommendation_to_strengthen_eu_ets-2016-030-0608-01-e.pdf
[31] EU Reference Scenario 2016: Energy, transport and GHG emissions Trends to 2050
[32] South-East Europe Electricity Roadmap (SEERMAP), Presentation of program results, Belgrade, May 2017.

well as on the respective parameters in the interconnected electricity systems. To date, Greece basically remains a net electricity importer. The analysis of various scenarios as part of the SEERMAP Project[33] has demonstrated that Greece may still be a a net electricity importer but can also be converted into a net exporter under certain conditions. Given that the development of such scenarios requires the detailed modelization of all interconnected electricity systems, this analysis -and for all the scenarios examined- assumed that Greece remains a net electricity importer, and net imports are assumed in the order of 1800 GWh/year, which are quite lower than the net imports in previous years. This choice was made in order to to study the evolution of the Greek energy system under conditions of self-reliant coverage of the domestic demand, while it is assumed that small quantities of imported electricity will be used for short periods of "special conditions" when demand will be exceptionally high (e.g. wave heat) or part of the system's production potential will not be available (e.g. due to a breakdown).

As far as the domestic electricity system is concerned, it was assumed that during the decade 2020-2030 a series of infrastructure projects will be implemented and completed, aiming at the interconnection between island areas in Greece and the mainland's electricity system. Thus, as part of this analysis and for all the scenarios examined, it is assumed that the system's interconnection with Cyclades and Crete is completed. Moreover, it is assumed that by 2030 most major islands of the Aegean Sea and the Dodecanese will be interconnected with the mainland system. Some remote islands that will not be interconnected will have oil units, while certain existing stations will remain as backup in major islands (Lesvos, Samos, Rhodes), in order to cover ad hoc events.

4.6. Special assumptions for the electricity generation sector

The electricity generation sector in Greece is particularly critical in order to achieve the targets for the medium- and long-term reduction of greenhouse gas emissions, and it is expected to undergo a general transformation in the next few decades. Therefore, it is particularly useful to highlight certain assumptions made as part of this analysis.

4.6.1. Cost of electricity generation technologies

Tables 4-5 and **4-6** present the basic cost parameters for RES units and electricity generation stations that use fossil fuels. These assumptions have been used in all the scenarios examined in order to develop the energy balances and to estimate the levelized cost of electricity. Naturally, it should be stressed that the estimate of the levelized cost of electricity generated from fossil fuel is affected by the development of fuel and emissions allowance prices over time as adopted in the various scenarios. Moreover, given that several RES technologies have a relatively shorter life span compared to conventional electricity generation stations, in order to calculate the system's total levelized cost of electricity, we assume that these are replaced after a reasonable period of time, namely 5-10 years after the end of their nominal life cycle.

Table 4-5: Assumptions for the calculation of the cost of electricity generation from RES[34]

	Standard installation (MW)	Investment cost (€$_{2015}$/kW)	OM Cost (% on the investment cost)	Load Factor	Life Years
IS wind farm	30	1350	0.036	0.245	20
Wind farm on an island	10	1550	0.04	0.3	20

[33] South-East Europe Electricity Roadmap (SEERMAP), Presentation of program results, Belgrade, May 2017.

[34] The main cost parameters originate from the Report on the sector of electricity generation from RES as part of the planning for the reform of the support mechanism, the WWF Report 2015: "Clean alternatives in Ptolemais V"; the cost of photovoltaic systems originates from the "International Energy Agency 2014: Technology Roadmap: Solar Photovoltaic Energy" Report.

Wind farm on the sea	100	3000	0.025	0.38	20
PV 500 kW	0.5	2015:1450 2030:1000 2050: 850	0.025	0.165	20
PV rooftops	0.01	2015:1595 2030:1100 2050: 935	0.005	0.15	25
Small hydroelectric systems	5	2300	0.033	0.37	20
Geothermal energy	20	4000	0,055	0.9	20
Solar thermal energy without storage	20	3800	0.025	0.2	25
Solar thermal energy with storage	30	5300	0.025	0.36	25
Biomass	3	3000	0.28	0.8	20
Gas from landfill sites	5	2300	0.16	0.75	20
Biogas from organic residue	5	2900	0.38	0.85	20

Table 4-6: Assumptions for the calculation of the cost of electricity generation from conventional electricity generation stations

	Standard installation (MW)	Investment cost (€2015/kW)	Efficiency (%)	FOM cost (€2015/MWh)	VOM cost (€2015/MWh)	Fuel cost (€2015/GJ)	Load factor	Life Years
Natural gas, CCGT	450	880 [a]	55%	2,283	2	7.5 [c]	0.46	30
Lignite (standard unit)	300	1584 [a]	33%	3.425 [b]	2	2.69 [d]	0.75	40
Ptolemais V	660	2106	41.5	3.425 [b]	2	2.69 [d]	0.75	40

[a] Ecofys report 2014 for DG Energy Annex 4, pp. 21

[b] DIW datadoc, pp. 40, subcritical

[c] Ecofys report 2014 for DG Energy Annex 4, pp. 7

[d] Understanding Lignite Generation Costs in Europe, Booz&Co

[e] Includes an allowance emission cost of 6 €$_{2015}$/t CO_2.

4.6.2. Integrating and closing down electricity generation units

At this stage, 6 steam-electric power stations (SEPS) operate in Greece using lignite, 2 in the Kozani Prefecture (Ag. Dimitrios SEPS, Kardia SEPS), 2 in the Florina Prefecture (Amyntaio SEPS, Meliti SEPS) and 2 in the Arcadia Prefecture (Megalopoli III SEPS, Megalopoli IV SEPS). As of 1/1/2016, the Kardia and Amyntaio SEPS were included in a derogation status for a limited period of operation according to article 33 paragraph (1) of the Directive on industrial emissions. Despite PPC and the government's attempts to subject them to article 33 paragraph's provisions (4) that would allow them extra hours of operation, the European Commission ascertained that none of the 2 SEPS fulfils the necessary conditions. As a result, the 2 SEPS will operate for up to 17,500 hours during the 8-year period 2016-2023 (significantly lower compared to their operation period until 2015). Consequently, in BaU, it was assumed that the 2 SEPS have a specific restriction on their operation period and will close down in 2023[35]. In addition, in this scenario and according to the adequacy study by the IPTO, it is assumed that the Megalopoli III SEPS will close down in 2025, the same as the Megalopoli IV SEPS. Finally, it is assumed that the 4 older from the 5 units in the Ag. Dimitrios SEPS will become obsolete and close down in 2030 since by then they will have completed a 45-year life span. Thus, it is assumed that out of the currently existing lignite units, only the 2 most recent will operate after 2030, namely Meliti I and Ag. Dimitrios V. The above assumptions concerning the timing for closing down are summarized in **Table 4-7**, while any differentiations in this time planning included in the other scenarios examined, are mentioned in the presentation of these scenarios in Chapter 5.

[35] It is noted that this is a moderate assumption, since other studies (CRES, sufficiency study by the IPTO) assume that the closing down of these 2 SEPS will take place earlier (2019-2020).

Table 4-7: Assumptions concerning the end of operation of electricity generation units in BaU.

Unit	Power output (MW)	Fuel used	Year of closing down
Lavrio II	287	Fuel oil	2015
Kardia I	275	Lignite	2023
Kardia II	275	Lignite	2023
Kardia III	280	Lignite	2023
Kardia IV	280	Lignite	2023
Amyntaio I	273	Lignite	2023
Amyntaio II	273	Lignite	2023
Megalopoli III	255	Lignite	2025
Megalopoli IV	256	Lignite	2025
Ag. Dimitrios I	274	Lignite	2030
Ag. Dimitrios II	274	Lignite	2030
Ag. Dimitrios III	283	Lignite	2030
Ag. Dimitrios IV	283	Lignite	2030

Since significant investments were made in natural gas units in the past decade, **Table 4-8** summarizes the natural gas units that will be available in the electric system in the next few years. In addition to these units and the existing lignite units (the availability of which during the study period is defined based on the closing down plan presented on Table 4-7), the baseline scenario used as part of this study (BaU) for the interconnected system also includes the lignite unit Ptolemais V (net power of 600 MW and total power of 660 MW), which is assumed to be integrated in the electrical system in 2021. Other scenarios presented in Chapter 5 examine both the integration of another lignite unit (Meliti II) as well as the non-integration of some new lignite unit.

Table 4-8: Natural gas units known to be available in the system for the period after 2015.

Unit	Power output (MW)	Year of integration	Technology
Lavrio IV	550		Combined cycle
Komotini SEPS	476		Combined cycle
Iron I, II, III	3x49=147	2004	Gas turbines
Lavrio V	378	2005	Combined cycle
Energiaki Thessaloniki	389	2006	Combined cycle
Aluminium	334	2008	Combined cycle / cogeneration
Iron II in Viotia	422	2010	Combined cycle
Protergia CC	433	2011	Combined cycle
Elpedison in Thisvi	410	2011	Combined cycle
Korinthos Power	433	2012	Combined cycle
Aliveri V SEPS	416	2013	Combined cycle
Megalopoli V	800	2015	Combined cycle

4.6.3. Energy storage needs

Both BaU and the other scenarios examined foresee the installation of a significant number of new wind and photovoltaic units. The large-scale utilization of intermittent RES creates additional storage requirements in order to guarantee sufficient energy supply. As part of this analysis, it is assumed that the requirements for electricity storage can be covered by integrating pumping hydroelectric systems in the system. Specifically, the following assumptions were adopted for all the scenarios examined:

- According to various detailed simulations, such as for instance the one developed by CRES and presented to the Hellenic Parliament on 22/11/2016, the existing electricity system can satisfactorily manage the penetration of intermittent RES up to a 8 GW level.
- For a RES penetration over these levels, it is assumed that for each additional GW of intermittent RES, an extra amount of approximately 0.25 GW of pumping hydroelectric units should be integrated in the system[36].
- There are large margins for converting the existing hydroelectric units into pumping stations. According to a NTUA study[37], existing hydroelectric units can be converted into pumping units using the following cost prices:
    - 400 MW at 520 €/kW
    - 1410 MW at 725 €/kW
    - 275 MW at 885 €/kW

Due to the relatively low cost, we assume these conversions will be given priority in all scenarios where the penetration of the intermittent RES requires the installation of additional storage systems.

- If, in some scenarios, these conversions do not suffice for meeting the storage needs resulting from the penetration of the contemplated RES, then it is assumed that new pumping hydroelectric projects are constructed at a cost of 2300 €/kW[38].

4.6.4. Upgrading existing lignite stations

As of 1/1/2016, the emission limits for sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter (PM) prescribed in the Directive on industrial emissions (2010/75/EU) are in force, which are summarized on the second and third column of **Table 4.9**. **Table 4.10** presents the actual emissions of the 6 PPC lignite SEPS during the last 3 years (2013-2015) for which there are complete data available, based on official YPEN data, and the specifications contained in the relevant Environmental Terms Approving Decision for the Ptolemais V unit under construction.

Table 4.9: Emission limits for PPC lignite units pursuant to the Directive on industrial emissions (2010/75/EU)

Pollutant	Emission Limits (mg/Nm^3)			
	Directive on industrial emissions 2010/75/EU		New LCP BREF	
	Existing SEPS	New SEPS	Existing SEPS	New SEPS
Sulphur dioxide (SO_2)	200	150	130	75

[36] These levels of pumping requirements are also presented, for instance, in the report by Caralis G, Papantonis D and Zervos A (2012), "The role of pumped storage systems towards the large scale wind integration in the Greek power supply system". Renewable and Sustainable Energy Reviews 16. Respectively, slightly lower pumping requirements, amounting to 0.2 GW per 1 GW of contemplated RES, are demonstrated in the simulation developed by CRES and presented to the Hellenic Parliament on 22/11/2016.

[37] Stefanakos I. P. (2012). Possibilities for constructing pumped storage systems in areas of Continental Greece, Research Program 62/2423 PAE.

[38] http://2050-calculator-tool-wiki.decc.gov.uk/cost_categories/60

Nitrogen oxides (NO_x)	200	200	150	85
Particulate Matter (PM)	20	10	8-12	5

Table 4.10: Actual emissions of SEPS lignite units in Greece during the 3-year period 2013-2015

SEPS	SO_2 emissions (mg/Nm^3)				NO_x emissions (mg/Nm^3)				PM emissions (mg/Nm^3)			
	2012	2013	2014	Average	2012	2013	2014	Average	2012	2013	2014	Average
Kardia I	244,0	75,0	115,0	144,7	326,0	320,0	288,0	311,3	313,0	253,0	309,0	291,7
Kardia II	283,0	65,0	185,0	177,7	284,0	331,0	280,0	298,3	290,0	421,0	225,0	312,0
Kardia III	305,0	175,0	244,0	241,3	339,0	336,0	301,0	325,3	34,0	76,0	49,0	53,0
Kardia IV	374,0	158,0	170,0	234,0	344,0	360,0	287,0	330,3	37,0	66,0	50,0	51,0
Amyntaio I+II	1144	575,0	1255,0	991,3	192,5	194,5	229,5	205,5	25,1	26,8	68,8	40,2
Ag. Dim. I+II	414,9	444,2	313,9	390,8	394,5	333,3	348,3	358,7	20,5	11,7	26,9	19,7
Ag. Dim. III+IV	635,6	639,0	360,9	545,1	383,8	348,6	361,2	364,5	7,9	6,2	9,2	7,8
Ag. Dim. V	777,5	984,5	512,1	758,0	322,3	315,3	302,8	313,5	18,9	16,9	29,3	21,7
Meliti I	108,0	90,5	121,6	106,7	143,0	167,7	118,0	142,9	4,3	2,9	2,0	3,1
Megalopoli III	279,0	151,0	223,9	217,7	130,0	114,0	137,0	127,0	4,0	5,2	2,6	3,9
Megalopoli IV	269	237	194,9	258,3	269	186	172,3	209,1	13,5	9,6	10,1	11,1
Ptolemais V				150				200				10

As already mentioned, PPC has decided to apply for the integration of the 6 units in the Kardia and Amyntaio SEPS to the derogation of article 33 of the Directive, according to which the stations' emissions can exceed these limits, on condition that they will operate less during a limited 8-year period, before closing down permanently.

Moreover, PPC has subjected its remaining 8 lignite units (Ag. Dimitrios, Meliti I, Megalopolis III and Megalopoli IV SEPS) to article 32 of the Directive, according to which these lignite units receive an extension for compliance with the emissions limits of the Directive until June 2020, on condition that they proceed to all the necessary interventions that will ensure the gradual emissions decrease. The relevant time schedule is mentioned in detail in the so-called "Transitional National Plan for Emission Reduction" (TNPER) which was integrated in national law in the form of a Joint Ministerial Decision[39]. There have already been major delays in terms of its fulfilment.

Moreover, on 28/4/2017 and with Greece's consent, there was a decision at EU level to adopt the new Best Available Techniques manual (LCP BREF), which sets new, stricter emissions limits for the 3 pollutants (see 4th and 5th columns on **Table 4.9**), also setting a distinct limit for mercury (Hg). Pursuant to the Directive on industrial emissions, all major combustion facilities are obliged to comply with these new limits within 4 years. Consequently, all the Greek lignite units that will operate in 2021 will have to carry out upgradings ensuring that their emissions fall below the limits on **Table 4.9** (columns 4 and 5). It is noted that the specifications for PPC's new, under construction, lignite unit "Ptolemais V" are also outside the limits of the new BREF. Consequently, the new PPC unit will also have to proceed to upgradings even before starting to operate.

By comparing the emissions data on **Table 4.10** to the maximum permissible limits of the new LCP BREF, it is ascertained that the emissions from Amyntaio SEPS are on an average more than 7.5 times over the new SO_2 emissions limit for existing units and 13 times over the respective limit for new units, while emissions from the 3 stacks of the Ag. Dimitrios SEPS range between 3 and 6 times over the new BREF limits for existing units. Moreover, the 2 units of Kardia SEPS emit approximately 30 times more particles than the new limit for existing units and approximately 60 times over the respective limit for new units. Finally, the Ag. Dimitrios and

[39] GG B'1793. 2015

Kardia SEPS emit over twice more NO_x than the LCP BREF limit for existing units. It is necessary to clarify that, in case it is decided to extend the operation of either the Kardia SEPS or the Amyntaio SEPS, and after their corresponding 17.500 hours of operation are used up, these units will have to be integrated in the system as new units, namely to comply with the even stricter limits of LCP BREF for new units.

Taking into account the actual emissions levels of the last three years, the difference from the desirable limits of the new LCP BREF, and the cost for the necessary upgradings mentioned in the recent relevant Report by DNV GL-Energy[40], the technology for the upgrading projects regarding each pollutant was selected, as well as the respective installation and operational cost for each of the existing SEPS, including Ptolemais V. It is underlined that in each case, the least expensive technology was selected, which was not necessarily the Best Available Technique pursuant to the LCP BREF. Thus, for example, while pursuant to the LCP BREF, the Best Available Technique for reducing sulphur dioxide emissions in large combustion units, which also emit large quantities of heavy metals is wet desulphurization, in the cases of Ag. Dimitrios I-II and Ag. Dimitrios III-IV SEPS, dry desuplhurization was selected, since this is a significantly cheaper option. Specifically, upgradings will have to be made in the following lignite power stations:

Ag. Dimitrios Station

In all the scenarios examined, the Ag. Dimitrios I-IV units will close down in 2030, while the Ag. Dimitrios V unit will continue to operate beyond that time. The continued operation of these units will require:

- A reduction in NOx emissions below 175 mg/Nm^3. In order to reduce emissions to such a level, a Selective Non-Catalytic Reduction (SNCR) technology will have to be installed in all 3 stacks of the station, the efficiency of which amounts to 60%, the investment cost to 50 €/kW, while the annual operational cost is estimated at approximately 7.2% of the investment cost.
- A reduction in SO_2 emissions below 130 mg/Nm^3. In order to achieve this target, in the 2 chimneys of the Ag. Dimitrios I-IV units, the existing dry desulphurization system will have to be upgraded so that its efficiency can reach 80%. The investment cost is estimated at 40 €/kW, while the annual operational cost is estimated at approximately 7.3-8.7% of the investment cost. For the Ag. Dimitrios V unit, a wet desulphurization system will have to be installed, the efficiency of which amounts to 98%, the cost investment to 350 €/kW, while the annual operation cost is estimated at approximately 4.9% of the investment cost.
- A reduction in dust emissions below 12 mg/Nm^3 for the Ag. Dimitrios I, II, V units and below 8 mg/Nm^3 for units III and IV. It will be necessary to upgrade the existing electrostatic filters in units I-II and V, with an investment cost of 15 €/kW, and an annual operational cost in the order of 4% of the investment cost.

Amyntaio Station

For the scenarios foreseeing an extended operation of the Amyntaio lignite station and after using up the 17,500 hours of its operation, the following interventions are taken into account:

- Installation of a SNCR system to reduce NOx emissions below the level of 85 mg/Nm3. The investment cost is calculated at 50 €/kW, while the annual operational cost was estimated at approximately 5.8% of the investment cost.
- Installation of a wet desulphurization system to reduce SO2 emissions with a cost similar to the Ag. Dimitrios V unit.
- Installation of electrostatic filters to reduce the dust emissions, with a cost of 75 €/kW and an annual operation cost amounting to 4% of the investment cost.

Megalopoli IV

[40] DNV GL-Energy (2016). Hard Coal/Lignite fired power plants in EU28: Fact-based scenario to meet commitments under the LCP BREF, European Climate Foundation.

Finally, the operation of the Megalopoli IV unit beyond 2025 in some scenarios will require:

- Installation of a SNCR system to reduce NOx emissions below the level of 175 mg/Nm3. The investment cost is calculated at 50 €/kW, while the annual operational cost was estimated at approximately 6.3% of the investment cost.
- Upgrading of the wet desulphurization system to reduce SO2 emissions at the level of 130 mg/Nm3 with an investment cost in the order of 70 €/kW and an annual operational cost at the level of 4.9% of the investment cost.

Ptolemais V

Despite the fact that the specifications for Ptolemais V comply with the limits of the Directive on industrial emissions for new units, there is still a significant difference with the respective limits of the new BREF. In order to comply with the latter and assuming that the emissions by Ptolemais V will fully comply with its specifications, the following upgradings will be required:

- Installation of a SNCR system to reduce NO_x emissions at 85 mg/Nm3. The investment cost is calculated at 50 €/kW, while the annual operational cost was estimated at approximately 5.6% of the investment cost.
- Upgrading of the wet desulphurization system to reduce SO_2 emissions at the level of 75 mg/Nm^3 with an investment cost in the order of 70 €/kW and an annual operational cost at the level of 4.6% of the investment cost.
- Upgrading of the electrostatic filters, with an investment cost of 15 €/kW, and an annual operational cost in the order of 4% of the investment cost.

4.7. Assumptions for the evolution of final consumption

The evolution of the final energy consumption in the energy system examined is estimated using the energy model and is calculated at sector level, taking into account the economic scenario adopted, the fuel prices in the energy market, the cost of the various alternative technologies, and the economic and regulatory policies applied per sector. In the last decade, the Greek economy went through a prolonged period of reduced economic activity and reduction in incomes. This resulted in major changes in the energy behaviour of households and enterprises. Broader population groups suffer from energy poverty; as a consequence, a high percentage of residential buildings do not achieve suitable thermal comfort conditions. The economic scenario adopted assumed a mild economic recovery for the Greek economy. This development will result in a gradual and long-term improvement in the economic status of households and enterprise performances. Since the application of energy saving measures requires, in several cases, the commitment of capital, the question is the final consumers' financial capability to proceed to such interventions, as well as to whether these will lead to reduced energy consumption, or will contribute to the improvement of living standards and the better fulfillment of energy needs (rebound effect).

The energy scenarios developed as part of this analysis are divided in two groups in terms of the energy saving policies they adopt. The first group, which also includes the BaU scenario, integrates energy saving measures and policies in the final consumption sectors, but with a relatively low investment cost and which can be implemented while incomes are limited. These mainly include the following:

- Penetration of more efficient devices in residential buildings and businesses of the tertiary sector.
- Promoting low energy consumption bulbs and lights.
- Promoting solar systems for water heating.
- Promoting more efficient air conditioning systems and heating systems based on electricity.

- Limiting the traditional biomass used for space heating.
- Modernizing the vehicle fleet.
- Railway electrification.
- Promoting biofuels.
- More general interventions in the industry and promotion of RES, such as biomass and solar energy.

The second group of scenarios (EE and LPO) incorporate more ambitious (financial and regulatory) policies for the promotion of energy saving programs. Thus, the aforementioned interventions are adopted by a larger percentage of the final consumers per sector, but at the same time higher cost measures are also promoted, such as:

- Energy upgrading of buildings by insulating their envelope, installing double-triple glazings, etc.
- Promoting the renewal of central heating systems.
- Promoting electrification in transportation.
- Large-scale interventions in industrial units for energy savings.

The LPO scenario in particular adopts even more ambitious energy saving policies, involving the following:

- More ambitious rates of energy upgrading of the building stock and the replacement of old boilers.
- More ambitious targets for biofuel promotion.
- Interventions for reducing the energy consumption in the agricultural sector.
- Interventions for the reconstruction of production and radical energy upgradings in the industry.
- Ambitious programs for the promotion of biomass in the industry.

In both groups of scenarios, the issue is whether the applied interventions will result in the expected energy savings or the expected decrease in energy related costs will lead to increased consumption.

5. RESULTS

5.1. Presentation of the scenarios

As part of this analysis, 5 main energy scenarios were developed and comparatively assessed, which are briefly presented below:

- *Business as Usual Scenario (BaU)*, which prescribes the evolution of the energy system based on the already applied and agreed upon policies, taking into account the cost saving aspect of alternative technologies, as well as the requirement for the amortization of applied or future investments within a reasonable time period. In particular, regarding conventional electricity generation, BaU includes the construction of Ptolemais lignite unit V, the environmental upgrading of Ag. Dimitrios I-IV units, which will close down in 2030, a limited operation of 17,500 hours for the Kardia and Amyntaio stations, which will close down in 2023 because the two SEPS will be subjected to a derogation status for a limited period of operation expiring at the latest in 2023 -according to article 33 of the Directive on industrial emissions (2010/75/EU), and the closing down of the Megalopoli III and IV units in 2025.
- *Extension of Lignite Use Scenario (LIG)*, with emphasis on maintaining the lignite's significant share in the Greek electricity generation mixture, through the construction of two new lignite units (Ptolemais V and Meliti II), as well as the radical upgrading of Amyntaio I and II Units and Megalopoli IV Unit, which will continue to operate after 2023. The Kardia station will close down in 2023 because it will be included to the derogation status, foreseen by article 33 of the Directive on industrial emissions (2010/75/EU), of a limited period of operation expiring in 2023 , while the Ag. Dimitrios I-IV units undergo an environmental upgrading and operate until 2030 when they will close down due to obsolescence Under these restrictions, the evolution of the system depends on the estimated energy demand, the cost saving aspect of alternative technologies, as well as the requirement for the amortization of applied or future investments within a reasonable time period. As far as the final consumption sectors are concerned, this scenario does not differ from BaU in terms of the policies applied.
- *Expansion with RES Scenario (RES)*, which assumes a limited lignite share in the electricity system and the latter's restructuring based on the estimated demand and the cost saving aspect of alternative technologies, limiting at the same time the requirements for the amortization of investments already made. Within this framework, no new lignite unit is to be constructed, while the plans for closing down the existing lignite units will proceed as prescribed in BaU. Moreover, as far as the final consumption sectors are concerned, this scenario does not differ from BaU in terms of the policies applied.
- *Energy Saving Scenario (EE)*, which differs from BaU by means of assuming more drastic energy saving policies in the final consumption sectors (electrification and vehicle fleet modernization in the transport sector, upgrading building reserves, promoting higher-efficiency equipment, etc.), while the electricity system expansion takes into account the cost saving aspect of alternative technologies by limiting the requirements for the amortization of already applied investments.
- *Energy Savings and Lignite Phase-Out Scenario (LPO)*, which differs from EE in that it assumes a more ambitious policy in order to limit the lignite share in the electricity system, leading to a complete phase out of lignite in 2050, and it adopts more ambitious energy saving policies in the final consumption sectors.

Table 5-1 briefly presents the assumptions adopted in the various scenarios for the lignite units' operation. The scenario results are presented in the following Sections and also in detail in the Annex. Moreover, as part of the discussion on specific energy policy issues, sensitivity analyses were also carried out for critical design parameters.

Table 5-1: Assumptions for the operation of lignite units in the Greek energy system for the various scenarios examined.

Unit	BaU	LIG	RES	EE	LPO
Megalopoli III	Shuts down in 2025				
Megalopoli IV	Shuts down in 2025	To be radically upgraded	Shuts down in 2025		
Ptolemais V	Becomes operational in 2021		Cancelled	Becomes operational in 2021	Cancelled
Kardia I-IV	Retire by 2023. Until then, limited operation up to 17,500 hours.				
Amyntaio I-II	Retire by 2023. Until then, limited operation up to 17,500 hours.	To be radically upgraded and to operate after 2023	retire by 2023. Until then, limited operation up to 17,500 hours.		
Ag. Dimitrios I-IV	To be environmentally upgraded and to close down in 2030.				
Ag. Dimitrios V	To be environmentally upgraded				To be environmentally upgraded. Retirement in 2040
Meliti I	To operate				Retirement in 2045
Meliti II	Not constructed	Becomes operational in 2022	Not constructed		

5.2. Total primary energy supply

Figure 5-1 presents the evolution of primary energy supply in the Greek energy system for all the scenarios examined. First of all, it seems that the primary energy supply for the overall period until 2050 and for all scenarios steadily remains below the 2015 levels. This is related both to the mild economic development scenario adopted, as well as to the overall improvement in the system's energy efficiency, by limiting the use of solid fuels and expanding the RES share. It is particularly noted that the energy system's energy intensity is improved in BaU from 0.136 ktoe/M€$_{2010}$ in 2015 to 0.091 ktoe/M€$_{2010}$ in 2035 and 0.081 ktoe/M€$_{2010}$ in 2050. In the more ambitious RES, EE and LPO scenarios, the energy intensity in 2050 amounts respectively to 0.077, 0.074 and 0.065 ktoe/M€$_{2010}$, while even in the LIG scenario, it amounts to 0.084 ktoe/M€$_{2010}$.

Limiting the role of solid fuels in electricity generation contributes to shrinking their share in the overall supply of primary energy in Greece. In 2035, the solid fuel share will amount to levels below 18% for all scenarios and below 10% for the RES, EE and LPO scenarios, while in 2050, the solid fuels' share drops to levels below 10% in BaU and down to 1.8% in LPO.

On the contrary, RES gain a gradually higher share in the overall supply of primary energy in Greece, mainly due to their utilization in electricity generation. Thus, in 2030, their share in the final consumption of primary energy in Greece amounts to levels of 19-27% in all scenarios (compared to 10% in 2015), and in 2050 this percentage rises to levels of 35% in the LPO scenario, 27% in the RES scenario, 25% in the EE scenario, 22% in the BaU scenario and 19% in the LIG scenario.

The share of oil products remains remarkably stable in all the scenarios and for the overall study period, and amounts to levels of 45% due to the utilization of oil products in the final consumption sectors; only by the end of the period and for the LPO scenario does it drop below

40%. Finally, the natural gas share also shows a slight rise, from 13.4% in 2015 to 20% in 2035 (except for the BAU scenario in which the share amounts to 23%), and to levels of 20-24% in 2050.

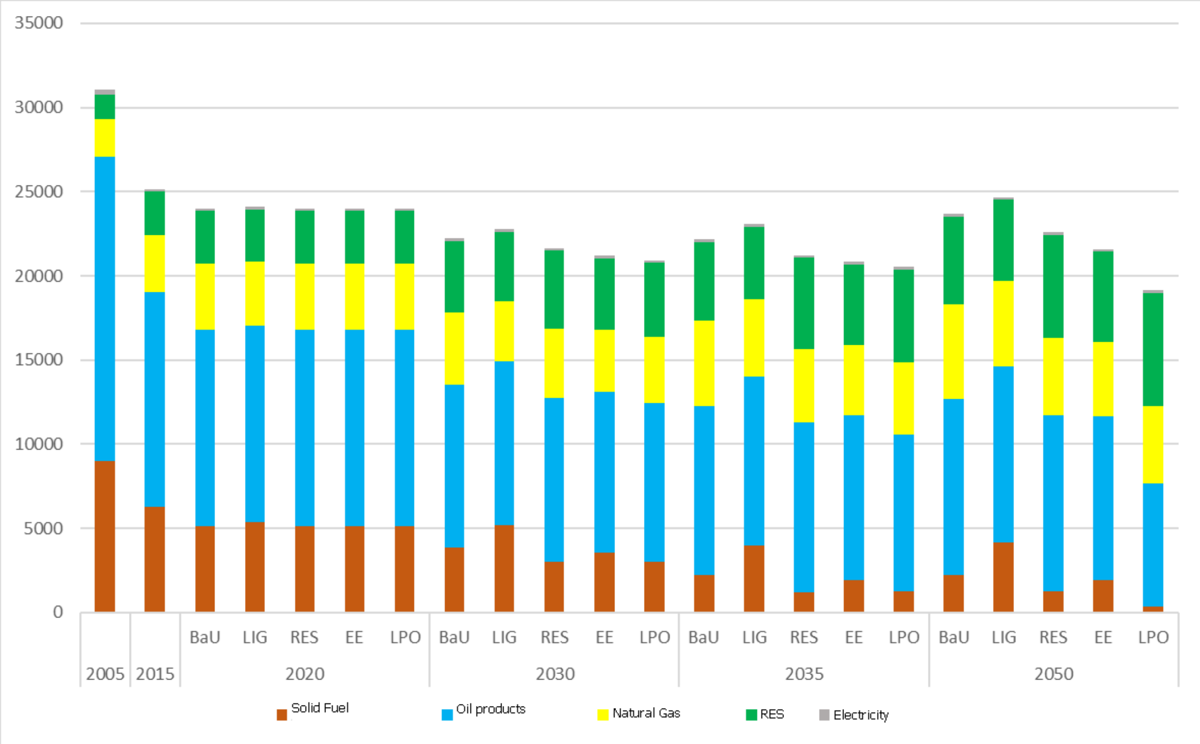


Figure 5-1: Evolution of the total primary energy supply to the Greek energy system based on the scenarios considered (in ktoe).

5.3. Final energy consumption

The evolution of demand in the final energy consumption sectors is a particularly critical factor for the overall performance of the energy system, in terms of both the RES penetration as well as the evolution of greenhouse gas emissions. **Figures 5-2** and **5-3** comparatively present the evolution of energy consumption in the final use sectors for the BaU, EE and LPO scenarios. The final energy demand in the LIG and RES scenarios presents very small differences from BaU, given that in fact they integrate the same energy saving policies.

Following the high decrease in the final energy consumption observed during the period 2008-2015 due to the economic crisis, the energy demand in BaU shows a slightly increasing trend, resulting from the relatively mild economic development scenario adopted. Nevertheless, consumption does not reach the 2005 levels even in 2050. Interestingly, the indicative target for the total final energy consumption amounting to 18.4 Mtoe in 2020, as prescribed by Directive 2012/27/EU, is achieved in all scenarios. BaU integrates energy saving measures, mainly in terms of the penetration of more efficient devices, air conditioners, vehicles, etc., where the necessary investments made by the final consumers are relatively small and therefore can be implemented while incomes are relatively limited, as is the case during the overall period examined. On the contrary, the rates for the renewal and radical energy upgrading of the building stock are relatively slow. The EE scenario integrates more ambitious energy saving policies, includes a significant penetration of electric vehicles in transportation as of 2030 (electricity consumption in land transport -passenger and freight- exceeds 6% of consumption in 2050, while this percentage reaches 10% in passenger land transport), higher rates of building energy upgrading, higher rates of efficient device penetration, etc. Finally, the LPO scenario integrates even stronger energy saving policies, mainly in terms of energy upgrading of the existing building stock, biofuel penetration in transportation and biomass in the industry, implementation of ambitious energy saving measures in the industry and the agricultural sector, etc. However, in all the scenarios, especially EE and LPO, the decrease in energy consumption due to energy saving measures is somewhat lessened due to the rebound effect. The energy upgrading of buildings, primarily, and, secondarily, the purchase of more efficient vehicles may contribute to the decrease in energy consumption but, due to the lower operational cost, they motivate consumers to improve heating conditions and increase the transportation load. Besides, for this reason, both the EE and the LPO scenarios do not greatly differ in terms of the final energy consumption from the other scenarios, which do not integrate very ambitious energy saving policies.

The transportation and residential sectors have the highest shares of energy consumption during the overall study period in the BaU scenario. In the energy saving scenarios (EE and LPO), towards the end of the period, the decrease in energy consumption in the residential sector is quite high due to the upgrading of the building stock, the penetration of more efficient devices, etc. On the contrary, the decrease is smaller in the transportation sector, given that the additional policies integrated in these scenarios mainly focus on fuel differentiation (biofuel, electrification) and not so much on fleet modernization and the utilization of the transportation means, which are generally implemented in all scenarios. As far as the industry is concerned, the energy consumption in BaU increases despite the integration of energy saving policies due to the assumed economic recovery. In the EE and LPO scenarios, this increase is quite limited, especially towards the end of the period, by adopting more ambitious energy saving policies. Finally, the tertiary sector sees an increase in consumption in all the scenarios examined as a result of the economic recovery assumed as part of this analysis.

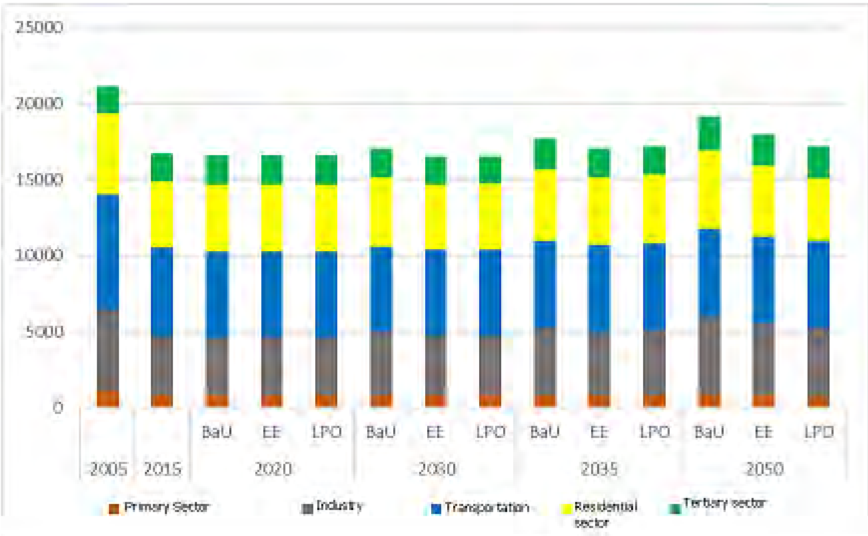


Figure 5-2: Evolution of the final energy consumption per sector in the BaU, EE and LPO scenarios (in ktoe).

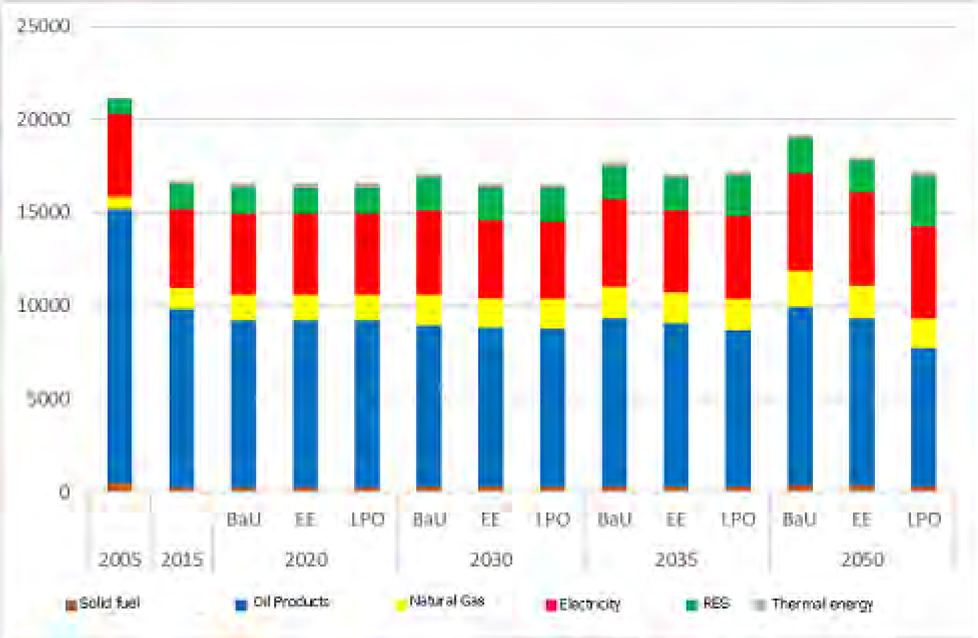


Figure 5-3: Evolution of the final energy consumption per fuel in the BaU, EE and LPO scenarios (in ktoe).

Oil products still have a dominant role in the final consumption sectors and their share is in the order of 50% in all the scenarios and for the total period examined (only during the time period until 2050 and in the LPO scenario do they drop down to 43%). The natural gas share increases and reaches the order of 10% in 2035. The electricity share also shows increasing trends. However, the fact that many consumers turn to electricity both in the building and transportation sectors according to the EE and LPO scenarios, in combination with the resulting increase in demand, are mitigated by the penetration in the system of more efficient electrical appliances, air conditioning units with a higher efficiency rate, etc. Thus, the final electricity demand reaches 54.8 TWh in BaU and 51 TWh in EE and LPO in 2035, and 61.3 TWh in BaU, 58.2 TWh in EE and 57.9 TWh in LPO in 2050.

The RES share in the final energy consumption actually more than triples during the period 2005-2035 and remains stable afterwards, except in the LPO scenario where it further increases. The significant increase in the electricity use in the buildings sector is offset by the decrease in the traditional biomass share used for residence heating. Moreover, a conservative target for the stabilization of biofuel use at the 2030 levels was adopted for the period after 2030, except for the LPO scenario which adopts more ambitious targets.

Figure 5-4 shows the evolution of the RES share in the gross final energy consumption. Although the target set for Greece for 2020 seems to be achieved in all scenarios, the 27% target set as a total for the EU for 2030 (and not at a national level) can be achieved by Greece in the RES, EE and LPO scenarios. Thus, if such a national target is adopted, it will take major efforts to be achieved, either by implementing significant investments in RES (as in the RES scenario), or by combining RES investments with the implementation of major energy saving measures in the final consumption sectors, as in the EE and LPO scenarios. In fact, given that the indicative targets for the Member States included in the European Commission's Staff Working Document set RES penetration levels for Greece in the gross final energy consumption in 2030 that range between 26% and 34%, adopting a target in the order of 30% or more will require significant efforts to increase RES penetration and energy savings.

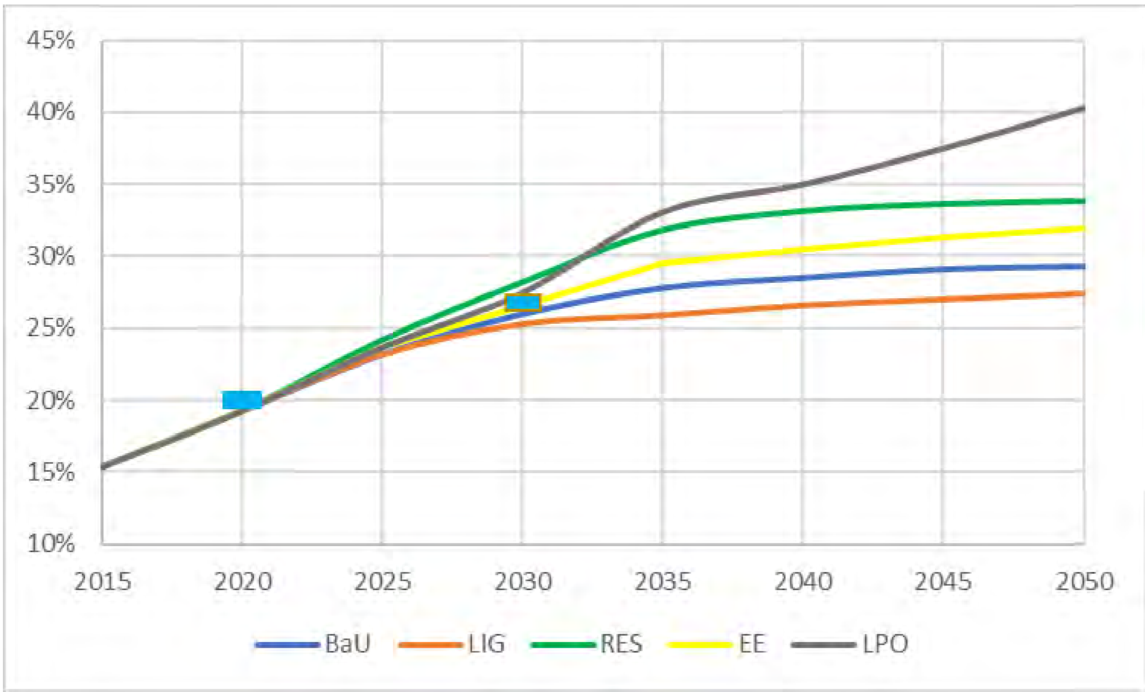


Figure 5-4: Evolution of the RES share in the gross final energy consumption based on the scenarios considered. It also includes the target for Greece for 2020 and the overall target for EU for 2030.

5.4. Electricity generation sector

The scenarios examined have significant variations regarding the electricity generation sector during the reference period, which are mainly due to the following:

- The decisions taken on retiring, upgrading and constructing new lignite units.
- The gradual decrease in the CO_2 emission allowance prices as a result of more ambitious policies in order to address climate change and modifications of the EU Emissions Trading System (EU ETS). It is still noted that in this study, the allowance prices adopted for the period after 2035 and especially after 2040 are conservative compared to estimates by other bodies, including the EU.
- The foreseen continuation of the decrease in the installation costs of photovoltaic systems both for large facilities and for residential-scale projects, supported both by the "photovoltaic systems on rooftops" mechanism and "net metering".
- The gradual but relatively mild increase in natural gas prices compared to the very low prices in 2015.

Figure 5-5 presents the development of the electricity generation sector in Greece per generation technology. All scenarios show a decrease in lignite electricity generation, which in 2030 ranges between 10.4 (RES and LPO scenarios) and 19.7 (LIG scenario) TWh, in 2035 between 3.5 (RES and LPO scenarios) and 15.2 (LIG scenario) TWh, while in 2050 it drops down to zero in the LPO scenario, ranges between 3.4 and 8 TWh in the RES, EE and BaU scenarios, and only in the LIG scenario amounts to 15.7 TWh. In the scenarios promoting environmentally-friendly practices (RES, EE, LPO), the lignite electricity generation is limited to 18-25% of the net production in 2030, to 6-12% in 2035 and to 0-11% in 2050. The role of oil units is also limited in the system, since following the system's connection with the Cyclades, Crete and most islands of the Eastern Aegean Sea and the Dodecanese by 2030, the majority of the Greek islands will thereafter be supplied by the interconnected system. On the contrary, natural gas maintains a significant share in the electricity system during the overall study period, since after 2030 it becomes the main conventional system technology. The natural gas units' share in the electricity generation mixture for the various scenarios ranges between 26-33% in 2035 and 22-32% in 2050.

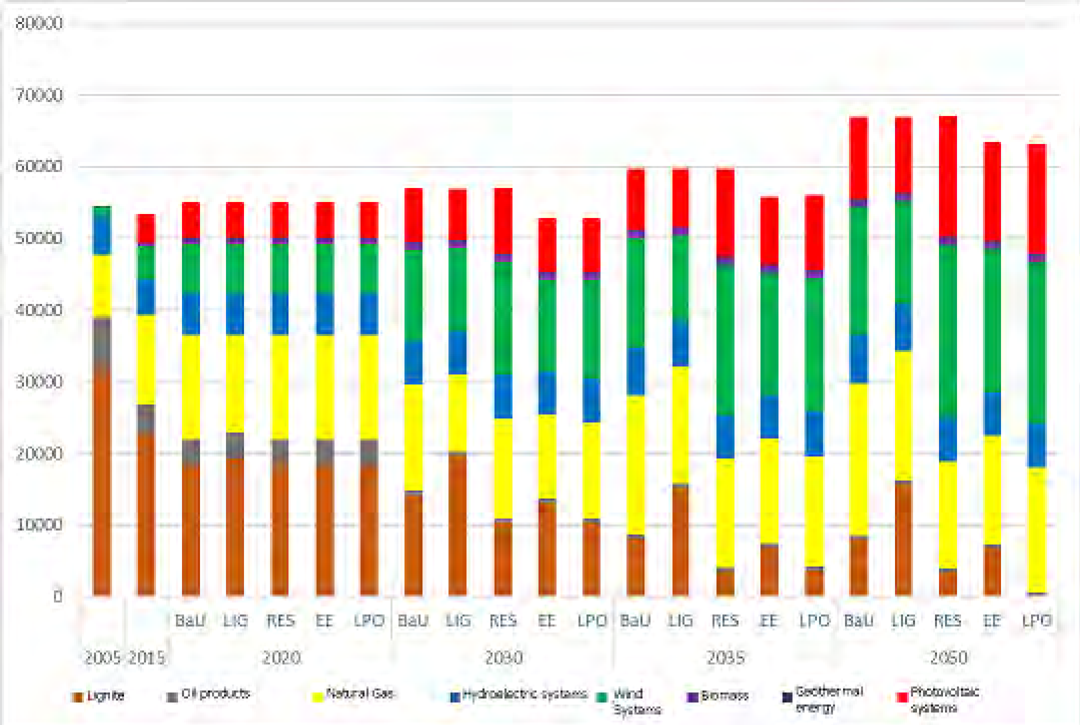


Figure 5-5: Evolution of the electricity generation in the Greek electricity system per technology (GWh).

In all the scenarios, a significant part of electricity generation is covered by RES technologies, particularly wind and photovoltaic systems. **Figure 5-6** shows the evolution of the generation share from RES in the gross final electricity consumption. In 2035, the RES share is estimated at 45% in the LIG scenario, 51% in BaU, 58% in EE, 62.9% in LPO and 66% in RES. In 2050, respectively, these shares are estimated at 47% in the LIG scenario, 54% in BaU, 63% in EE, 69% in LPO and 70% in RES. It is also noted that, mainly as a result of the policies applied in the last few years which have created an uncertain investment climate for RES, the achievement of the a 40% RES penetration target in the gross final electricity energy by 2020 is no longer realistic.

As regards the structuring of the Greek electricity system's installed power capacity (**Figure 5-7**), the installed power capacity of conventional units is significantly limited while, on the other hand, the installed power capacity of RES technologies increases, primarily as regards wind and photovoltaic systems and secondarily hydroelectric systems and other RES. In all the scenarios and for the overall study period, there is no new natural gas unit installed (but the combined cycle units constructed during the period 2005-2015 are still in operation), while the power of oil units is limited, since island areas are gradually connected to the interconnected system in Greece. The total installed power capacity of lignite units is limited in all scenarios due to closing down old units, but some scenarios include new lignite units (Ptolemais V and Meliti II).

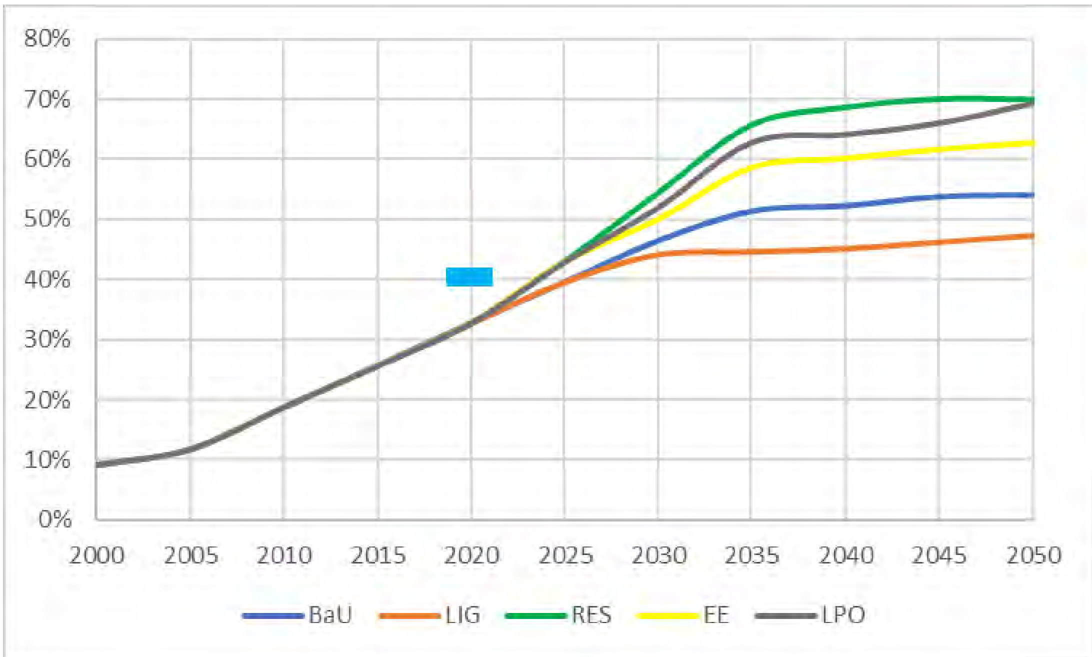


Figure 5-6: RES share in the gross final electricity consumption. The target set for Greece for 2020 is also noted.

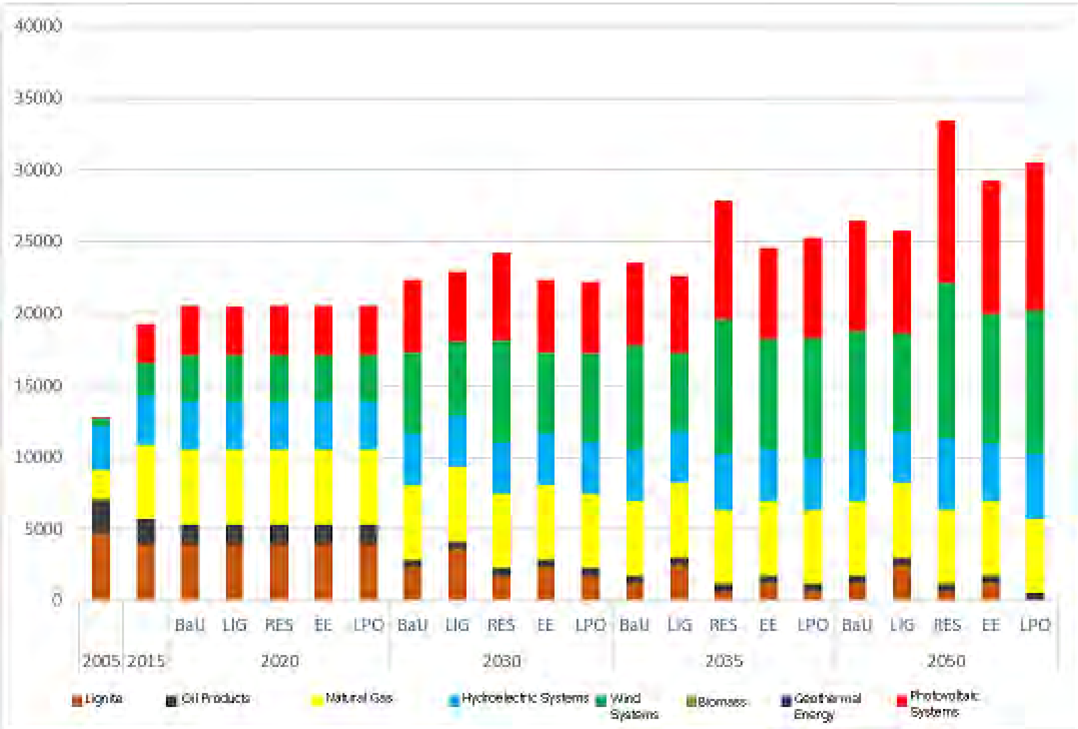


Figure 5-7: Evolution of the installed power capacity for production units in the Greek energy system per technology (in MW).

An important aspect in all scenarios are the newly installed RES facilities. **Figures 5-8** and **5-9** present the evolution of the installed power capacity for wind and photovoltaic systems in the electricity system. As far as wind systems are concerned, the installed power capacity in 2035 amounts to 5.3 GW in LIG, 7GW in BaU, 5.7 GW in EE, 8.2 GW in LPO and 9.2 GW in RES. In 2050, their power amounts to 6.7 GW in LIG, 8.1 GW in BaU, 8.8 GW in EE, 9.8 GW in LPO and 10.6 GW in RES. The installation of photovoltaic systems has even more dynamic characteristics, particularly after 2030. Thus, the installed power capacity in 2035 ranges between 5.3-7 GW in all scenarios except the RES scenario where it amounts to 8.2 GW, while in 2050 it amounts to 7.1 GW in LIG, 7.7 GW in BaU, 9.3 GW in EE, 10.2 GW in LPO and 11.3 GW in RES. As far as hydroelectric systems are concerned, all the scenarios include the installation of 191 MW, as well as the conversion of existing hydroelectric units in pumping units. All scenarios foresee the installation of new pumping hydroelectric systems as well, which have only a small contribution on electricity generation, since they function as storage systems of the energy generated by wind and photovoltaic systems. Finally, all scenarios include some small geothermal and biomass facilities.

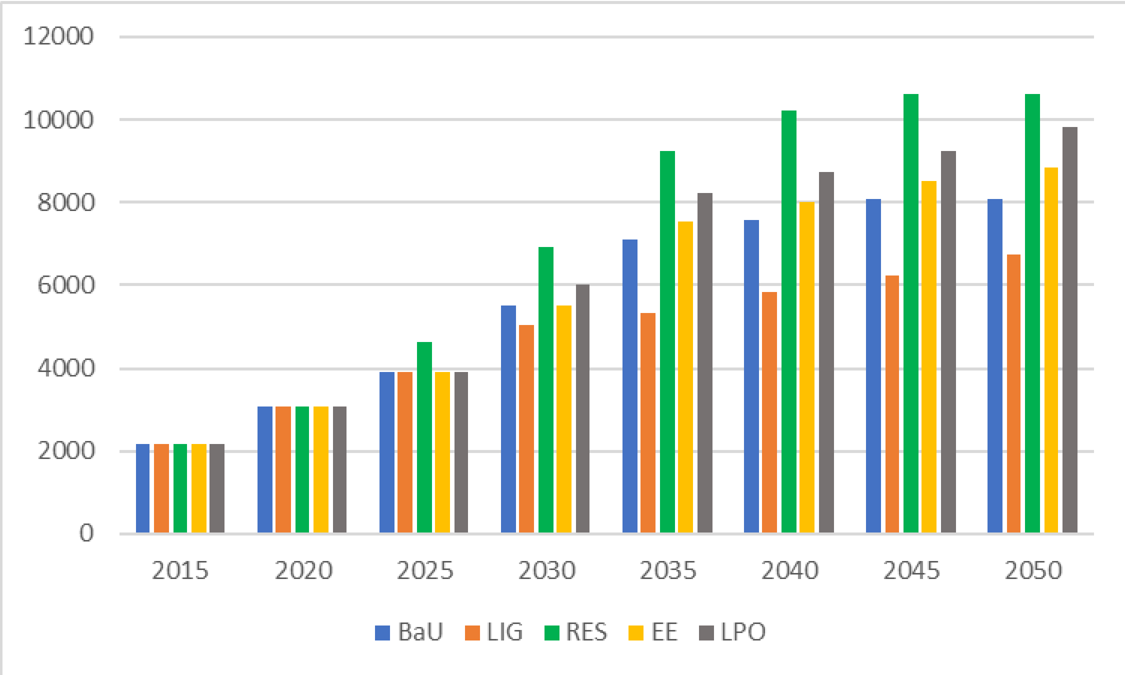


Figure 5-8: Evolution of the installed power capacity for wind systems in the Greek energy system (MW).

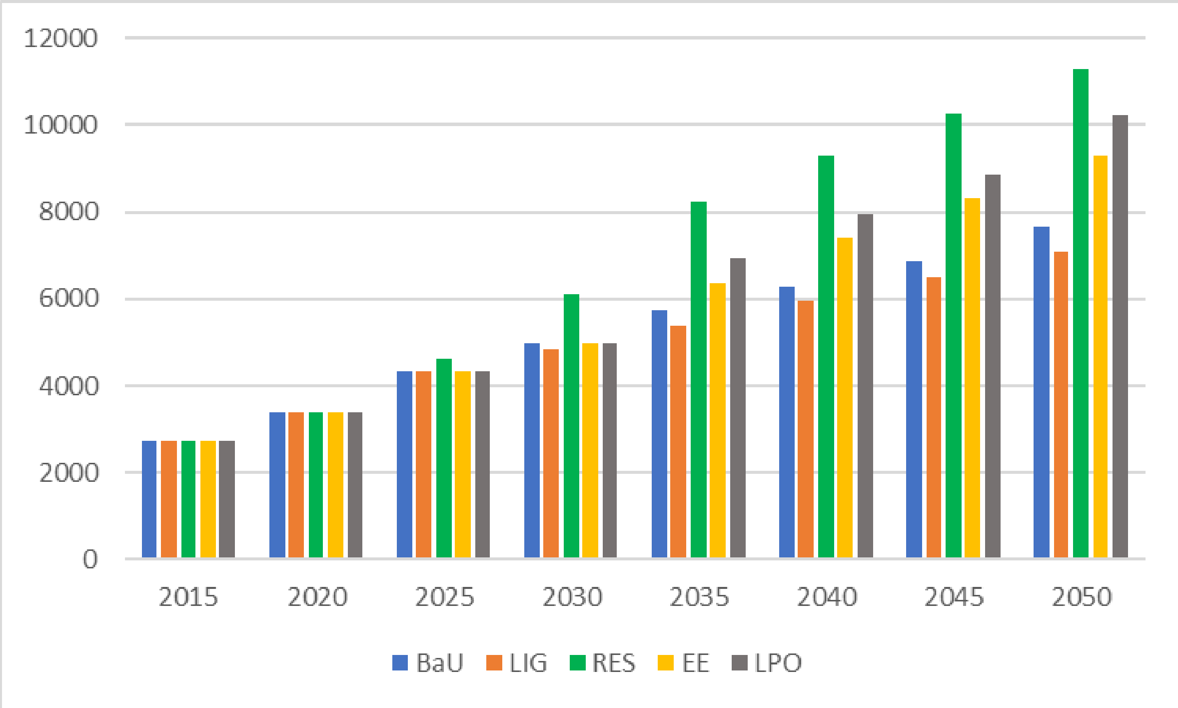


Figure 5-9: Evolution of the installed power capacity for photovoltaic systems in the Greek energy system (MW).

The higher penetration of wind and photovoltaic technologies in the electricity system creates additional energy storage needs, due to the intermittent nature of these technologies. In the scenarios considered, this storage is carried out by pumped storage, by utilizing the existing pumping systems, converting existing couples of PPC hydroelectric power stations into pumped storage systems and, if so required, by constructing new pumping hydroelectric power projects. The additional requirements for energy storage were estimated in the scenarios examined and are presented in **Figure 5-10**. These requirements during the period until 2050 amount to 1450 MW in LIG, 1950 MW in BaU, 2500 MW in EE, 3050 MW in LPO and 3500 MW in RES.

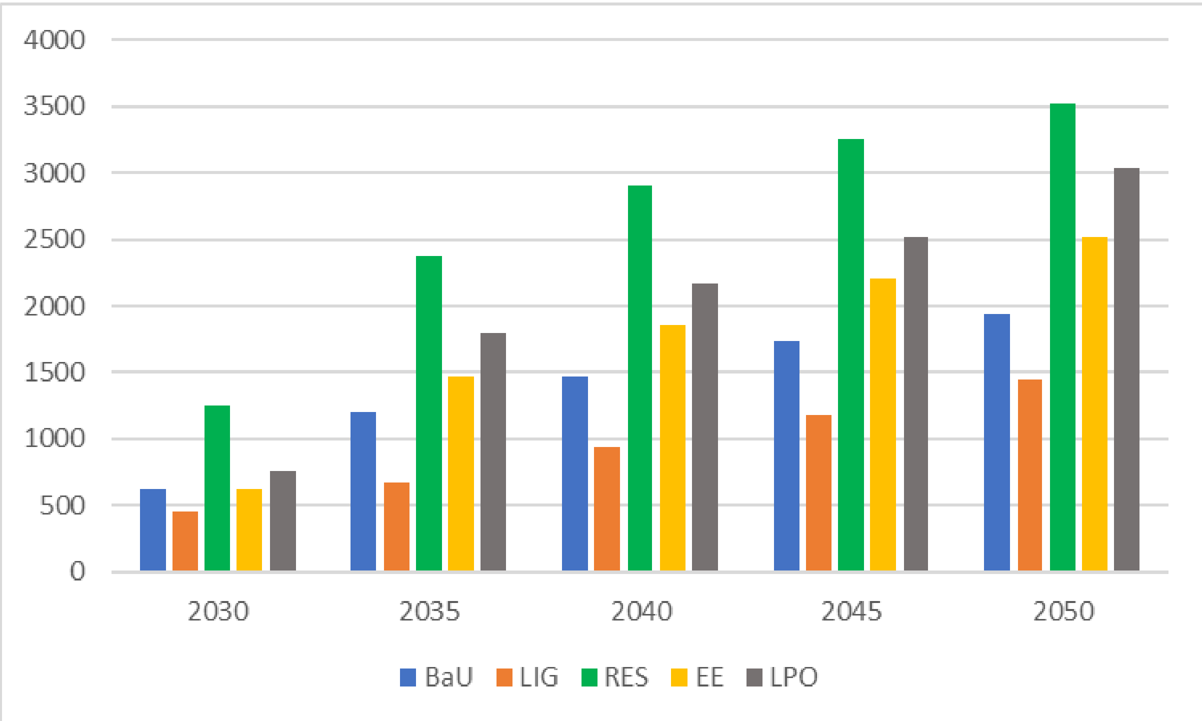


Figure 5-10: Additional energy storage requirements in the electricity system through pumped storage (MW).

5.5. Energy investments and electricity cost

The analysis presented in the previous section makes it clear that all the scenarios examined foresee significant investments in the electricity generation sector. **Table 5-2** presents the cumulative investments foreseen during the period 2015-2050 per scenario. These include investments:

- on new electricity generation units, either with conventional or renewable sources, including residential photovoltaic systems;
- on RES technologies after their life cycle expires in order to replace their equipment;
- on upgradings of old lignite units, in the scenarios where such an option is adopted, so as to comply with the emission limits set by the European environmental legislation;
- on pumped storage systems in order to ensure the security of the electricity system from the large-scale penetration of the intermittent RES.

The cost assumptions adopted in Chapter 4 were used for the calculations.

It is obvious that the BaU and LIG scenarios are the less demanding ones in terms of capital, since for the overall period 2015-2050 they require a commitment of 23-24 bil. €. On the contrary, the implementation of the RES scenario requires investments in the order of 33 bil. €. The energy saving scenarios (EE and LPO) come up in between and the investment requirements are calculated at 28-30 bil. €. In all scenarios, without exceptions, the larger part of investments is used for the development of wind and photovoltaic systems, while the amounts that need to be invested on the construction of electricity storage systems through pumped storage are also significant. As far as conventional electricity generation is concerned, the LIG scenario prescribes significant investments for the development of two new lignite units and the upgrading of some older ones.

Table 5-2: Total investments required on the electricity system based on the forecasts of each scenario during the period 2015-2050 (in mil. $€_{2015}$).

Technologies	BaU	LIG	RES	EE	LPO
RES	*22634*	*19873*	*33004*	*26269*	*29689*
Wind systems	12134	10298	15563	13133	14483
Photovoltaic industrial systems	5690	5147	9202	7190	8072
(Residential) photovoltaic systems	2524	2515	2524	2524	2524
Hydroelectric systems (including new pumping systems)	438	438	3734	1441	2627
Geothermal energy	32	32	32	32	32
Biomass	476	476	476	476	476
Conversion of hydroelectric systems into pumping systems	1340	968	1472	1472	1472
Conventional systems	*1664*	*3027*	*275*	*1664*	*275*
Lignite systems	1389	2431	0	1389	0
Natural gas	0	0	0	0	0
Oil	0	0	0	0	0
Upgradings	275	596	275	275	275
Total investments	***24298***	***22902***	***33280***	***27935***	***29964***

Despite the fact that environmental-friendly scenarios (RES, EE, LPO) require higher investments, they still do not add to the cost of electricity generation, given that they entail significantly lower expenditures for purchasing fuels and emission allowances. **Figure 5-11** presents the evolution of the levelized cost of electricity (LCOE) per scenario, which is calculated based on the electricity generation mix and taking into account, per technology, the investment cost, the stable and variable operational cost, the fuel cost and the emission allowances cost. All scenarios show similar results, namely a stabilization of the electricity cost after 2025 in the order of 100-105 €/MWh. During the period 2015-2025, there is an increase in the electricity generation cost mainly due to the assumed increase in natural gas prices as well as in emission allowance prices. In fact, in certain scenarios, the increase is relatively higher, mainly due to investments made either in lignite units or in RES, as well as due to the lower load factor of natural gas units in some of these. Towards the end of the period examined (after 2040), it seems that the two scenarios combining RES and energy saving policies show a slightly lower cost which is attributed to the fact that they use RES (therefore, they reduce the emission allowance costs), but at the same time their penetration does not reach the RES scenario levels and therefore lower investments on pumped storage are required. The trends concerning the cost reduction, evident in all scenarios as of 2040, also relate to the replacement of RES units (wind and photovoltaic systems) that were installed in the beginning of the period examined and whose life cycle will be over by then, which now takes place at a lower installation cost, especially in case of photovoltaic systems.

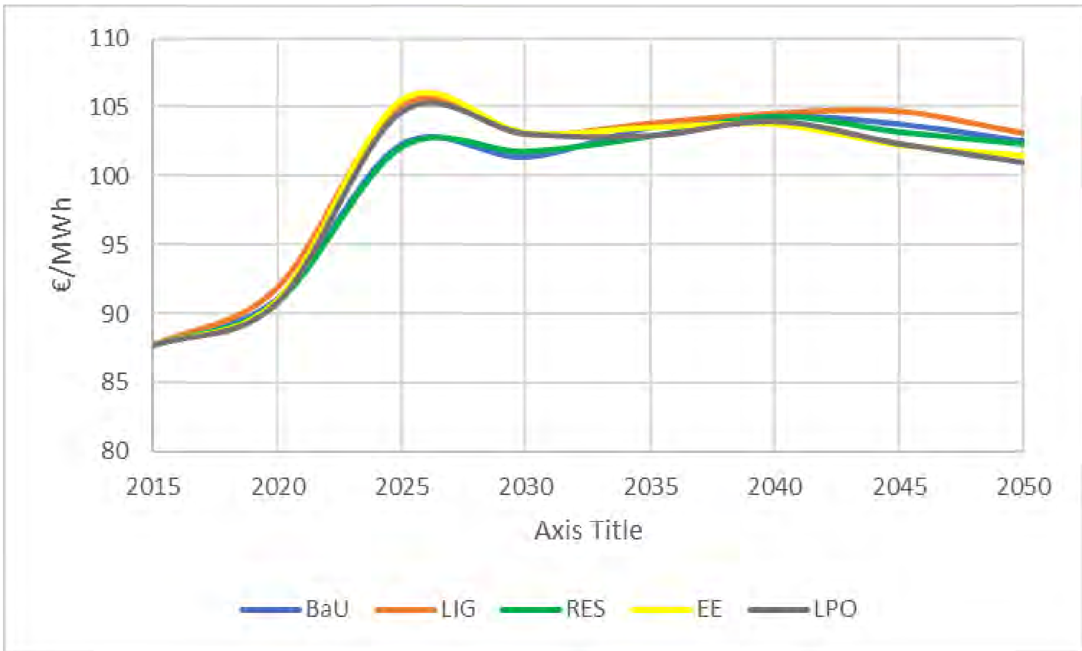


Figure 5-11: Evolution of the levelized cost of electricity in the scenarios examined (in €/MWh).

The differences in the electricity generation cost prices between the 5 scenarios is even more apparent for the emission allowance prices according to the European Commission's estimate, which in its most recently published scenario[41] estimates the allowance prices in the order of 15 €/t CO_2 in 2020, 22.5 €/t CO_2 in 2025, 33.5 €/t CO_2 in 2030, 42 €/t CO_2 in 2035, 50 €/t CO_2 in 2040, 69 €/t CO_2 in 2045 and 88 €/t CO_2 in 2050.

Figure 5-12 presents the evolution of the levelized cost of electricity in all the scenarios examined, based on the aforementioned emission allowance prices.It is clear that the use of fossil fuels, particularly lignite, in the electricity system actually becomes prohibitive. It is noted that by the end of the period examined, the levelized cost of electricity in the LPO scenario is by 9% and 12.1% lower than in the BaU and LIG scenarios respectively, while the cost in the RES and EE scenarios is by 8.8% and 7.2% lower than in the LIG scenario. The levelized cost of electricity in LPO for 2030 is already by 1.5 €/MWh lower than in the LIG scenario, but this difference rises

[41] EU Reference Scenario 2016: Energy, transport and GHG emissions Trends to 2050

significantly in the next few years and amounts to 3.6 €/MWh in 2035, 4.9 €/MWh in 2040 and almost 15 €/MWh in 2050. It is interesting that the levelized cost of electricity in the Lignite Phase Out Scenario (LPO) shows a dropping trend towards the end of the period examined, mainly due to the fact that the extra charge for purchasing emission allowances for this scenario is very small compared to the others, since lignite electricity generation is significantly reduced and even eliminated in 2050.

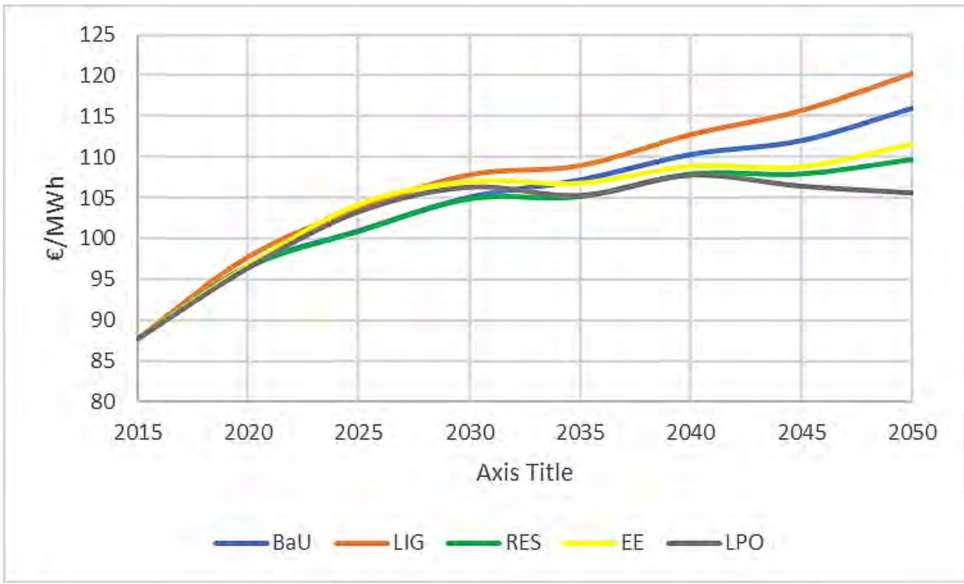


Figure 5-12: Evolution of the levelized cost of electricity in the scenarios examined, by adopting the emission allowance prices presented in the European Commission's Reference Scenario 2016 (in €/MWh).

5.6. Greenhouse gas emissions

Figure 5-13 summarizes the evolution of the total energy system greenhouse gas emissions (GHG), while **Figure 5-14** focuses on the evolution of the GHG emissions in the electricity generation sector. In detail, the results are also presented on **Table 5-3**.

It is obvious that the GHG emissions from the energy sector show a significant drop in all scenarios. From 106.4 Mt CO_2eq emitted in 2005, they are expected to drop down to 57-68 Mt CO_2eq in 2030 and to 38-68 Mt CO_2eq in 2050. By adopting one of the RES, EE and LPO scenarios, the energy system emissions will closely approach or fall below 50 Mt CO_2eq already in 2035, while the implementation of the LPO scenario in particular will lead to emissions of 47.8 Mt CO_2eq in 2035 and to 38.6 Mt CO_2eq in 2050, 64% lower than the 2005 levels. On the contrary, the continued focus on lignite electricity generation, as expressed through the LIG scenario, leads to GHG emissions in the order of 64.7 Mt CO_2eq in 2035 and of 68.2 Mt CO_2eq in 2050 (only 36% lower than the 2005 levels).

Table 5-3: Evolution of greenhouse gas emissions in the Greek energy system and specifically in the electricity generation sector for the period 2000-2050 for various scenarios examined (in kt CO2eq).

Scenarios	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Total energy sector											
BaU	96742	106443	92765	78447	71923	66872	62246	56558	57893	58319	59280
LIG	96742	106443	92765	78447	72889	69916	67830	64706	66490	67364	68228
RES	96742	106443	92765	78447	71923	64006	57573	49606	50102	50561	51540
EE	96742	106443	92765	78447	71923	63537	59145	52257	52882	52945	53024

LPO	96742	106443	92765	78447	71923	62201	56422	47777	46235	42572	38630
Electricity generation sector											
BaU	51719	54507	48487	38493	33010	28564	23612	17037	17395	17188	17542
LIG	51719	54507	48487	38493	33934	31465	28968	24893	25690	25919	26176
RES	51719	54507	48487	38493	33010	25804	19078	10252	9778	9599	9977
EE	51719	54507	48487	38493	33010	25618	21082	13655	13717	13699	13716
LPO	51719	54507	48487	38493	33010	24356	18863	10493	10541	8676	6524

As far as coal intensity in the Greek economy is concerned, this drops from 0.50 kt CO_2eq/mil. €$_{2010}$ in 2000 to 0.19 per kt CO_2eq/mil. €$_{2010}$ in 2035 and 0.13 kt CO_2eq/mil. €$_{2010}$ in 2050, based on the estimates in the LPO scenario. On the contrary, in 2050, this improvement is limited to 0.20 per kt CO_2eq/mil. €$_{2010}$ according to BaU and to 0.23 per kt CO_2eq/mil. €$_{2010}$ according to the LIG scenario. In the scenarios that do not include major energy saving measures, the potential to decrease emissions is slightly reversed after 2035, since final demand recovers to some extent, the investments on RES slow down in some of these (BaU, LIG), while the further decrease in emissions will require additional policies in the final consumption sectors. On the contrary, in LPO, the decrease in emissions continues after 2035, mainly due to to the ambitious energy saving policies applied in the final consumption sectors, the further RES penetration and, mostly, due to the decrease in lignite electricity generation.

The differences in emissions are even more impressive in the electricity generation sector, highlighting this sector's decisive role in the development of a low carbon emission economy. The total emissions from this sector drop down from 54.5 Mt CO_2eq in 2005 to a range of 10.5-25 Mt CO_2eq in 2035 and of 6.5-26.2 Mt CO_2eq in 2050. In 2030, both the RES and LPO scenarios lead to emissions below 20 Mt CO_2eq, while in 2050, these two scenarios lead to emissions below 10 Mt CO_2eq, and the EE scenario to emissions lower than 14 Mt CO_2eq. On the contrary, the LIG scenario leads to emissions over 25 Mt CO_2eq during the overall study period.

Therefore, the combined promotion of RES and energy savings policies, parallel to the phasing out of lignite, pushes the Greek energy system in a direction that is characterized not only by a lower levelized cost of electricity but also by significant benefits for the protection of the environment.

Notably, the average emissions factor for the electricity system decreases from 1060 kg CO_2eq/MWh in 2000 to approximately 400 kg CO_2eq/MWh in 2030, 285 kg CO_2eq/MWh in 2035 and 260 kg CO_2eq/MWh in 2050 according to BaU. The LIG scenario leads to approximately 420 kg CO_2eq/MWh in 2035 and 390 kg CO_2eq/MWh in 2050. On the contrary, the adoption of the Lignite Phase Out Scenario (LPO) leads to a more than double decrease in the average system factor compared to BaU and LIG, amounting to 190 kg CO_2eq/MWh in 2035. The difference between LPO and LIG almost quadruples in 2050, since the Lignite Phase Out Scenario leads to an emissions factor of 100 kg CO_2eq/MWh.

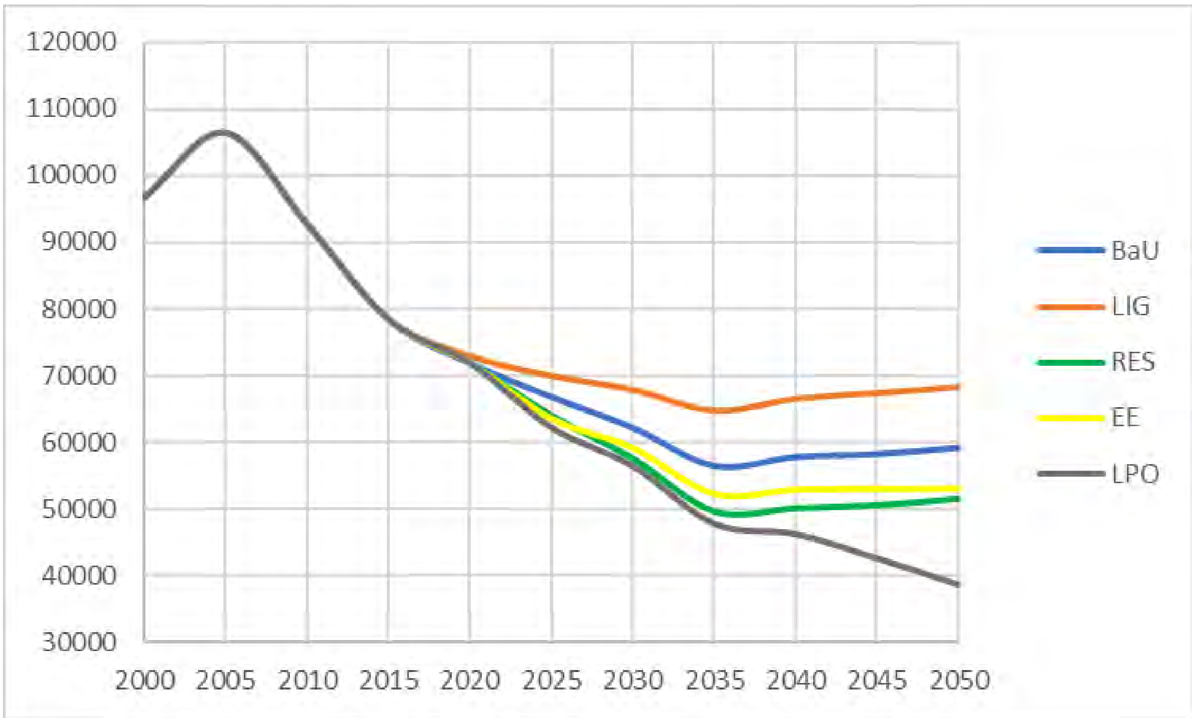


Figure 5-13: Evolution of greenhouse gas emissions from the Greek energy sector per policy scenario until 2050 (in kt CO2eq).

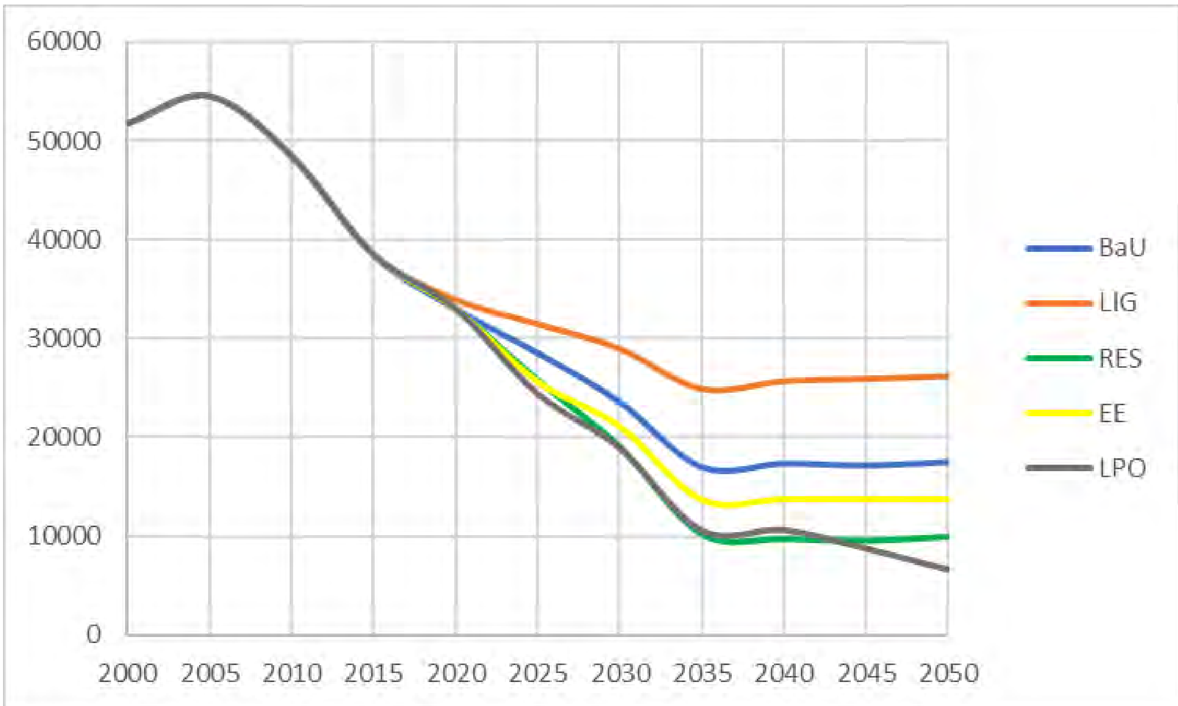


Figure 5-14: Evolution of greenhouse gas emissions from the electricity generation sector per policy scenario until 2050 (in kt CO2eq).

Finally, **Table 5-4** presents the evolution of the GHG emissions from the energy sector during the period 2005-2050, differentiated between the sectors included in the EU Emissions Trading System (EU ETS) and to those outside the system. It should be noted that the calculations of the emissions outside EU ETS do not include emissions from the other sectors (industrial processes, waste, etc.) where the possibilities to decrease emissions are more limited. Consequently, it is necessary to decrease emissions from the energy sector beyond the targets set by EU in order to achieve the overall decrease targets.

First, it is noted that the emissions of the outside the EU ETS sectors in 2030 range between -32% and -35% in all scenarios, which demonstrates the low ambition of its initial target (-16%) for Greece set as part of the relevant Regulation of the European Parliament and the Council (Effort Sharing Regulation)4. Nevertheless, a complete assessment of this target's feasibility will have to include the evolution of the emissions outside the energy sector. In the BaU, LIG and RES scenarios, we note a reversal in the emission decrease trend after 2030, which leads to an increase in GHG emissions in 2050 compared to 2030. On the contrary, in the two scenarios adopting ambitious energy saving policies (EE and LPO) and particularly in the Lignite Phase Out Scenario, the progress achieved by 2030 continues, leading to a 46% decrease in emissions in 2050 compared to 2005, mostly due to the measures adopted in the building sector.

In the sectors included in the EU ETS, it is noted that the Expansion of Lignite Use Scenario (LIG) fails to meet the European emissions' decrease target by 43% compared to the 2005 levels, while all the rest achieve it in principle. A complete assessment of the target achievement will also have to take into account emissions outside the energy sector which fall under the EU ETS. The decrease approaches 54% and 55% in the Increased RES Penetration (RES) and Lignite Phase Out (LPO) scenarios respectively, while LPO achieves a 75% decrease in 2050 compared to 2005.

Table 5-4: Evolution of greenhouse gas emissions from the energy sector during the period 2005-2050, differentiated between the fields included in the trading system or not, for all the scenarios examined (in kt CO2eq).

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	Change 2030/ 2005	Change 2050/ 2005
BaU												
EU ETS	65125	56872	48214	43091	38985	34432	28088	28674	28732	29385	-47%	-55%
Outside EU ETS	41317	35893	30233	28832	27887	27814	28469	29219	29587	29894	-33%	-28%
LIG												
EU ETS	65125	56872	48214	44013	41881	39774	35919	36943	37435	37992	-39%	-42%
Outside EU ETS	41317	35893	30233	28876	28035	28056	28787	29547	29929	30236	-32%	-27%
RES												
EU ETS	65125	56872	48214	43091	36234	29916	21336	21095	21182	21860	-54%	-66%
Outside EU ETS	41317	35893	30233	28832	27772	27657	28271	29007	29378	29680	-33%	-28%
EE												
EU ETS	65125	56872	48214	43091	36054	31916	24727	25019	25265	25584	-51%	-61%
Outside EU ETS	41317	35893	30233	28832	27482	27229	27530	27863	27680	27440	-34%	-34%
LPO												
EU ETS	65125	56872	48214	43091	34794	29485	21333	20754	18659	16157	-55%	-75%
Outside EU ETS	41317	35893	30233	28832	27407	26937	26444	25480	23913	22473	-35%	-46%

5.7. Comparative cost analysis for upgrading existing or constructing new lignite units

A main issue for long-term energy planning, on which diametrically opposite views are often expressed, is the economic feasibility of new lignite units (e.g. Ptolemais V, Meliti II), compared to the upgrading of existing units or the use of RES systems, in combination with pumped storage or even the use of combined cycle natural gas units, in order to meet the shares corresponding to conventional electricity generation. The defining factor in order to answer this question is the evolution of emission allowance prices and of those for natural gas. The Amyntaio SEPS was selected as a lignite SEPS to be compared to Ptolemais V due to their comparable power capacity. In order to calculate its upgrading cost, it was assumed that the SEPS will be integrated as a new unit in the system after using up the 17,500 hours of operation and following all the necessary upgradings so that the SEPS can comply with the emission limits of the new BREF for new units.

Figure 5-15 presents the comparative evolution of the levelized cost of electricity for various levels of emission allowance prices: (a) for the Ptolemais V unit, (b) for the Amyntaio lignite station, where it is assumed that there will be a radical environmental and operational upgrading, (c) for the combined cycle natural gas unit for low (2015 level) and relatively higher (as expected to evolve during the period until 2040) natural gas prices. The same graph also presents the range of the levelized cost of RES technologies, which was developed based on wind and photovoltaic system technologies, including (for the estimation of the upper range limit) the cost of the necessary pumped storage. The remaining assumptions used in the economic analysis, including the lignite cost, are the same as presented in Chapter 4.

It is obvious that for allowance prices up to 30 €/t CO_2, the Amyntaio station upgrading solution leads to a lower electricity cost compared to the construction of the new Ptolemais V unit.

In case the natural gas prices in the market are in the order of 7.5 €/GJ, lignite electricity generation (either through the new Ptolemais V unit or through the upgrading of the Amyntaio station) is economically more efficient than the natural gas units for allowance prices up to 25 €/t CO_2. For natural gas prices in the order of 12.7 €/GJ, the Ptolemais V unit is economically more beneficial compared to the natural gas units for allowance prices up to 70 €/t CO_2 and so is the Amyntaio unit for allowance prices up to 60 €/t CO_2. In general, for emission allowance prices over 30 €/t CO_2, the solution of the Ptolemais V unit is preferable only in case of relatively high natural gas prices in the market. On the contrary, for natural gas prices up to 25% higher than the current ones, and for allowance prices over 30 €/t CO_2, the solution of the combined cycle natural gas units is more economical. Therefore, the Ptolemais V unit performs better compared to other conventional solutions only in case the emission allowance price exceeds 30 €/t CO_2 and natural gas prices in the market are relatively high. If the allowance price is a lot higher than 30 €/t CO_2, the Ptolemais V unit solution is still economically more attractive only in case of relatively high natural gas prices.

However, in case the allowance prices exceed 30 €/t CO_2 (so that Ptolemais V becomes a more economical solution than the upgraded Amyntaio SEPS) and the natural gas prices in the market are relatively high (so that Ptolemais V becomes a more economical solution than the natural gas units), the levelized cost of electricity from RES is lower than that for Ptolemais V. Especially for emission allowance prices in the order of 50-55 €/t CO_2 lignite electricity generation becomes more expensive than RES even if their cost includes pumped storage, while for an allowance cost in the order of 25 €/t CO_2, lignite electricity generation becomes more expensive than generation from wind farms.

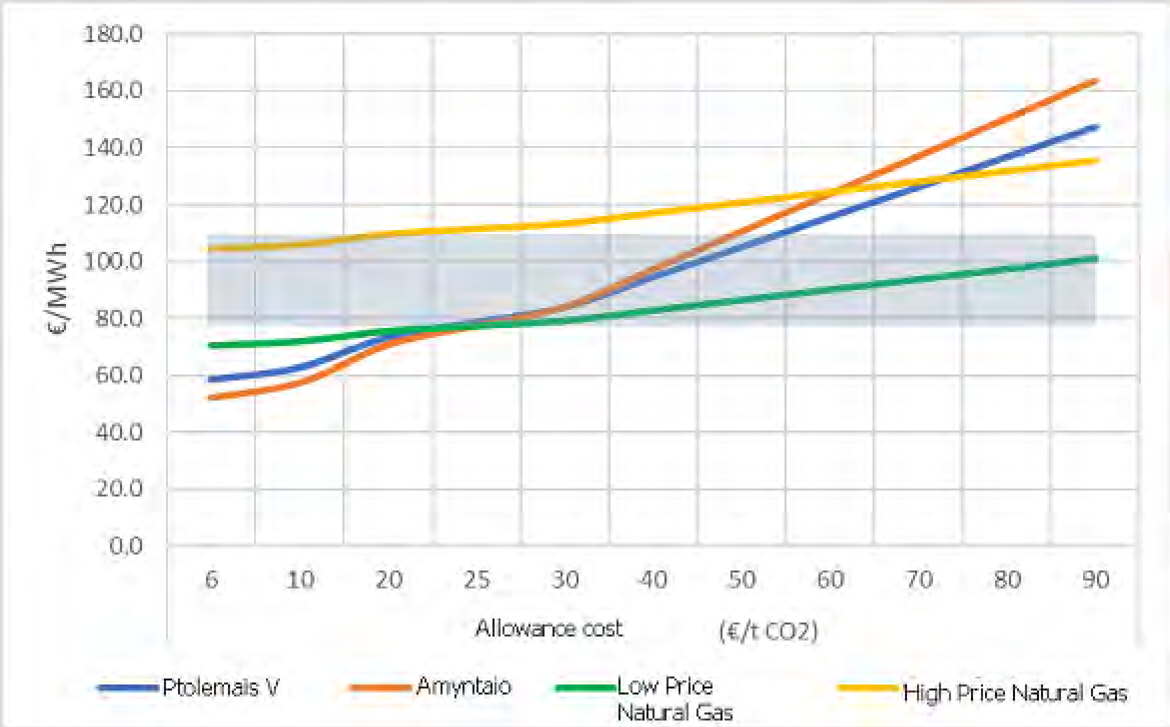


Figure 5-15: Comparison between the levelized cost of electricity for the Ptolemais V lignite unit, the upgraded Amyntaio lignite station and a combined cycle unit using natural gas as fuel, for various levels of emission allowance prices (in €/MWh). The grey area represents the range of the levelized cost of energy from RES (wind and photovoltaic systems), including the cost of pumped storage in the upper limit.

6. CONCLUDING REMARKS

NO SCENARIO ACHIEVES A 40% RES TARGET IN ELECTRICITY GENERATION BY 2020

As part of this study, 5 alternative scenarios were developed and assessed for the future evolution of the Greek energy system during the time period until 2050. The analysis was carried out using the ENPEP/Balance hybrid model, a partial equilibrium simulating model . Even if all energy sector systems are examined, emphasis is given to the analysis of the impact from potential options and developments in electricity generation.

Main Conclusions:

1. The Business as Usual and Expansion of Lignite Use scenarios do not achieve the EU targets for 2030.
2. The scenarios RES, Energy Efficiency and efficiency combined with lignite phase out bring about a 61-65% decrease in emissions until 2030.
3. All scenarios include a strong penetration of renewable energy sources.
4. The necessary investments in the 5 scenarios range between 23 bil. € (lignite expansion) and 33 bil. € (RES).
5. The Business as Usual and Lignite Expansion scenarios do not lead to cheaper electricity, since they also include the cost of fuels and purchasing of emission allowances.
6. Wind energy competes with lignite electricity generation for allowance prices in the order of 25 €/t CO_2.
7. Adherence to lignite electricity generation aggravates all the parameters of the Greek electricity system.

The main conclusions of the analysis are as follows:

- In every scenario Greece fails to achieve the RES penetration targets for 2020 as prescribed in Law 3851/2010 for electricity generation. Specifically, taking into account current conditions in the market and the existing legal framework, all scenarios assume that it is realistic to introduce only 1,600 MW of newly installed RES during the period 2016-2020, which will finally lead to a 32.7% RES share in the gross final energy consumption, significantly lower than the set target of 40%. In order to achieve this target and assuming a 3:2 ratio of wind/photovoltaic generation, it was assumed that another 1,100 MW of wind systems and 1,100 MW of photovoltaic systems will be required.
- The BaU and LIG scenarios, in which fossil fuels maintain a significant share in electricity generation and which do not integrate strong energy saving policies in the final consumption sectors, fail to reach the energy and environmental targets set by EU for 2030. The RES percentage in the gross final consumption amounts to 25-26% (26-28% in 2035). Greenhouse gas emissions are decreased by 36-42% compared to 2005 for the overall energy system, and by 47-57% in electricity generation. During the period by 2050, the decrease in emissions compared to 2005 amounts to 36-43% for the overall energy system and to 52-68% for electricity generation.
- On the contrary, the RES, EE and LPO scenarios include a strong RES penetration and, per case, more intense energy saving interventions in the final consumption sectors and they present clearly better performances in terms of achieving the energy and environmental targets under discussion. For 2030, greenhouse gas emissions are decreased by 44-47% compared to 2005 for the overall energy system (51-55% in 2035), and by 61-65% in electricity generation (75-81%). During the period until 2050, the decrease in emissions compared to 2005 amounts to 50-64% for the overall energy system and to 75-88% for electricity generation.

- All the scenarios include major investments in RES technologies in the electricity generation sector. As far as wind systems are concerned, their installed power capacity in 2035 amounts to 5.3 GW in LIG, 7 GW in BaU, 7.5GW in EE, 8.2 GW in LPO and 9.2 GW in RES. In 2050, their capacity amounts to 6.7 GW in LIG, 8 GW in BaU, 8.8 GW in EE, 9.8 GW in LPO and 10.6 GW in RES. The installation progress of photovoltaic systems has even more dynamic characteristics, particularly after 2030. Thus, the installed power capacity in 2035 ranges between 5.3-7 GW in all scenarios, except RES where it amounts to 8.2 GW , while in 2050 it amounts to 7.1 GW in LIG, 7.7 GW in BaU, 9.3 GW in EE, 10.2 GW in LPO and 11.3 GW in RES. The integration in the electricity system of the intermittent RES at this scale creates additional needs in energy storage, which during the period until 2050 were estimated at 1,450 MW in LIG, 1,950 MW in BaU, 2,500 MW in EE, 3,050 MW in LPO and 3,500 MW in RES. It is therefore concluded that in order to achieve the environmental and energy targets discussed by the EU for 2030 and 2050, extremely high investments on RES technologies will have to be planned in the electricity generation system. The promotion of energy saving policies in the final consumption sectors seems to somewhat mitigate the necessity for new investments on RES. However, it should be noted that extremely strong efforts will be required in order to achieve the energy saving targets with the implementation of relevant programs. Since the country has gone through a decade of unprecedented shrinkage in GDP and family income, it is estimated that the relative improvement of the economic conditions will bring about a strong rebound effect and, therefore, the implementation of programs for energy savings and energy cost reduction will contribute to the improvement in energy conditions within buildings, the increase in the transportation load serviced, etc., but the decrease in energy consumption will most probably be smaller than the expected one.
- Based on the analysis carried out in each scenario, the necessary cumulative investments in the electricity system for the period 2015-2050 have been estimated. According to the calculations, they amount to 23 bil. € in LIG, 24 bil. € in BaU, 28 bil. € in EE, 30 bil. € in LPO and 33 bil. € in RES. While the necessary investments in RES are higher by 9-10 bil. € compared to BaU and LIG, the implementation of EE and LPO requires significantly lower funds, approx. 5-7 bil. € over those required in LIG and BaU.
- The LIG and BaU scenarios, although of a lower capital intensity, do not lead to a lower electricity cost compared to the other scenarios considered, given that they also involve charges for fuels and the purchase of emission allowances. For the conservative evolution of the emission allowance price adopted as part of this analysis, the levelized cost of electricity shows a similar behaviour in all scenarios (since the bigger investments in the scenarios with a higher RES penetration are offset by the higher operational cost for the scenarios characterized by larger conventional electricity generation shares), and only towards the end of the reference period do the EE and LPO scenarios lead to a slightly lower electricity generation cost. Nevertheless, this picture is significantly different if the most recent scenario for the evolution of the emission allowance price is adopted as presented by the European Commission, where the levelized cost of electricity for the RES, EE and LPO scenarios is now significantly lower than the cost for the BaU and LIG scenarios. As a result, based on the scenario for the evolution of the emission allowance prices prescribed by the European Commission, the implementation of investments on new lignite units, such as Ptolemais V (included in BaU, LIG and EE) and Meliti II (included in LIG), will lead to a significant increase in electricity prices.
- The evolution of the emission allowance prices, in combination with natural gas prices, are determining factors in order to evaluate the feasibility of constructing new lignite units. The analysis has shown that, at the conventional electricity generation level, low emission allowance prices, below 30 €/t CO_2, favour the radical upgrading of existing lignite units instead of the construction of new ones, while for higher emission allowance prices and up to some extent, the construction of new lignite units is more appealing from a financial point of view only in combination with higher natural gas prices in the market. Wind energy seems to be competitive to lignite electricity generation for emission allowance prices in the order of 25 €/t CO_2, while if the pumped storage cost is included in the RES cost, lignite electricity generation exceeds the RES cost for emission allowance prices in the order of 50-55 €/t CO_2.

- In the long-term, the adherence to lignite electricity generation seems be an aggravating factor for all the parameters of the electricity system. Following the expected increase in the emission allowance prices at European level as a result of the EU ETS reform, and in combination with the stricter European environmental legislation which imposes lower permissible emission levels for SO_2, NO_x and particles and, therefore, costly upgradings, lignite no longer contributes to the decrease of the electricity cost as in the past, while at the same time it undermines the achievement of a series of energy and environmental targets. On the other hand, phasing out of lignite, in combination with a rational plan for RES development and energy savings in the final consumption sectors, as described in the LPO scenario, seems to combine the significant emissions' decrease in the energy and particularly in the electricity system, with lower electricity prices and achieving the targets for RES. RES technologies, and especially wind and photovoltaic systems, are technologically mature and already competitive to conventional units in financial terms. A critical dimension in energy planning is energy savings, especially given the high rates of energy poverty among Greek households. The current and future energy saving programs will have to aim for a decrease in energy consumption, and an improvement of the energy services provided to the consumers.

ANNEX A

THE ENPEP/BALANCE ENERGY MODEL

A.1 Introduction

One of the most widespread energy models internationally used for long-term forecasts of analytical energy balances and the consequent emitted environmental loads is ENPEP (ENergy and Power Evaluation Program). ENPEP, developed in the Argonne National Laboratory[42], is actually a "hybrid type" model, having being developed from an energy model of the “top-down” type in its initial design, and it includes various sub-models aiming at the full energy analysis/simulation of the energy/electricity system, at the same time quantifying its environmental and social consequences. Thus, the energy system analysis attempts to estimate the alternative possibilities for its evolution, in order to improve not only the system's behaviour, but also the determination of the socio-economic requirements for its viability. ENPEP is currently used internationally by a large number of research groups, both in developed and developing countries, in order to analyze energy systems and particularly to investigate/assess policies for the decrease of greenhouse gas emissions.

Through the analysis/simulation of an energy system, it is possible to assess and predict the potential developments in all the sectors of economic activity, so that the energy supplied can meet the respective demand. For this reason, ENPEP/Balance (Balance is the main ENPEP model) uses a non-linear partial equilibrium approach, while the energy system examined is simulated to a significant degree of detail through an energy network that depicts the energy flows from the stage of supply until final demand. A main assumption of the model is that both energy producers and consumers react and adjust their behaviour according to changes in prices. Moreover, energy demand depends on the prices of alternative technologies and fuels, while the supply prices for technologies and fuels may be affected by their total demand. ENPEP/Balance finds a level of equilibrium at each decision node, by determining a set of prices and quantities that meet all the relevant requirements and limitations. Since the shares of the various energy technologies in the market depend on energy prices and these, in turn, are affected by the total quantities in demand by the consumers, the model uses a repetitive process in order to determine the problem solution.

The main model input data include the structure of the energy system, a detailed energy balance, as well as energy product prices for the baseline year, a forecast for the evolution of future energy demand per sector / use, as well as potential technical and political restrictions (**Figure A-1**).

[42] Argonne National Laboratory (ANL), 2000. Description of BALANCE model. Technical Report.

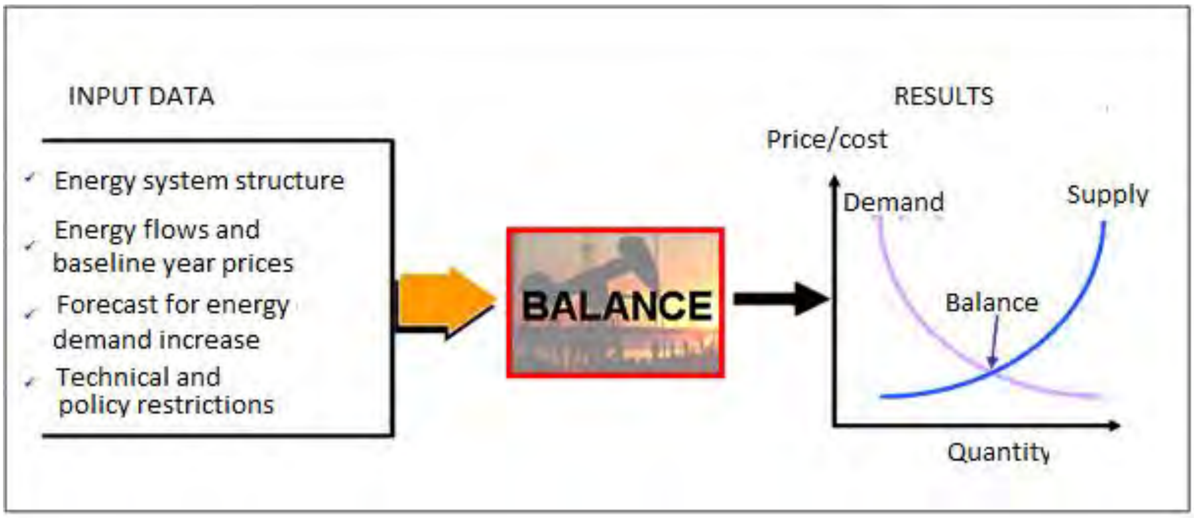


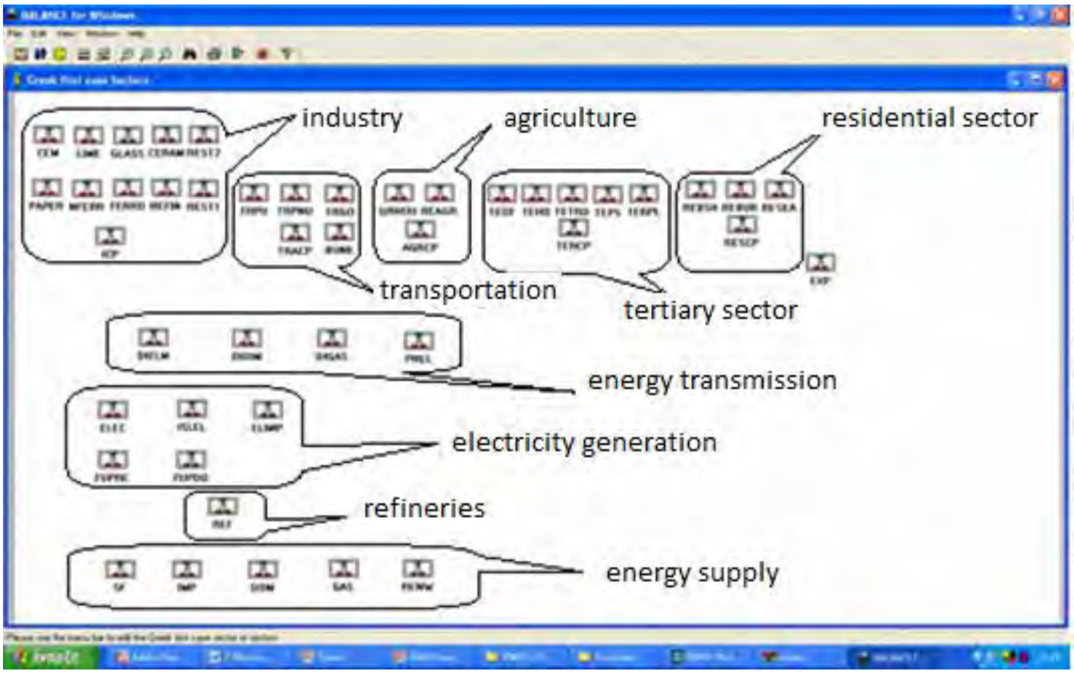
Figure A-1: General graph representation of the ENPEP /BALANCE model.

A.2. The Energy network and the partial equilibrium solution achieved

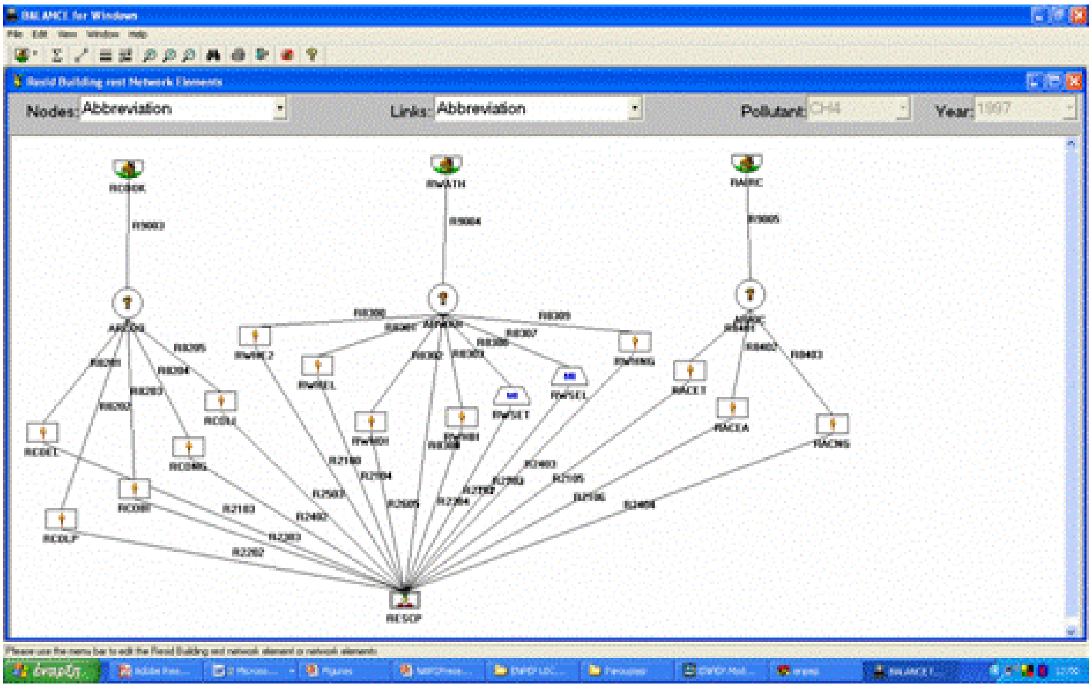
As already mentioned, the analysis of energy systems through ENPEP/Balance requires their representation by means of a detailed energy network in order to describe the energy flows from the stage of supply until the sectors of final consumption. The energy networks in ENPEP are produced using nodes and connections which represent the various elements of an energy system. The different nodes represent fossil fuels and renewable energy sources, various conversion technologies, refinery units, thermal and hydroelectric electricity generation units, cogeneration units, boilers and burners, the decision-making process as part of the energy market operation, taxes and grants, and energy demand. The links connect the nodes by transferring information and data (i.e. quantities and prices) from one to another.

Each node of the energy network is actually a sub-routine of the energy model and is described by specific equations correlating the energy quantities and prices between the node's input and output links.

Figure A-2 is a graphical representation of the modelization of the Greek energy system in ENPEP/Balance, by breaking it down in its various sectors (Figure A-2a) and by depicting the main energy uses, technologies, fuels, etc. for each sector. (Figure A-2b).



(a)



(b)

Figure A-2: Development of the energy network in ENPEP with its sectors (A-2a), and with selected energy uses, technologies and energy sources per sector (A-2b).

As a rule, the energy network in ENPEP is developed so that the demand nodes are placed on top, the energy supply nodes at the bottom and the various energy conversion nodes in the middle. Once the energy network is developed and the historical energy flows are depicted for the baseline year, the model foresees the future energy demand and the energy prices based on the evolution of specific determining parameters. This is achieved by means of a repetitive process, where:

- The demand for energy sources is calculated by simulating the energy flows from the top of the energy network and the energy demand for specific uses towards its base and the energy supply ("top-down calculation sequence").
- The energy prices are calculated through the extraction cost and the energy conversion cost by following the energy flows from the network's top to bottom ("bottom-up calculation sequence").
- During the estimation of the demand for energy sources described above, the model calculates the energy flows using the energy prices from the immediately previous bottom-up calculation sequence.
- The repetitive process continues until the model converges to a set of energy prices and quantities that meet all the relevant equations and restrictions that have been set by the energy network.
- The shares of the various energy technologies/resources are estimated based on a specific algorithm described in detail in the next paragraph as a function of the relevant prices for the alternative options.
- Since the shares of the various energy technologies and/or resources in the market depend on energy prices and these, in turn, are affected by the total quantities in demand by the consumers, the model uses the repetitive process described above in order to converge to a specific set of energy prices and quantities. The top-down and bottom-up calculation sequences are repeated until the differences in the energy flows of the energy network links vary only slightly from one sequence of calculations to the next.

A.3 Estimating the Shares of the Alternative Energy Resources / Technologies

A key role in the model operation is held by the decision-making nodes where the penetration shares for alternative options (technologies, fuels, etc.) are estimated. In each decision-making node, the penetration shares for alternative options are estimated based on an algorithm where the share of each technology/fuel is determined as a function of its price and of the prices for the alternative options available to meet the given demand levels. Let us assume, for example, that it is possible for a specific level of energy demand (Q_D) at a decision-making node to be covered by two alternative options A and B, with a unit price, respectively, of P_A and P_B. Based on the algorithm used in the ENPEP, the share (MS_A) of option A is calculated through the equation[43]:

$$MS_A = \frac{Q_A}{Q_A + Q_B} = \frac{\left(\frac{1}{P_A \, x \, Pm_A}\right)^{\gamma}}{\left(\frac{1}{P_A \, x \, Pm_A}\right)^{\gamma} + \left(\frac{1}{P_B \, x \, Pm_B}\right)^{\gamma}} \qquad (1)$$

Where:

Q_A *and* Q_B: the energy demand covered by option A and B respectively, for which the following must apply:

$$Q_D = Q_A + Q_B \qquad (2)$$

[43] Conzelmann G, 2001. Greenhouse gas mitigation analysis using ENPEP: a modelling guide. Center for Energy, Environmental, and Economic Systems Analysis (CEEESA) Decision and Information Sciences Division Argonne National Laboratory.

Pm_A and Pm_B: multipliers used to differentiate between the unit cost prices for options A and B, representing potential costs/benefits that are not reflected in their prices.

γ: a dimensionless factor determining the degree to which the change in the relative prices of the alternative options results in a change in their shares in the energy system. In case the γ factor is relatively high (e.g. 15), then small differences in the relative prices of the alternative energy technologies result in big changes in the penetration shares. On the contrary, the closer the γ factor values get to 0, then even large differences in the relative prices of the alternative options do not result in major differences in their penetration shares in the energy market. The choice of a refinery as the crude oil supply source is an indicative example in which the decision largely depends on the prices offered and therefore the γ value in the respective decision-making node must be high. On the contrary, the purchase of a car is also affected, in addition to its price, by a significant number of other parameters and, therefore, the penetration shares of the available models show a relatively lower sensitivity to their prices. **Figure A-3** is a graphical representation of the effect the γ value has on the penetration of two competitive energy technologies A and B.

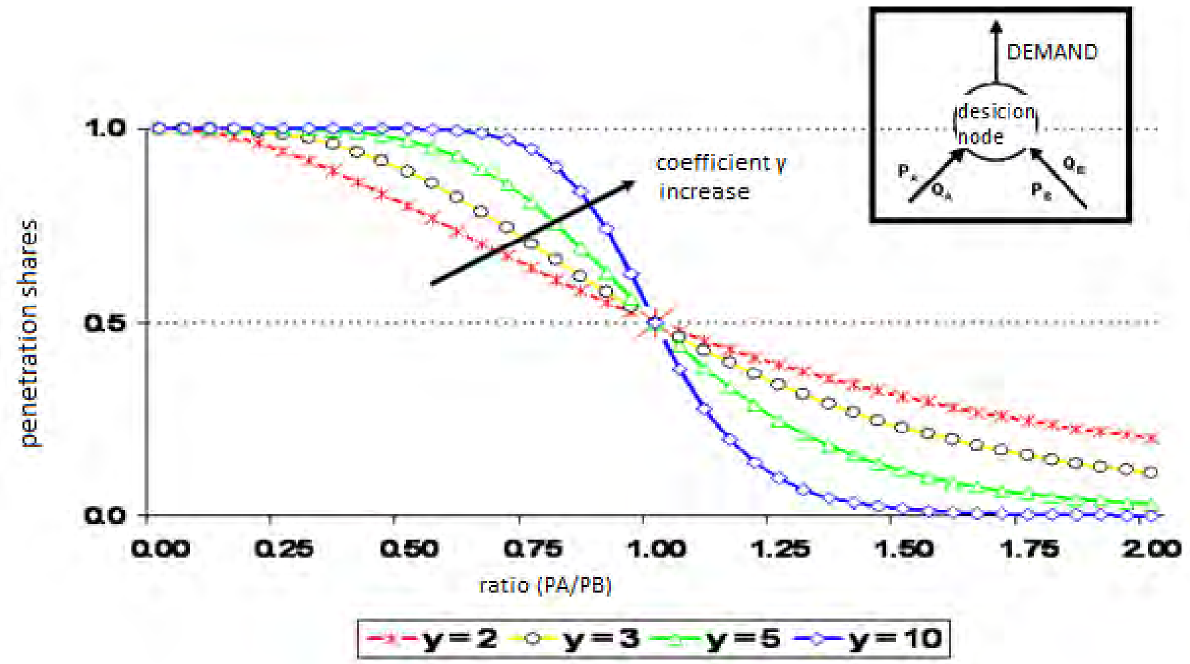


Figure A-3: Effect of the dimensionless γ factor on the penetration shares of alternative energy technologies

The decision-making nodes also have several aspects which are used in order to simulate the energy market as realistically as possible. Thus, cases in which the energy market does not directly respond to the changes in the energy prices are simulated through a dimensionless time lag factor λ that is integrated in the decision-making nodes. Such cases can occur when the final consumer already possesses competitive equipment to the one with the lowest price at a given time, or for instance when it is difficult for the consumer to obtain the cheapest option. The time lag factor actually determines the part of the energy market that can respond to price changes. This, the penetration share of a technology in a decision-making node that has been calculated through Equation 1, is adjusted through the Equation:

$$MS_{A,T} = MS_{A,T-1} + \left(MS_{A,T*} - MS_{A,T-1}\right) \times \lambda \qquad (3)$$

Where:

$MS_{A,T}$: the estimated penetration share of option A in the present year T, if there are time lag circumstances in the energy market.

$MS_{A,T-1}$: the estimated penetration share of option A in the previous year.

MS_{A,T^*}: the estimated penetration share of option A in the year T as calculated by Equation 1, namely on condition that there are no time lag conditions in the energy market.

λ: the time lag factor, with values ranging between 0 and 1. A value equal to 1 indicates that there are no time lag situations in the specific energy market, and that there is a direct response/adjustment to price variability. On the contrary, an λ value equal to 0 indicates that the energy market does not respond to price variability. In real conditions of capital intensive energy investments, it is expected that the time lags will be larger than those requiring relatively small capital.

Finally, the model allows to integrate potential technical restrictions set (e.g. natural gas pipeline capacity), government policies (e.g. taxes, grants, priority to the use of domestic fuels), customers' preferences, etc., thus affecting the shares eventually covered by the various alternative options at a network node.

A.4 Solution at energy system level

The approach followed by ENPEP/Balance is based on the assumption that the energy sector consists in autonomous energy producers and consumers, each trying to achieve its own distinct targets. Besides, this also reflects the real operation of the energy market in which many decision-makers are involved, and the final arrangement of the energy system may differ from the theoretically "optimum" level. Sectors such as electricity generation, industry, services, buildings, have completely different characteristics and the decision-makers' choices most likely have completely different targets, duration, etc. The model concludes to a solution in which there is an equilibrium between energy demand and supply, taking into account the market operation and any potential technical/political restrictions, but without intending the system optimization among the various sectors of economic activity. In fact, ENPEP/Balance determines the intersection point of the energy demand and supply curves for all energy resources and all energy uses included in the energy network. Equilibrium is achieved when the model comes up with a set of prices and quantities that meet all the equations included in the energy network under the existing restrictions. For this reason, a repetitive process is followed, based on the Jacobi technique, which is described above.

Using ENPEP/Balance, it is possible for energy analysts to make long-term predictions (up to 70 years ahead) for energy balances, as well as for the resulting emissions of greenhouse gases and other gas pollutants. The analysis is carried out on an annual basis, this allowing to extract important information concerning the energy balances foreseen and their potential differentiations during a time period, which may be due to the penetration of new technologies, the application of sectoral policies, etc. At the same time, it is possible to answer questions regarding differentiations and the economic impact that will result from the application of an energy or environmental tax, an Emissions Trading System and, in general, various economic – environmental – regulatory policies.

ANNEX B

DETAILED RESULTS FOR THE ENERGY SCENARIOS

1. Results for the Business as Usual (BaU) Scenario

Table 1-1. Energy Balance Summary

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
PRIMARY GENERATION (ktoe)	**9845**	**10026**	**9710**	**8630**	**7992**	**8121**	**7812**	**6588**	**6795**	**6940**	**7097**
solid fuel	8296	8490	7494	6015	4874	4343	3551	1937	1962	1889	1902
Oil products	261	91	50	0	0	0	0	0	0	0	0
RES	1289	1444	2167	2615	3118	3779	4261	4651	4833	5051	5195
Natural Gas	0	0	0	0	0	0	0	0	0	0	0
NET IMPORTS (ktoe)	**18221**	**21058**	**18984**	**16529**	**16018**	**14644**	**14399**	**15583**	**16022**	**16283**	**16569**
solid fuel	823	499	344	249	250	275	287	288	303	321	342
Oil products	15740	17966	15203	12751	11675	10234	9714	10054	10287	10384	10457
RES	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	1659	2268	2947	3375	3938	3980	4243	5086	5278	5423	5615
Electricity	-1	325	490	154	154	154	154	154	154	154	154
GROSS DOMESTIC CONSUMPTION (ktoe)	**28067**	**31083**	**28694**	**25159**	**24010**	**22765**	**22211**	**22170**	**22817**	**23222**	**23666**
solid fuel	9119	8989	7838	6264	5125	4618	3838	2224	2265	2210	2244
Oil products	16001	18057	15253	12751	11675	10234	9714	10054	10287	10384	10457
RES	1289	1444	2167	2615	3118	3779	4261	4651	4833	5051	5195
Natural Gas	1659	2268	2947	3375	3938	3980	4243	5086	5278	5423	5615
Electricity	-1	325	490	154	154	154	154	154	154	154	154
NET ELECTRICITY GENERATION (ktoe)	**4200**	**4686**	**4504**	**4597**	**4739**	**4752**	**4899**	**5138**	**5363**	**5565**	**5753**
Lignite	2601	2726	2364	1962	1582	1466	1222	699	708	684	688
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	651	629	394	343	314	186	51	51	51	51	51
Natural Gas	567	746	813	1077	1245	1162	1279	1671	1723	1761	1825
RES	382	585	934	1214	1598	1938	2346	2717	2880	3069	3189
FINAL ENERGY CONSUMPTION (ktoe)	**18514**	**21156**	**19403**	**16698**	**16553**	**16674**	**17048**	**17704**	**18308**	**18754**	**19174**
per sector											
agricultural	1130	1157	899	791	796	806	817	830	843	854	864
industrial	5246	5342	4658	3920	3874	4004	4204	4460	4716	4936	5160
residential	4364	5294	4863	4351	4432	4438	4523	4686	4871	5025	5168
tertiary	1320	1821	1878	1807	1883	1879	1927	2026	2126	2193	2258
transportation	6453	7541	7105	5829	5568	5546	5576	5702	5751	5746	5724
per fuel											
solid fuel	815	461	292	232	243	272	290	304	319	338	358
oil products	12681	14729	12203	9542	8971	8572	8669	9001	9268	9419	9552
electricity	3747	4429	4435	4241	4353	4363	4511	4712	4922	5096	5268
thermal energy	19	34	172	184	201	204	205	207	208	209	211
RES	894	827	1180	1338	1399	1680	1754	1773	1791	1821	1845
natural gas	358	676	1121	1161	1387	1583	1619	1709	1800	1871	1940
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	94078	103605	90421	75755	69490	64552	60065	54646	55967	56400	57354
CH_4 (kt)	69.5	73.4	62.6	58.5	49.7	46.0	40.7	29.6	29.4	28.7	28.6
N_2O (kt)	3.1	3.4	2.6	4.1	4.0	3.9	3.9	3.9	4.0	4.0	4.1
CO_2 eq (kt)	**96742**	**106443**	**92765**	**78447**	**71923**	**66872**	**62246**	**56558**	**57893**	**58319**	**59280**
INDEXES											
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
GNP (M€ 2010)	189901	229785	226032	184468	205133	210623	222188	243533	264935	279181	292849
Gross Domestic Cons./GNP (ktoe/M€ 2010)	0.15	0.135	0.127	0.136	0.117	0.108	0.100	0.091	0.086	0.083	0.081
Gross Domestic Cons./inh. (toe / inh.)	2.57	2.83	2.58	2.32	2.19	2.07	2.01	2.01	2.07	2.12	2.18
Gross Final Energy Consumption (ktoe)	19299	21949	19794	17539	17724	18079	18653	19501	20323	20875	21408
RES in the final energy consumption	7.7%	6.4%	11.2%	15.4%	19.3%	23.2%	26.0%	27.8%	28.5%	29.1%	29.3%
Coal intensity (kt CO_2/M€ 2010)	0.50	0.45	0.40	0.41	0.34	0.31	0.27	0.22	0.21	0.20	0.20
CO_2 emissions / inh. (t CO_2 / inh.)	8.63	9.44	8.13	6.98	6.34	5.86	5.44	4.95	5.08	5.14	5.28
CO_2 emissions / Gross Energy Cons. (t / toe)	3.35	3.33	3.15	3.01	2.89	2.84	2.70	2.46	2.45	2.43	2.42
Dependence on imports (%)	65%	68%	66%	66%	67%	64%	65%	70%	70%	70%	70%

Table 1-2. Electricity generation

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ELECTRICITY DEMAND (TWh)	**43578**	**51509**	**51579**	**49323**	**50625**	**50742**	**52463**	**54801**	**57243**	**59266**	**61267**
Industry	14654	15049	13200	11932	11909	12177	12746	13409	14072	14607	15119
Transportation	186	209	337	361	675	675	698	721	721	733	733
Agriculture	2698	2873	2768	3117	3280	3454	3559	3663	3768	3873	3977
Tertiary	12235	16468	17619	17096	17968	17899	18457	19422	20411	21074	21736
Residential	13805	16910	17666	16817	16782	16538	17003	17573	18259	18980	19701
NET ELECTRICITY GENERATION (TWh)	**50579**	**60115**	**60906**	**55905**	**57557**	**57708**	**59418**	**62197**	**64814**	**67163**	**69350**
Lignite	30250	31703	27493	22818	18399	17050	14212	8129	8234	7955	8001
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	7571	7315	4582	3989	3652	2163	593	593	593	593	593
Natural Gas	6594	8676	9455	12526	14479	13514	14875	19434	20038	20480	21225
Hydroelectric systems	3989	5350	7385	4815	5862	6036	6036	6466	6524	6583	6745
Wind systems	454	1314	3012	4826	6862	8932	12688	15456	16456	17759	17782
Biomass	0	140	279	361	779	1023	1023	1023	1023	1023	1023
Geothermal energy	0	0	0	0	0	58	58	58	58	58	58
Photovoltaic systems	0	0	186	4117	5082	6501	7490	8595	9444	10293	11479
Imports	1733	5617	8513	2442	2442	2442	2442	2442	2442	2442	2442
INSTALLED POWER CAPACITY (MW)	**10931**	**12716**	**14911**	**19279**	**20484**	**21015**	**22315**	**23499**	**24563**	**25626**	**26423**
Lignite	4457	4746	4746	3912	3912	2856	2345	1231	1231	1231	1231
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	2114	2289	2201	1810	1404	980	532	532	532	532	532
Natural Gas	1062	2063	3208	5188	5188	5188	5188	5188	5188	5188	5188
Hydroelectric systems	3072	3106	3215	3389	3389	3580	3580	3580	3580	3580	3580
Wind systems	226	491	1298	2182	3088	3925	5522	7082	7582	8082	8082
Biomass		20	41	52	112	147	147	147	147	147	147
Geothermal energy		0	0	0	0	8	8	8	8	8	8
Photovoltaic systems	0	1	202	2746	3391	4332	4993	5732	6295	6859	7656
LOAD INDEX (%)											
Lignite	77%	76%	66%	67%	54%	68%	69%	75%	76%	74%	74%
Coal											
Oil products	41%	36%	24%	25%	30%	25%	13%	13%	13%	13%	13%
Natural Gas	71%	48%	34%	28%	32%	30%	33%	43%	44%	45%	47%
Hydroelectric systems	15%	20%	26%	16%	20%	19%	19%	21%	21%	21%	22%
Wind systems	23%	30%	26%	25%	25%	26%	26%	25%	25%	25%	25%
Biomass		79%	79%	79%	79%	79%	79%	79%	79%	79%	79%
Geothermal energy						75%	75%	75%	75%	75%	75%
Photovoltaic systems			10%	17%	17%	17%	17%	17%	17%	17%	17%
FUEL CONSUMPTION (ktoe)	**11652**	**12156**	**10637**	**9356**	**8449**	**7347**	**6340**	**5467**	**5592**	**5593**	**5730**
Solid Fuel	8303	8526	7527	6014	4864	4328	3530	1903	1928	1855	1868
Oil products	2047	2038	1284	1128	1035	622	186	186	186	186	186
Natural Gas	1302	1592	1826	2214	2551	2397	2624	3378	3478	3552	3675
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	51532	54311	48319	38318	32845	28417	23480	16922	17277	17070	17421
CH_4 (kt)	0.6	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
N_2O (kt)	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.3	0.4	0.4	0.4
CO_2 eq (kt)	**51719**	**54507**	**48487**	**38493**	**33010**	**28564**	**23612**	**17037**	**17395**	**17188**	**17542**
INDEXES	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
RES share in generation (%)	9.1%	12.5%	20.7%	26.4%	33.7%	40.8%	47.9%	52.9%	53.7%	55.1%	55.4%
RES share in gross electricity consumption (%)	9.1%	11.7%	18.7%	25.6%	32.7%	39.5%	46.4%	51.3%	52.2%	53.7%	54.0%
RES share in installed power capacity (%)	30.2%	28.5%	31.9%	43.4%	48.7%	57.1%	63.9%	70.4%	71.7%	72.9%	73.7%
Domestic electricity generation (%)	71.0%	70.7%	73.2%	69.1%	67.1%	71.6%	72.8%	66.5%	66.9%	67.4%	67.4%

Table 1-3. Cost of Electricity Generation

	2015	2020	2025	2030	2035	2040	2045	2050
A. Investments (M€ 2015)		**2515**	**4262**	**3467**	**3653**	**2727**	**4885**	**2790**
A.1 RES		***2239***	***2873***	***3467***	***3653***	***2727***	***4885***	***2790***
Wind systems		1223	1167	2425	2464	1764	1868	1223
Large photovoltaic systems		439	353	583	563	564	2355	833
Residential photovoltaic systems		439	802	85	164	158	444	432
Hydroelectric systems		0	438	0	0	0	0	0
Geothermal energy		0	32	0	0	0	0	0
Biomass		138	81	0	46	48	25	138
Pumping systems		0	0	373	417	193	193	164
A.2 Conventional		***275***	***1389***	***0***	***0***	***0***	***0***	***0***
Lignite		0	1389	0	0	0	0	0
Natural Gas		0	0	0	0	0	0	0
Oil products		0	0	0	0	0	0	0
Anti-pollution		275	0	0	0	0	0	0
A.3 Total investments (cumulative)		***2515***	***6776***	***10243***	***13896***	***16623***	***21508***	***24298***
B. Levelized cost (€ 2015/MWh)	**87.70**	**91.08**	**102.33**	**101.42**	**103.56**	**104.40**	**103.81**	**102.57**
C. Levelized cost except for investments before 1995 (€ 2015/MWh)	**72.45**	**76.74**	**91.65**	**92.49**	**97.18**	**98.29**	**97.92**	**96.87**

Table 1-4. Energy Consumption and Indexes in the Industry

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	23748	28525	22368	18592	17619	17969	18827	20440	22025	23110	24137
FINAL ENERGY CONSUMPTION (ktoe)	**5246**	**5342**	**4658**	**3920**	**3874**	**4004**	**4204**	**4460**	**4716**	**4936**	**5160**
per sector											
non-metallic minerals	1374	1517	909	821	911	1003	1111	1172	1237	1316	1405
cement	1154	1263	801	730	809	888	981	1023	1070	1133	1205
lime	64	79	51	53	50	50	52	56	61	63	66
glass	27	34	30	29	27	27	28	31	33	34	36
ceramic industry	129	141	27	10	25	37	49	61	74	86	98
paper	161	129	141	120	112	113	117	127	137	143	150
non-ferrous	746	834	653	840	838	828	824	821	820	819	820
iron industry	195	220	171	97	108	121	139	153	166	176	185
other industries	2769	2642	2784	2041	1904	1939	2013	2187	2357	2482	2600
per fuel											
solid fuel (coal and lignite)	802	455	284	223	233	263	281	294	309	328	349
oil products	2622	2813	2092	1638	1439	1367	1457	1555	1653	1734	1819
diesel	509	453	314	291	196	152	151	156	161	163	166
fuel oil	852	676	362	301	227	189	189	194	198	200	202
other oil products	1261	1685	1416	1046	1017	1026	1117	1205	1295	1371	1451
natural gas	339	530	727	718	845	953	974	1021	1067	1107	1146
biomass-waste	217	233	285	168	167	207	228	265	303	337	370
solar systems and other RES	0	2	4	6	5	6	7	7	9	10	11
electricity	1260	1294	1135	1026	1024	1047	1096	1153	1210	1256	1300
cogeneration steam	6	14	132	142	160	162	163	164	165	165	166
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	9952	10226	6862	7734	7758	7942	8321	8633	8956	9286	9647
CH_4 (kt)	0.5	0.6	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.8
N_2O (kt)	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5
CO_2 eq (kt)	**10041**	**10331**	**6950**	**7815**	**7852**	**8052**	**8437**	**8760**	**9093**	**9432**	**9803**
INDEXES											
energy intensity (ktoe / M€ 2010)	0.22	0.19	0.21	0.21	0.22	0.22	0.22	0.22	0.21	0.21	0.21
CO2 emissions per energy unit (t / toe)	1.90	1.91	1.47	1.97	2.00	1.98	1.98	1.94	1.90	1.88	1.87
emissions intensity (kt CO_2 / M€ 2010)	0.42	0.36	0.31	0.42	0.44	0.44	0.44	0.42	0.41	0.40	0.40

Table 1-5. Energy Consumption and Indexes in transportation

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
GNP per inh. (€ 2010/inh.)	17416	20947	20328	16989	18708	19116	20124	22058	24046	25466	26983
Private consumption per household (€2010/hh)	35791	40844	38374	30744	31913	31662	32362	34443	36456	37488	38568
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
TRANSPORTATION LOAD											
passenger transportation (Gpkm)	**128**	**160**	**175**	**168**	**170**	**173**	**176**	**180**	**182**	**182**	**182**
road transportation	118	149	164	160	162	165	168	172	173	173	173
cars and motorcycles	98	130	145	144	147	150	153	157	158	159	158
buses	20	20	19	16	15	14	14	15	15	15	15
trains	3	3	4	4	4	4	4	4	4	4	4
domestic aviation	2	1	1	1	1	1	1	1	1	1	1
domestic navigation	5	6	6	4	4	4	4	4	4	4	4
freight transportation (Gtkm)	**27**	**31**	**28**	**21**	**20**	**20**	**21**	**22**	**24**	**24**	**25**
trucks	19	21	20	14	13	13	14	15	16	17	18
trains	0	0	0	0	0	0	0	0	0	0	0
domestic navigation	8	9	8	7	7	7	7	7	7	7	7
FINAL ENERGY CONSUMPTION (ktoe)	**6453**	**7541**	**7105**	**5829**	**5568**	**5546**	**5576**	**5702**	**5751**	**5746**	**5724**
per transportation means											
road transportation	5320	6413	6091	5147	4894	4867	4891	5001	5044	5036	5014
cars and motorcycles	2901	3670	3707	3488	3425	3413	3398	3405	3351	3280	3199
buses	158	152	141	119	105	100	101	102	102	100	99
trucks	2261	2591	2243	1539	1364	1354	1392	1494	1592	1656	1716
trains	49	54	58	55	54	54	56	58	59	59	59
domestic aviation	515	416	244	188	187	189	191	195	196	197	196
domestic navigation	569	658	712	439	434	435	439	448	452	453	454
per type of activity											
passenger transportation	4127	4875	4794	4233	4149	4137	4129	4150	4100	4029	3946
freight transportation	2326	2666	2311	1596	1419	1409	1447	1552	1652	1717	1778
per fuel											
Solid Fuel	0	0	0	0	0	0	0	0	0	0	0
oil products	6437	7508	6938	5614	5256	5037	5021	5144	5192	5186	5164
diesel	2199	2550	2257	1886	1879	1960	1960	2061	2133	2172	2202
fuel oil	253	316	435	252	249	249	251	257	259	260	260
petrol	3403	4126	3901	3039	2671	2353	2329	2336	2307	2260	2208
LPG	26	31	68	227	245	257	261	265	266	267	267
other oil products	556	485	275	211	213	217	220	225	226	227	227
natural gas	0	15	15	19	23	26	26	27	27	27	27
biofuel	0	0	124	164	230	424	470	470	470	470	470
electricity	16	18	29	31	58	58	60	62	62	63	63
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	18427	21192	21991	16559	15529	14917	14870	15246	15399	15388	15330
CH_4 (kt)	4.9	4.8	4.3	5.8	5.1	4.8	4.8	4.8	4.7	4.7	4.6
N_2O (kt)	1.2	1.3	1.1	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6
CO_2 eq (kt)	**18899**	**21708**	**22418**	**17221**	**16140**	**15513**	**15465**	**15846**	**15995**	**15976**	**15908**
INDEXES											
energy consumption per inh. (toe / inh.)	0.59	0.69	0.64	0.54	0.51	0.50	0.51	0.52	0.52	0.52	0.53
biofuel share (%)	0.0%	0.0%	2.1%	3.4%	5.0%	9.3%	10.3%	10.0%	10.0%	10.0%	10.0%
coal intensity (kt CO_2 / M€ 2010)	0.10	0.09	0.10	0.09	0.08	0.07	0.07	0.06	0.06	0.06	0.05
CO2 emissions per inh. (t CO_2 / inh.)	1.7	1.9	2.0	1.5	1.4	1.4	1.3	1.4	1.4	1.4	1.4
passenger transportation efficiency (toe/Mpkm)	32.4	30.5	27.4	25.2	24.5	24.0	23.5	23.0	22.6	22.1	21.7
freight transportation efficiency (toe/Mpkm)	85.9	86.4	81.4	74.8	70.5	69.9	69.9	70.1	70.2	70.1	70.0

Table 1-6. Energy Consumption and Indexes in the Agricultural Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	7635	7799	6519	6658	6110	5936	5907	6139	6313	6243	6119
FINAL ENERGY CONSUMPTION (ktoe)	**1130**	**1157**	**899**	**791**	**796**	**806**	**817**	**830**	**843**	**854**	**864**
per energy use											
greenhouses	208	173	176	178	181	184	187	190	194	197	200
other agricultural uses	922	984	723	613	615	622	630	640	650	657	664
per fuel											
Solid Fuel	0	0	0	0	0	0	0	0	0	0	0
oil products	884	885	619	470	456	444	443	444	445	443	441
diesel	811	830	541	391	373	360	359	360	360	358	356
other oil products	73	54	78	79	83	84	84	85	85	85	86
natural gas	0	0	0	0	0	0	0	0	0	0	0
biomass-waste	11	22	37	47	52	59	61	64	66	69	71
solar systems and other RES	3	3	5	6	6	7	7	8	8	8	8
electricity	232	247	238	268	282	297	306	315	324	333	342
cogeneration steam	0	0	0	0	0	0	0	0	0	0	0
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	2612	2705	1682	1443	1400	1365	1362	1366	1368	1363	1357
CH_4 (kt)	0.4	0.4	0.4	0.8	0.9	1.0	1.0	1.0	1.1	1.1	1.1
N_2O (kt)	0.9	1.0	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CO_2 eq (kt)	**2896**	**3004**	**1876**	**1616**	**1571**	**1536**	**1534**	**1540**	**1544**	**1539**	**1534**
INDEXES											
energy intensity (toe / M€ 2010)	148	148	138	119	130	136	138	135	134	137	141
energy consumption per inh. (toe / inh.)	0.10	0.11	0.08	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08
emissions intensity (kt CO_2 / M€ 2010)	0.34	0.35	0.26	0.22	0.23	0.23	0.23	0.22	0.22	0.22	0.22

Table 1-7. Energy Consumption and Indexes in the Agricultural Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA Added Value (M€ 2010)	128017	157443	161870	135150	147644	152541	161914	178183	194620	205655	216323
FINAL ENERGY CONSUMPTION (ktoe)	**1320**	**1821**	**1878**	**1807**	**1883**	**1879**	**1927**	**2026**	**2126**	**2193**	**2258**
per sector											
offices	101	303	311	287	298	298	307	323	339	351	363
commerce	395	541	588	531	599	596	606	628	649	666	682
hotels	368	463	429	457	477	480	497	530	562	586	610
public sector	455	515	550	532	509	506	517	546	575	590	603
per energy use											
heating	326	470	474	442	444	440	445	468	490	507	523
air-conditioning	536	734	756	747	787	798	823	869	916	946	975
electrical appliances and lighting	459	617	648	618	652	642	659	689	719	739	759
per fuel											
Solid Fuel	0	0	3	4	4	4	4	4	4	4	4
oil products	253	337	221	178	165	155	156	164	172	176	181
natural gas	12	60	124	137	151	161	160	166	170	174	177
biomass-waste	0	0	0	0	0	0	0	0	0	0	0
solar systems and other RES	3	4	6	7	8	9	10	11	12	13	14
electricity	1052	1416	1515	1470	1545	1539	1587	1670	1755	1812	1869
cogeneration steam	0	5	9	11	10	11	11	12	12	13	14
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	785	1549	1150	935	926	921	921	962	1001	1026	1050
CH_4 (kt)	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N_2O (kt)	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CO_2 eq (kt)	**786**	**1552**	**1152**	**961**	**950**	**945**	**945**	**988**	**1027**	**1053**	**1078**
INDEXES energy intensity (toe / M€ 2010)	10.31	11.57	11.60	13.37	12.75	12.32	11.90	11.37	10.92	10.66	10.44
energy consumption per inh. (toe / inh.)	0.12	0.17	0.17	0.17	0.17	0.17	0.17	0.18	0.19	0.20	0.21
emissions intensity (t CO_2 / M€ 2010)	6.1	9.8	7.1	6.9	6.3	6.0	5.7	5.4	5.1	5.0	4.9

Table 1-8. Energy Consumption and Indexes in the Residential Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
GNP per inh. (€ 2010/inh.)	17416	20947	20328	16989	18708	19116	20124	22058	24046	25466	26983
Private consumption (M€ 2010)	126461	153952	156803	127077	137192	140864	148598	162873	177188	186715	195856
Private consumption per household (€ 2010/hh)	35791	40844	38374	30744	31913	31662	32362	34443	36456	37488	38568
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
Household size (residents/household)	3.09	2.91	2.72	2.63	2.55	2.48	2.40	2.33	2.27	2.20	2.14
FINAL ENERGY CONSUMPTION (ktoe)	**4364**	**5294**	**4863**	**4351**	**4432**	**4438**	**4523**	**4686**	**4871**	**5025**	**5168**
per energy use											
heating	3053	3846	3311	2805	2840	2823	2869	2990	3131	3238	3336
cooking	291	287	295	298	310	320	331	340	350	358	365
hot water	557	632	639	624	629	630	631	630	629	626	619
air-conditioning	38	62	94	132	148	169	190	211	236	266	299
electrical appliances and lighting	426	467	524	493	506	497	503	513	526	537	548
per fuel											
Solid Fuel	13	5	5	5	5	5	5	5	5	5	5
oil products	2484	3186	2333	1643	1654	1569	1593	1694	1806	1879	1947
diesel	2354	3124	2280	1580	1579	1486	1510	1614	1729	1804	1874
other oil products	130	62	53	62	75	83	83	80	76	75	73
natural gas	6	72	255	287	368	443	459	495	535	563	590
biomass-waste	579	463	581	777	740	743	740	711	680	667	650
solar systems and other RES	81	99	140	162	191	225	232	238	243	248	250
electricity	1187	1454	1519	1446	1443	1422	1462	1511	1570	1632	1694
cogeneration steam	13	15	31	31	31	31	31	31	31	31	31
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	7653	9960	6742	5714	5933	5842	5954	6349	6788	7079	7352
CH_4 (kt)	5.0	3.4	3.6	10.6	10.2	10.2	10.2	9.8	9.4	9.2	9.0
N_2O (kt)	0.2	0.1	0.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1
CO_2 eq (kt)	**7830**	**10089**	**6871**	**6276**	**6479**	**6382**	**6495**	**6890**	**7327**	**7621**	**7895**
INDEXES											
energy intensity (ktoe / M€ 2010)	0.035	0.034	0.031	0.034	0.032	0.032	0.030	0.029	0.027	0.027	0.026
energy consumption per inh. (toe / inh.)	0.40	0.48	0.44	0.40	0.40	0.40	0.41	0.42	0.44	0.46	0.48
emissions intensity (kt CO_2/ M€ 2010)	0.061	0.065	0.043	0.045	0.043	0.041	0.040	0.039	0.038	0.038	0.038
CO2 emissions per inh. (t / inh.)	0.70	0.91	0.61	0.53	0.54	0.53	0.54	0.58	0.62	0.65	0.68

2. Results for the Expansion of Lignite Use (LIG) Scenario

Table 2-1. Energy Balance Summary

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
PRIMARY GENERATION (ktoe)	**9845**	**10026**	**9710**	**8630**	**8241**	**8962**	**9046**	**7978**	**8225**	**8409**	**8616**
solid fuel	8296	8490	7494	6015	5124	5183	4901	3684	3778	3786	3812
Oil products	261	91	50	0	0	0	0	0	0	0	0
RES	1289	1444	2167	2615	3117	3779	4145	4294	4448	4623	4805
Natural Gas	0	0	0	0	0	0	0	0	0	0	0
NET IMPORTS (ktoe)	**18221**	**21058**	**18984**	**16529**	**15864**	**14040**	**13721**	**15098**	**15574**	**15840**	**16058**
solid fuel	823	499	344	249	252	282	298	302	318	337	357
Oil products	15740	17966	15203	12751	11675	10235	9715	10054	10286	10383	10456
RES	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	1659	2268	2947	3375	3782	3368	3554	4588	4815	4966	5091
Electricity	-1	325	490	154	154	154	154	154	154	154	154
GROSS DOMESTIC CONSUMPTION (ktoe)	**28067**	**31083**	**28694**	**25159**	**24105**	**23002**	**22767**	**23076**	**23799**	**24249**	**24675**
solid fuel	9119	8989	7838	6264	5377	5465	5199	3986	4095	4123	4169
Oil products	16001	18057	15253	12751	11675	10235	9715	10054	10286	10383	10456
RES	1289	1444	2167	2615	3117	3779	4145	4294	4448	4623	4805
Natural Gas	1659	2268	2947	3375	3782	3368	3554	4588	4815	4966	5091
Electricity	-1	325	490	154	154	154	154	154	154	154	154
NET ELECTRICITY GENERATION (ktoe)	**4200**	**4686**	**4504**	**4597**	**4736**	**4743**	**4894**	**5129**	**5368**	**5554**	**5751**
Lignite	2601	2726	2364	1962	1662	1775	1694	1307	1340	1339	1349
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	651	629	394	343	314	186	51	51	51	51	51
Natural Gas	567	746	813	1077	1163	843	920	1412	1482	1523	1552
RES	382	585	934	1214	1597	1938	2230	2359	2496	2641	2799
FINAL ENERGY CONSUMPTION (ktoe)	**18514**	**21156**	**19403**	**16698**	**16553**	**16671**	**17047**	**17705**	**18310**	**18755**	**19176**
per sector											
agricultural	1130	1157	899	791	796	806	817	830	843	854	864
industrial	5246	5342	4658	3920	3874	4004	4204	4460	4717	4937	5160
residential	4364	5294	4863	4351	4432	4437	4523	4686	4872	5026	5169
tertiary	1320	1821	1878	1807	1883	1878	1927	2026	2126	2193	2259
transportation	6453	7541	7105	5829	5568	5546	5576	5702	5751	5746	5724
per fuel											
solid fuel	815	461	292	232	243	272	290	304	319	338	358
oil products	12681	14729	12203	9542	8971	8573	8669	9001	9267	9418	9550
electricity	3747	4429	4435	4241	4353	4359	4509	4712	4924	5099	5272
thermal energy	19	34	172	184	201	204	205	207	208	209	211
RES	894	827	1180	1338	1399	1680	1754	1773	1791	1821	1844
natural gas	358	676	1121	1161	1387	1583	1620	1709	1800	1871	1940
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	94078	103605	90421	75755	70413	67450	65409	62478	64234	65099	65956
CH_4 (kt)	69.5	73.4	62.6	58.5	51.4	51.7	49.7	41.3	41.6	41.4	41.4
N_2O (kt)	3.1	3.4	2.6	4.1	4.0	3.9	3.9	4.0	4.1	4.1	4.2
CO_2 eq (kt)	**96742**	**106443**	**92765**	**78447**	**72889**	**69916**	**67830**	**64706**	**66490**	**67364**	**68228**
INDEXES											
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
GNP (M€ 2010)	189901	229785	226032	184468	205133	210623	222188	243533	264935	279181	292849
Gross Domestic Cons./GNP (ktoe/M€ 2010)	0.15	0.135	0.127	0.136	0.118	0.109	0.102	0.095	0.090	0.087	0.084
Gross Domestic Consumption/inh. (toe / inh.)	2.57	2.83	2.58	2.32	2.20	2.09	2.06	2.09	2.16	2.21	2.27
Gross Final Energy Consumption (ktoe)	19299	21949	19794	17539	17729	18094	18683	19544	20371	20924	21457
RES in the final energy consumption	7.7%	6.4%	11.2%	15.4%	19.3%	23.2%	25.3%	25.9%	26.6%	27.0%	27.4%
Coal intensity (kt CO_2/M€ 2010)	0.50	0.45	0.40	0.41	0.34	0.32	0.29	0.26	0.24	0.23	0.23
CO_2 emissions / inh. (t CO_2 / inh.)	8.63	9.44	8.13	6.98	6.42	6.12	5.92	5.66	5.83	5.94	6.08
CO_2 emissions / Gross Energy Cons. (t / toe)	3.35	3.33	3.15	3.01	2.92	2.93	2.87	2.71	2.70	2.68	2.67
Dependence on imports (%)	65%	68%	66%	66%	66%	61%	60%	65%	65%	65%	65%

Table 2-2. Electricity generation

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ELECTRICITY DEMAND (TWh)	**43578**	**51509**	**51579**	**49323**	**50625**	**50695**	**52440**	**54801**	**57266**	**59301**	**61313**
Industry	14654	15049	13200	11932	11909	12177	12746	13421	14072	14607	15119
Transportation	186	209	337	361	675	675	698	721	721	733	733
Agriculture	2698	2873	2768	3117	3280	3442	3559	3663	3768	3873	3977
Tertiary	12235	16468	17619	17096	17968	17887	18445	19434	20422	21085	21748
Residential	13805	16910	17666	16817	16782	16515	16991	17573	18271	19003	19736
NET ELECTRICITY GENERATION (TWh)	**50579**	**60115**	**60906**	**55905**	**57522**	**57603**	**59360**	**62093**	**64872**	**67035**	**69326**
Lignite	30250	31703	27493	22818	19329	20643	19701	15200	15584	15573	15689
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	7571	7315	4582	3989	3652	2163	593	593	593	593	593
Natural Gas	6594	8676	9455	12526	13526	9804	10700	16422	17236	17712	18050
Hydroelectric systems	3989	5350	7385	4815	5862	6036	6036	6303	6315	6362	6466
Wind systems	454	1314	3012	4826	6862	8932	11595	11991	12712	13514	14410
Biomass	0	140	279	361	779	1023	1023	1023	1023	1023	1023
Geothermal energy	0	0	0	0	0	58	58	58	58	58	58
Photovoltaic systems	0	0	186	4117	5071	6501	7222	8071	8920	9758	10607
Imports	1733	5617	8513	2442	2442	2442	2442	2442	2442	2442	2442
INSTALLED POWER CAPACITY (MW)	**10931**	**12716**	**14911**	**19279**	**20475**	**22011**	**22892**	**22641**	**23705**	**24668**	**25732**
Lignite	4457	4746	4746	3912	3912	3852	3597	2483	2483	2483	2483
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	2114	2289	2201	1810	1404	980	532	532	532	532	532
Natural Gas	1062	2063	3208	5188	5188	5188	5188	5188	5188	5188	5188
Hydroelectric systems	3072	3106	3215	3389	3389	3580	3580	3580	3580	3580	3580
Wind systems	226	491	1298	2182	3088	3925	5022	5322	5822	6222	6722
Biomass		20	41	52	112	147	147	147	147	147	147
Geothermal energy		0	0	0	0	8	8	8	8	8	8
Photovoltaic systems	0	1	202	2746	3382	4332	4818	5382	5945	6509	7072
LOAD INDEX (%)											
Lignite	77%	76%	66%	67%	56%	61%	63%	70%	72%	72%	72%
Coal											
Oil products	41%	36%	24%	25%	30%	25%	13%	13%	13%	13%	13%
Natural Gas	71%	48%	34%	28%	30%	22%	24%	36%	38%	39%	40%
Hydroelectric systems	15%	20%	26%	16%	20%	19%	19%	20%	20%	20%	21%
Wind systems	23%	30%	26%	25%	25%	26%	26%	26%	25%	25%	24%
Biomass		79%	79%	79%	79%	79%	79%	79%	79%	79%	79%
Geothermal energy						75%	75%	75%	75%	75%	75%
Photovoltaic systems			10%	17%	17%	17%	17%	17%	17%	17%	17%
FUEL CONSUMPTION (ktoe)	**11652**	**12156**	**10637**	**9356**	**8545**	**7582**	**7012**	**6729**	**6960**	**7049**	**7130**
Solid Fuel	8303	8526	7527	6014	5116	5175	4891	3664	3758	3767	3793
Oil products	2047	2038	1284	1128	1035	622	186	186	186	186	186
Natural Gas	1302	1592	1826	2214	2395	1785	1934	2879	3015	3095	3151
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	51532	54311	48319	38318	33768	31312	28822	24752	25546	25772	26028
CH_4 (kt)	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
N_2O (kt)	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
CO_2 eq (kt)	**51719**	**54507**	**48487**	**38493**	**33934**	**31465**	**28968**	**24893**	**25690**	**25919**	**26176**
INDEXES	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
RES share in generation (%)	9.1%	12.5%	20.7%	26.4%	33.7%	40.9%	45.6%	46.0%	46.5%	47.6%	48.7%
RES share in gross electricity consumption (%)	9.1%	11.7%	18.7%	25.6%	32.7%	39.6%	44.2%	44.7%	45.2%	46.3%	47.4%
RES share in installed power capacity (%)	30.2%	28.5%	31.9%	43.4%	48.7%	54.5%	59.3%	63.8%	65.4%	66.7%	68.1%
Domestic electricity generation (%)	71.0%	70.7%	73.2%	69.1%	68.8%	78.3%	80.2%	71.5%	71.4%	71.7%	72.1%

Table 2-3. Cost of Electricity Generation

	2015	2020	2025	2030	2035	2040	2045	2050
A. Investments (M€ 2015)		**2788**	**5351**	**2494**	**1524**	**2727**	**4731**	**3287**
A.1 RES		***2227***	***2883***	***2494***	***1524***	***2727***	***4731***	***3287***
Wind systems		1223	1167	1750	763	1764	1733	1898
Large photovoltaic systems		439	353	408	394	564	2355	634
Residential photovoltaic systems		427	813	85	164	158	444	424
Hydroelectric systems		0	438	0	0	0	0	0
Geothermal energy		0	32	0	0	0	0	0
Biomass		138	81	0	46	48	25	138
Pumping systems		0	0	250	157	193	175	193
A.2 Conventional		***560***	***2467***	***0***	***0***	***0***	***0***	***0***
Lignite		0	2431	0	0	0	0	0
Natural Gas		0	0	0	0	0	0	0
Oil products		0	0	0	0	0	0	0
Anti-pollution		560	36	0	0	0	0	0
A.3 Total investments (cumulative)		***2788***	***8138***	***10632***	***12156***	***14883***	***19614***	***22902***
B. Levelized cost (€ 2015/MWh)	**87.70**	**91.88**	**105.19**	**103.07**	**103.86**	**104.59**	**104.74**	**103.15**
C. Levelized cost except for investments before 1995 (€ 2015/MWh)	**72.45**	**77.53**	**93.45**	**92.65**	**95.88**	**96.96**	**97.37**	**96.04**

Table 2-4. Energy Consumption and Indexes in the Industry

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	23748	28525	22368	18592	17619	17969	18827	20440	22025	23110	24137
FINAL ENERGY CONSUMPTION (ktoe)	**5246**	**5342**	**4658**	**3920**	**3874**	**4004**	**4204**	**4460**	**4717**	**4937**	**5160**
per sector											
non-metallic minerals	1374	1517	909	821	911	1003	1111	1172	1237	1316	1405
cement	1154	1263	801	730	809	888	981	1023	1070	1133	1205
lime	64	79	51	53	50	50	52	56	61	63	66
glass	27	34	30	29	27	27	28	31	33	34	36
ceramic industry	129	141	27	10	25	37	49	61	74	86	98
paper	161	129	141	120	112	113	117	127	137	144	150
non-ferrous	746	834	653	840	838	827	824	821	820	819	820
iron industry	195	220	171	97	108	121	139	153	166	176	185
other industries	2769	2642	2784	2041	1904	1939	2013	2187	2357	2482	2601
per fuel											
solid fuel (coal and lignite)	802	455	284	223	233	263	281	294	309	328	349
oil products	2622	2813	2092	1638	1439	1367	1457	1555	1653	1734	1819
diesel	509	453	314	291	196	152	151	156	161	163	166
fuel oil	852	676	362	301	227	189	189	194	198	200	202
other oil products	1261	1685	1416	1046	1017	1026	1117	1205	1295	1371	1451
natural gas	339	530	727	718	845	953	974	1021	1067	1107	1146
biomass-waste	217	233	285	168	167	207	228	265	303	337	370
solar systems and other RES	0	2	4	6	5	6	7	7	9	10	11
electricity	1260	1294	1135	1026	1024	1047	1096	1154	1210	1256	1300
cogeneration steam	6	14	132	142	160	162	163	164	165	165	166
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	9952	10226	6862	7734	7758	7942	8321	8633	8956	9286	9647
CH_4 (kt)	0.5	0.6	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.8
N_2O (kt)	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5
CO_2 eq (kt)	**10041**	**10331**	**6950**	**7815**	**7852**	**8052**	**8437**	**8760**	**9093**	**9432**	**9803**
INDEXES											
energy intensity (ktoe / M€ 2010)	0.22	0.19	0.21	0.21	0.22	0.22	0.22	0.22	0.21	0.21	0.21
CO2 emissions per energy unit (t / toe)	1.90	1.91	1.47	1.97	2.00	1.98	1.98	1.94	1.90	1.88	1.87
emissions intensity (kt CO_2 / M€ 2010)	0.42	0.36	0.31	0.42	0.44	0.44	0.44	0.42	0.41	0.40	0.40

Table 2-5. Energy Consumption and Indexes in transportation

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
GNP per inh. (€ 2010/inh.)	17416	20947	20328	16989	18708	19116	20124	22058	24046	25466	26983
Private consumption per household (€2010/hh)	35791	40844	38374	30744	31913	31662	32362	34443	36456	37488	38568
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
TRANSPORTATION LOAD											
passenger transportation (Gpkm)	**128**	**160**	**175**	**168**	**170**	**173**	**176**	**180**	**182**	**182**	**182**
road transportation	118	149	164	160	162	165	168	172	173	173	173
cars and motorcycles	98	130	145	144	147	150	153	157	158	159	158
buses	20	20	19	16	15	14	14	15	15	15	15
trains	3	3	4	4	4	4	4	4	4	4	4
domestic aviation	2	1	1	1	1	1	1	1	1	1	1
domestic navigation	5	6	6	4	4	4	4	4	4	4	4
freight transportation (Gtkm)	**27**	**31**	**28**	**21**	**20**	**20**	**21**	**22**	**24**	**24**	**25**
trucks	19	21	20	14	13	13	14	15	16	17	18
trains	0	0	0	0	0	0	0	0	0	0	0
domestic navigation	8	9	8	7	7	7	7	7	7	7	7
FINAL ENERGY CONSUMPTION (ktoe)	**6453**	**7541**	**7105**	**5829**	**5568**	**5546**	**5576**	**5702**	**5751**	**5746**	**5724**
per transportation means											
road transportation	5320	6413	6091	5147	4894	4867	4891	5001	5044	5036	5014
cars and motorcycles	2901	3670	3707	3488	3425	3413	3398	3405	3351	3280	3199
buses	158	152	141	119	105	100	101	102	102	100	99
trucks	2261	2591	2243	1539	1364	1354	1392	1494	1592	1656	1716
trains	49	54	58	55	54	54	56	58	59	59	59
domestic aviation	515	416	244	188	187	189	191	195	196	197	196
domestic navigation	569	658	712	439	434	435	439	448	452	453	454
per type of activity											
passenger transportation	4127	4875	4794	4233	4149	4137	4129	4150	4100	4029	3946
freight transportation	2326	2666	2311	1596	1419	1409	1447	1552	1652	1717	1778
per fuel											
Solid Fuel	0	0	0	0	0	0	0	0	0	0	0
oil products	6437	7508	6938	5614	5256	5037	5021	5144	5192	5186	5164
diesel	2199	2550	2257	1886	1879	1960	1960	2061	2133	2172	2202
fuel oil	253	316	435	252	249	249	251	257	259	260	260
petrol	3403	4126	3901	3039	2671	2353	2329	2336	2307	2260	2208
LPG	26	31	68	227	245	257	261	265	266	267	267
other oil products	556	485	275	211	213	217	220	225	226	227	227
natural gas	0	15	15	19	23	26	26	27	27	27	27
biofuel	0	0	124	164	230	424	470	470	470	470	470
electricity	16	18	29	31	58	58	60	62	62	63	63
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	18427	21192	21991	16559	15529	14917	14870	15246	15399	15388	15330
CH_4 (kt)	4.9	4.8	4.3	5.8	5.1	4.8	4.8	4.8	4.7	4.7	4.6
N_2O (kt)	1.2	1.3	1.1	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6
CO_2 eq (kt)	**18899**	**21708**	**22418**	**17221**	**16140**	**15513**	**15465**	**15846**	**15995**	**15976**	**15908**
INDEXES											
energy consumption per inh. (toe / inh.)	0.59	0.69	0.64	0.54	0.51	0.50	0.51	0.52	0.52	0.52	0.53
biofuel share (%)	0.0%	0.0%	2.1%	3.4%	5.0%	9.3%	10.3%	10.0%	10.0%	10.0%	10.0%
coal intensity (kt CO_2 / M€ 2010)	0.10	0.09	0.10	0.09	0.08	0.07	0.07	0.06	0.06	0.06	0.05
CO2 emissions per inh. (t CO_2 / inh.)	1.7	1.9	2.0	1.5	1.4	1.4	1.3	1.4	1.4	1.4	1.4
passenger transportation efficiency (toe/Mpkm)	32.4	30.5	27.4	25.2	24.5	24.0	23.5	23.0	22.6	22.1	21.7
freight transportation efficiency (toe/Mpkm)	85.9	86.4	81.4	74.8	70.5	69.9	69.9	70.1	70.2	70.1	70.0

Table 2-6. Energy Consumption and Indexes in the Agricultural Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	7635	7799	6519	6658	6110	5936	5907	6139	6313	6243	6119
FINAL ENERGY CONSUMPTION (ktoe)	**1130**	**1157**	**899**	**791**	**796**	**806**	**817**	**830**	**843**	**854**	**864**
per energy use											
greenhouses	208	173	176	178	181	184	187	190	194	197	200
other agricultural uses	922	984	723	613	615	622	630	640	650	657	664
per fuel											
Solid Fuel	0	0	0	0	0	0	0	0	0	0	0
oil products	884	885	619	470	456	444	443	444	445	443	441
diesel	811	830	541	391	373	360	359	360	360	358	356
other oil products	73	54	78	79	83	84	84	85	85	85	86
natural gas	0	0	0	0	0	0	0	0	0	0	0
biomass-waste	11	22	37	47	52	59	61	64	66	69	71
solar systems and other RES	3	3	5	6	6	7	7	8	8	8	8
electricity	232	247	238	268	282	296	306	315	324	333	342
cogeneration steam	0	0	0	0	0	0	0	0	0	0	0
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	2612	2705	1682	1443	1400	1365	1362	1366	1368	1363	1357
CH_4 (kt)	0.4	0.4	0.4	0.8	0.9	1.0	1.0	1.0	1.1	1.1	1.1
N_2O (kt)	0.9	1.0	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CO_2 eq (kt)	**2896**	**3004**	**1876**	**1616**	**1571**	**1537**	**1534**	**1540**	**1544**	**1539**	**1534**
INDEXES											
energy intensity (toe / M€ 2010)	148	148	138	119	130	136	138	135	134	137	141
energy consumption per inh. (toe / inh.)	0.10	0.11	0.08	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08
emissions intensity (kt CO_2 / M€ 2010)	0.34	0.35	0.26	0.22	0.23	0.23	0.23	0.22	0.22	0.22	0.22

Table 2-7. Energy Consumption and Indexes in the Agricultural Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	128017	157443	161870	135150	147644	152541	161914	178183	194620	205655	216323
FINAL ENERGY CONSUMPTION (ktoe)	**1320**	**1821**	**1878**	**1807**	**1883**	**1878**	**1927**	**2026**	**2126**	**2193**	**2259**
per sector											
offices	101	303	311	287	298	297	307	323	339	351	363
commerce	395	541	588	531	599	596	606	628	650	666	683
hotels	368	463	429	457	477	479	497	530	562	586	610
public sector	455	515	550	532	509	506	517	546	575	590	603
per energy use											
heating	326	470	474	442	444	439	445	468	491	507	524
air-conditioning	536	734	756	747	787	797	823	869	916	946	975
electrical appliances and lighting	459	617	648	618	652	641	659	689	720	740	760
per fuel											
Solid Fuel	0	0	3	4	4	4	4	4	4	4	4
oil products	253	337	221	178	165	155	156	164	172	176	181
natural gas	12	60	124	137	151	162	161	166	170	174	177
biomass-waste	0	0	0	0	0	0	0	0	0	0	0
solar systems and other RES	3	4	6	7	8	9	10	11	12	13	14
electricity	1052	1416	1515	1470	1545	1538	1586	1671	1756	1813	1870
cogeneration steam	0	5	9	11	10	11	11	12	12	13	14
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	785	1549	1150	935	926	922	922	963	1001	1026	1050
CH_4 (kt)	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N_2O (kt)	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CO_2 eq (kt)	**786**	**1552**	**1152**	**961**	**950**	**946**	**946**	**988**	**1028**	**1053**	**1078**
INDEXES											
energy intensity (toe / M€ 2010)	10.31	11.57	11.60	13.37	12.76	12.31	11.90	11.37	10.93	10.67	10.44
energy consumption per inh. (toe / inh.)	0.12	0.17	0.17	0.17	0.17	0.17	0.17	0.18	0.19	0.20	0.21
emissions intensity (t CO_2 / M€ 2010)	6.1	9.8	7.1	6.9	6.3	6.0	5.7	5.4	5.1	5.0	4.9

Table 2-8. Energy Consumption and Indexes in the Residential Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
GNP per inh. (€ 2010/inh.)	17416	20947	20328	16989	18708	19116	20124	22058	24046	25466	26983
Private consumption (M€ 2010)	126461	153952	156803	127077	137192	140864	148598	162873	177188	186715	195856
Private consumption per household (€ 2010/hh)	35791	40844	38374	30744	31913	31662	32362	34443	36456	37488	38568
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
Household size (residents/household)	3.09	2.91	2.72	2.63	2.55	2.48	2.40	2.33	2.27	2.20	2.14
FINAL ENERGY CONSUMPTION (ktoe)	**4364**	**5294**	**4863**	**4351**	**4432**	**4437**	**4523**	**4686**	**4872**	**5026**	**5169**
per energy use											
heating	3053	3846	3311	2805	2840	2823	2869	2991	3131	3238	3336
cooking	291	287	295	298	310	320	331	340	350	358	365
hot water	557	632	639	624	629	630	631	630	629	626	619
air-conditioning	38	62	94	132	148	169	190	211	236	266	299
electrical appliances and lighting	426	467	524	493	506	496	502	513	526	538	549
per fuel											
Solid Fuel	13	5	5	5	5	5	5	5	5	5	5
oil products	2484	3186	2333	1643	1654	1569	1593	1694	1805	1878	1946
diesel	2354	3124	2280	1580	1579	1486	1511	1614	1729	1803	1873
other oil products	130	62	53	62	75	83	83	80	76	75	73
natural gas	6	72	255	287	368	443	459	495	535	563	590
biomass-waste	579	463	581	777	740	743	740	711	680	667	650
solar systems and other RES	81	99	140	162	191	226	232	238	243	247	250
electricity	1187	1454	1519	1446	1443	1420	1461	1511	1571	1634	1697
cogeneration steam	13	15	31	31	31	31	31	31	31	31	31
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	7653	9960	6742	5714	5932	5844	5955	6350	6786	7076	7348
CH_4 (kt)	5.0	3.4	3.6	10.6	10.1	10.2	10.2	9.8	9.4	9.2	9.0
N_2O (kt)	0.2	0.1	0.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1
CO_2 eq (kt)	**7830**	**10089**	**6871**	**6276**	**6479**	**6384**	**6497**	**6890**	**7325**	**7618**	**7891**
INDEXES											
energy intensity (ktoe / M€ 2010)	0.035	0.034	0.031	0.034	0.032	0.032	0.030	0.029	0.027	0.027	0.026
energy consumption per inh. (toe / inh.)	0.40	0.48	0.44	0.40	0.40	0.40	0.41	0.42	0.44	0.46	0.48
emissions intensity (kt CO_2/ M€ 2010)	0.061	0.065	0.043	0.045	0.043	0.041	0.040	0.039	0.038	0.038	0.038
CO2 emissions per inh. (t / inh.)	0.70	0.91	0.61	0.53	0.54	0.53	0.54	0.58	0.62	0.65	0.68

3. Results for the Expansion with RES (RES) Scenario

Table 3-1. Energy Balance Summary

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
PRIMARY GENERATION (ktoe)	**9845**	**10026**	**9710**	**8630**	**7992**	**7673**	**7404**	**6353**	**6661**	**6877**	**7050**
solid fuel	8296	8490	7494	6015	4874	3726	2737	945	915	891	908
Oil products	261	91	50	0	0	0	0	0	0	0	0
RES	1289	1444	2167	2615	3118	3947	4667	5409	5746	5986	6142
Natural Gas	0	0	0	0	0	0	0	0	0	0	0
NET IMPORTS (ktoe)	**18221**	**21058**	**18984**	**16529**	**16018**	**14820**	**14253**	**14871**	**15077**	**15242**	**15529**
solid fuel	823	499	344	249	250	271	281	280	295	313	334
Oil products	15740	17966	15203	12751	11675	10234	9714	10054	10287	10383	10455
RES	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	1659	2268	2947	3375	3938	4161	4105	4383	4341	4391	4586
Electricity	-1	325	490	154	154	154	154	154	154	154	154
GROSS DOMESTIC CONSUMPTION (ktoe)	**28067**	**31083**	**28694**	**25159**	**24010**	**22493**	**21657**	**21224**	**21739**	**22119**	**22579**
solid fuel	9119	8989	7838	6264	5125	3996	3017	1224	1210	1204	1242
Oil products	16001	18057	15253	12751	11675	10234	9714	10054	10287	10383	10455
RES	1289	1444	2167	2615	3118	3947	4667	5409	5746	5986	6142
Natural Gas	1659	2268	2947	3375	3938	4161	4105	4383	4341	4391	4586
Electricity	-1	325	490	154	154	154	154	154	154	154	154
NET ELECTRICITY GENERATION (ktoe)	**4200**	**4686**	**4504**	**4597**	**4739**	**4750**	**4902**	**5134**	**5374**	**5565**	**5769**
Lignite	2601	2726	2364	1962	1582	1200	890	303	293	285	290
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	651	629	394	343	314	186	51	51	51	51	51
Natural Gas	567	746	813	1077	1245	1257	1207	1306	1236	1225	1290
RES	382	585	934	1214	1598	2107	2753	3474	3794	4004	4137
FINAL ENERGY CONSUMPTION (ktoe)	**18514**	**21156**	**19403**	**16698**	**16553**	**16676**	**17048**	**17703**	**18307**	**18757**	**19179**
per sector											
agricultural	1130	1157	899	791	796	806	817	830	843	854	864
industrial	5246	5342	4658	3920	3874	4005	4204	4459	4716	4937	5161
residential	4364	5294	4863	4351	4432	4439	4523	4686	4871	5026	5170
tertiary	1320	1821	1878	1807	1883	1880	1928	2026	2125	2194	2260
transportation	6453	7541	7105	5829	5568	5546	5576	5702	5751	5746	5724
per fuel											
solid fuel	815	461	292	232	243	272	290	304	319	338	358
oil products	12681	14729	12203	9542	8971	8572	8668	9001	9268	9418	9550
electricity	3747	4429	4435	4241	4353	4367	4512	4711	4921	5101	5278
thermal energy	19	34	172	184	201	204	205	207	208	209	211
RES	894	827	1180	1338	1399	1679	1754	1773	1791	1820	1844
natural gas	358	676	1121	1161	1387	1583	1619	1709	1800	1871	1939
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	94078	103605	90421	75755	69490	61797	55547	47893	48388	48847	49820
CH_4 (kt)	69.5	73.4	62.6	58.5	49.7	41.9	35.2	22.9	22.4	22.0	21.9
N_2O (kt)	3.1	3.4	2.6	4.1	4.0	3.9	3.8	3.8	3.9	3.9	3.9
CO_2 eq (kt)	**96742**	**106443**	**92765**	**78447**	**71923**	**64006**	**57573**	**49606**	**50102**	**50561**	**51540**
INDEXES											
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
GNP (M€ 2010)	189901	229785	226032	184468	205133	210623	222188	243533	264935	279181	292849
Gross Domestic Cons./GNP (ktoe/M€ 2010)	0.15	0.135	0.127	0.136	0.117	0.107	0.097	0.087	0.082	0.079	0.077
Gross Domestic Consumption/inh. (toe / inh.)	2.57	2.83	2.58	2.32	2.19	2.04	1.96	1.92	1.97	2.02	2.08
Gross Final Energy Consumption (ktoe)	19299	21949	19794	17539	17724	18061	18626	19460	20280	20836	21372
RES in the final energy consumption	7.7%	6.4%	11.2%	15.4%	19.3%	24.2%	28.2%	31.8%	33.1%	33.6%	33.8%
Coal intensity (kt CO_2/M€ 2010)	0.50	0.45	0.40	0.41	0.34	0.29	0.25	0.20	0.18	0.17	0.17
CO_2 emissions / inh. (t CO_2 / inh.)	8.63	9.44	8.13	6.98	6.34	5.61	5.03	4.34	4.39	4.46	4.59
CO_2 emissions / Gross Energy Cons. (t / toe)	3.35	3.33	3.15	3.01	2.89	2.75	2.56	2.26	2.23	2.21	2.21
Dependence on imports (%)	65%	68%	66%	66%	67%	66%	66%	70%	69%	69%	69%

Table 3-2. Electricity generation

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ELECTRICITY DEMAND (TWh)	**43578**	**51509**	**51579**	**49323**	**50625**	**50788**	**52475**	**54789**	**57231**	**59325**	**61383**
Industry	14654	15049	13200	11932	11909	12188	12746	13409	14072	14619	15131
Transportation	186	209	337	361	675	675	698	721	721	733	733
Agriculture	2698	2873	2768	3117	3280	3454	3559	3663	3768	3873	3989
Tertiary	12235	16468	17619	17096	17968	17922	18457	19422	20411	21097	21760
Residential	13805	16910	17666	16817	16782	16549	17015	17573	18259	19003	19759
NET ELECTRICITY GENERATION (TWh)	**50579**	**60115**	**60906**	**55905**	**57557**	**57685**	**59453**	**62151**	**64942**	**67163**	**69536**
Lignite	30250	31703	27493	22818	18399	13956	10351	3524	3408	3315	3373
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	7571	7315	4582	3989	3652	2163	593	593	593	593	593
Natural Gas	6594	8676	9455	12526	14479	14619	14037	15189	14375	14247	15003
Hydroelectric systems	3989	5350	7385	4815	5862	6036	6036	6036	6036	6036	6036
Wind systems	454	1314	3012	4826	6862	10455	15747	20911	23097	24062	24062
Biomass	0	140	279	361	779	1023	1023	1023	1023	1023	1023
Geothermal energy	0	0	0	0	0	58	58	58	58	58	58
Photovoltaic systems	0	0	186	4117	5082	6931	9153	12386	13909	15398	16945
Imports	1733	5617	8513	2442	2442	2442	2442	2442	2442	2442	2442
INSTALLED POWER CAPACITY (MW)	**10931**	**12716**	**14911**	**19279**	**20484**	**21407**	**24223**	**27857**	**30400**	**32147**	**33436**
Lignite	4457	4746	4746	3912	3912	2256	1745	631	631	631	631
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	2114	2289	2201	1810	1404	980	532	532	532	532	532
Natural Gas	1062	2063	3208	5188	5188	5188	5188	5188	5188	5188	5188
Hydroelectric systems	3072	3106	3215	3389	3389	3580	3580	3875	4397	4755	5013
Wind systems	226	491	1298	2182	3088	4625	6922	9222	10222	10622	10622
Biomass		20	41	52	112	147	147	147	147	147	147
Geothermal energy		0	0	0	0	8	8	8	8	8	8
Photovoltaic systems	0	1	202	2746	3391	4624	6102	8254	9275	10264	11296
LOAD INDEX (%)											
Lignite	77%	76%	66%	67%	54%	71%	68%	64%	62%	60%	61%
Coal											
Oil products	41%	36%	24%	25%	30%	25%	13%	13%	13%	13%	13%
Natural Gas	71%	48%	34%	28%	32%	32%	31%	33%	32%	31%	33%
Hydroelectric systems	15%	20%	26%	16%	20%	19%	19%	18%	16%	14%	14%
Wind systems	23%	30%	26%	25%	25%	26%	26%	26%	26%	26%	26%
Biomass		79%	79%	79%	79%	79%	79%	79%	79%	79%	79%
Geothermal energy						75%	75%	75%	75%	75%	75%
Photovoltaic systems			10%	17%	17%	17%	17%	17%	17%	17%	17%
FUEL CONSUMPTION (ktoe)	**11652**	**12156**	**10637**	**9356**	**8449**	**6907**	**5381**	**3764**	**3601**	**3555**	**3698**
Solid Fuel	8303	8526	7527	6014	4864	3706	2709	903	873	849	865
Oil products	2047	2038	1284	1128	1035	622	186	186	186	186	186
Natural Gas	1302	1592	1826	2214	2551	2579	2486	2675	2541	2520	2647
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	51532	54311	48319	38318	32845	25665	18964	10169	9698	9520	9896
CH_4 (kt)	0.6	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
N_2O (kt)	0.6	0.6	0.5	0.5	0.5	0.4	0.3	0.2	0.2	0.2	0.2
CO_2 eq (kt)	**51719**	**54507**	**48487**	**38493**	**33010**	**25804**	**19078**	**10252**	**9778**	**9599**	**9977**
INDEXES	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
RES share in generation (%)	9.1%	12.5%	20.7%	26.4%	33.7%	44.4%	56.2%	67.7%	70.6%	72.0%	71.7%
RES share in gross electricity consumption (%)	9.1%	11.7%	18.7%	25.6%	32.7%	43.0%	54.4%	65.7%	68.6%	70.0%	69.9%
RES share in installed power capacity (%)	30.2%	28.5%	31.9%	43.4%	48.7%	60.6%	69.2%	77.2%	79.1%	80.2%	81.0%
Domestic electricity generation (%)	71.0%	70.7%	73.2%	69.1%	67.1%	69.6%	74.3%	73.6%	76.1%	77.1%	76.8%

Table 3-3. Cost of Electricity Generation

	2015	2020	2025	2030	2035	2040	2045	2050
A. Investments (M€ 2015)		**2515**	**4153**	**5683**	**6920**	**4833**	**5757**	**3419**
A.1 RES		***2239***	***4153***	***5683***	***6920***	***4833***	***5757***	***3419***
Wind systems		1223	2112	3370	3463	2439	1733	1223
Large photovoltaic systems		439	689	1400	1923	987	2732	1032
Residential photovoltaic systems		439	802	85	164	158	444	432
Hydroelectric systems		0	438	0	679	1201	823	593
Geothermal energy		0	32	0	0	0	0	0
Biomass		138	81	0	46	48	25	138
Pumping systems		0	0	827	645	0	0	0
A.2 Conventional		***275***	***0***	***0***	***0***	***0***	***0***	***0***
Lignite		0	0	0	0	0	0	0
Natural Gas		0	0	0	0	0	0	0
Oil products		0	0	0	0	0	0	0
Anti-pollution		275	0	0	0	0	0	0
A.3 Total investments (cumulative)		***2515***	***6668***	***12351***	***19270***	***24104***	***29861***	***33280***
B. Levelized cost (€ 2015/MWh)	**87.70**	**90.83**	**102.10**	**101.79**	**102.88**	**104.35**	**103.20**	**102.33**
C. Levelized cost except for investments before 1995 (€ 2015/MWh)	**72.45**	**76.49**	**91.42**	**92.86**	**96.50**	**98.25**	**97.31**	**96.65**

Table 3-4. Energy Consumption and Indexes in the Industry

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	23748	28525	22368	18592	17619	17969	18827	20440	22025	23110	24137
FINAL ENERGY CONSUMPTION (ktoe)	**5246**	**5342**	**4658**	**3920**	**3874**	**4005**	**4204**	**4459**	**4716**	**4937**	**5161**
per sector											
non-metallic minerals	1374	1517	909	821	911	1003	1111	1172	1237	1316	1405
cement	1154	1263	801	730	809	888	981	1023	1070	1133	1205
lime	64	79	51	53	50	50	52	56	61	63	66
glass	27	34	30	29	27	27	28	31	33	34	36
ceramic industry	129	141	27	10	25	37	49	61	74	86	98
paper	161	129	141	120	112	113	117	127	137	144	150
non-ferrous	746	834	653	840	838	828	823	821	820	820	821
iron industry	195	220	171	97	108	121	139	153	166	176	185
other industries	2769	2642	2784	2041	1904	1940	2013	2187	2357	2482	2601
per fuel											
solid fuel (coal and lignite)	802	455	284	223	233	263	281	294	309	328	349
oil products	2622	2813	2092	1638	1439	1367	1457	1555	1653	1734	1819
diesel	509	453	314	291	196	152	151	156	161	163	165
fuel oil	852	676	362	301	227	189	189	194	198	200	202
other oil products	1261	1685	1416	1046	1017	1026	1117	1205	1295	1371	1451
natural gas	339	530	727	718	845	953	974	1021	1067	1107	1146
biomass-waste	217	233	285	168	167	207	228	265	303	337	370
solar systems and other RES	0	2	4	6	5	6	7	7	9	10	11
electricity	1260	1294	1135	1026	1024	1048	1096	1153	1210	1257	1301
cogeneration steam	6	14	132	142	160	162	163	164	165	165	166
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	9952	10226	6862	7734	7758	7942	8321	8633	8956	9286	9647
CH_4 (kt)	0.5	0.6	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.8
N_2O (kt)	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5
CO_2 eq (kt)	**10041**	**10331**	**6950**	**7815**	**7852**	**8052**	**8437**	**8760**	**9093**	**9432**	**9803**
INDEXES											
energy intensity (ktoe / M€ 2010)	0.22	0.19	0.21	0.21	0.22	0.22	0.22	0.22	0.21	0.21	0.21
CO2 emissions per energy unit (t / toe)	1.90	1.91	1.47	1.97	2.00	1.98	1.98	1.94	1.90	1.88	1.87
emissions intensity (kt CO_2 / M€ 2010)	0.42	0.36	0.31	0.42	0.44	0.44	0.44	0.42	0.41	0.40	0.40

Table 3-5. Energy Consumption and Indexes in transportation

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
GNP per inh. (€ 2010/inh.)	17416	20947	20328	16989	18708	19116	20124	22058	24046	25466	26983
Private consumption per household (€2010/hh)	35791	40844	38374	30744	31913	31662	32362	34443	36456	37488	38568
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
TRANSPORTATION LOAD											
passenger transportation (Gpkm)	**128**	**160**	**175**	**168**	**170**	**173**	**176**	**180**	**182**	**182**	**182**
road transportation	118	149	164	160	162	165	168	172	173	173	173
cars and motorcycles	98	130	145	144	147	150	153	157	158	159	158
buses	20	20	19	16	15	14	14	15	15	15	15
trains	3	3	4	4	4	4	4	4	4	4	4
domestic aviation	2	1	1	1	1	1	1	1	1	1	1
domestic navigation	5	6	6	4	4	4	4	4	4	4	4
freight transportation (Gtkm)	**27**	**31**	**28**	**21**	**20**	**20**	**21**	**22**	**24**	**24**	**25**
trucks	19	21	20	14	13	13	14	15	16	17	18
trains	0	0	0	0	0	0	0	0	0	0	0
domestic navigation	8	9	8	7	7	7	7	7	7	7	7
FINAL ENERGY CONSUMPTION (ktoe)	**6453**	**7541**	**7105**	**5829**	**5568**	**5546**	**5576**	**5702**	**5751**	**5746**	**5724**
per transportation means											
road transportation	5320	6413	6091	5147	4894	4867	4891	5001	5044	5036	5014
cars and motorcycles	2901	3670	3707	3488	3425	3413	3398	3405	3351	3280	3199
buses	158	152	141	119	105	100	101	102	102	100	99
trucks	2261	2591	2243	1539	1364	1354	1392	1494	1592	1656	1716
trains	49	54	58	55	54	54	56	58	59	59	59
domestic aviation	515	416	244	188	187	189	191	195	196	197	196
domestic navigation	569	658	712	439	434	435	439	448	452	453	454
per type of activity											
passenger transportation	4127	4875	4794	4233	4149	4137	4129	4150	4100	4029	3946
freight transportation	2326	2666	2311	1596	1419	1409	1447	1552	1652	1717	1778
per fuel											
Solid Fuel	0	0	0	0	0	0	0	0	0	0	0
oil products	6437	7508	6938	5614	5256	5037	5021	5144	5192	5186	5164
diesel	2199	2550	2257	1886	1879	1960	1960	2061	2133	2172	2202
fuel oil	253	316	435	252	249	249	251	257	259	260	260
petrol	3403	4126	3901	3039	2671	2353	2329	2336	2307	2260	2208
LPG	26	31	68	227	245	257	261	265	266	267	267
other oil products	556	485	275	211	213	217	220	225	226	227	227
natural gas	0	15	15	19	23	26	26	27	27	27	27
biofuel	0	0	124	164	230	424	470	470	470	470	470
electricity	16	18	29	31	58	58	60	62	62	63	63
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	18427	21192	21991	16559	15529	14917	14870	15246	15399	15388	15330
CH_4 (kt)	4.9	4.8	4.3	5.8	5.1	4.8	4.8	4.8	4.7	4.7	4.6
N_2O (kt)	1.2	1.3	1.1	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6
CO_2 eq (kt)	**18899**	**21708**	**22418**	**17221**	**16140**	**15513**	**15465**	**15846**	**15995**	**15976**	**15908**
INDEXES											
energy consumption per inh. (toe / inh.)	0.59	0.69	0.64	0.54	0.51	0.50	0.51	0.52	0.52	0.52	0.53
biofuel share (%)	0.0%	0.0%	2.1%	3.4%	5.0%	9.3%	10.3%	10.0%	10.0%	10.0%	10.0%
coal intensity (kt CO_2 / M€ 2010)	0.10	0.09	0.10	0.09	0.08	0.07	0.07	0.06	0.06	0.06	0.05
CO2 emissions per inh. (t CO_2 / inh.)	1.7	1.9	2.0	1.5	1.4	1.4	1.3	1.4	1.4	1.4	1.4
passenger transportation efficiency (toe/Mpkm)	32.4	30.5	27.4	25.2	24.5	24.0	23.5	23.0	22.6	22.1	21.7
freight transportation efficiency (toe/Mpkm)	85.9	86.4	81.4	74.8	70.5	69.9	69.9	70.1	70.2	70.1	70.0

Table 3-6. Energy Consumption and Indexes in the Agricultural Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	7635	7799	6519	6658	6110	5936	5907	6139	6313	6243	6119
FINAL ENERGY CONSUMPTION (ktoe)	**1130**	**1157**	**899**	**791**	**796**	**806**	**817**	**830**	**843**	**854**	**864**
per energy use											
greenhouses	208	173	176	178	181	184	187	190	194	197	200
other agricultural uses	922	984	723	613	615	622	630	640	650	657	664
per fuel											
Solid Fuel	0	0	0	0	0	0	0	0	0	0	0
oil products	884	885	619	470	456	444	443	444	445	443	441
diesel	811	830	541	391	373	360	359	360	360	358	355
other oil products	73	54	78	79	83	84	84	85	85	85	86
natural gas	0	0	0	0	0	0	0	0	0	0	0
biomass-waste	11	22	37	47	52	59	61	64	66	69	71
solar systems and other RES	3	3	5	6	6	7	7	8	8	8	8
electricity	232	247	238	268	282	297	306	315	324	333	343
cogeneration steam	0	0	0	0	0	0	0	0	0	0	0
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	2612	2705	1682	1443	1400	1365	1361	1366	1368	1363	1356
CH_4 (kt)	0.4	0.4	0.4	0.8	0.9	1.0	1.0	1.0	1.1	1.1	1.1
N_2O (kt)	0.9	1.0	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CO_2 eq (kt)	**2896**	**3004**	**1876**	**1616**	**1571**	**1536**	**1533**	**1540**	**1543**	**1539**	**1533**
INDEXES											
energy intensity (toe / M€ 2010)	148	148	138	119	130	136	138	135	134	137	141
energy consumption per inh. (toe / inh.)	0.10	0.11	0.08	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08
emissions intensity (kt CO_2 / M€ 2010)	0.34	0.35	0.26	0.22	0.23	0.23	0.23	0.22	0.22	0.22	0.22

Table 3-7. Energy Consumption and Indexes in the Agricultural Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	128017	157443	161870	135150	147644	152541	161914	178183	194620	205655	216323
FINAL ENERGY CONSUMPTION (ktoe)	**1320**	**1821**	**1878**	**1807**	**1883**	**1880**	**1928**	**2026**	**2125**	**2194**	**2260**
per sector											
offices	101	303	311	287	298	298	307	322	339	351	363
commerce	395	541	588	531	599	596	606	627	649	666	683
hotels	368	463	429	457	477	480	497	530	562	586	611
public sector	455	515	550	532	509	506	517	546	575	590	603
per energy use											
heating	326	470	474	442	444	440	444	468	490	508	524
air-conditioning	536	734	756	747	787	798	823	869	916	946	975
electrical appliances and lighting	459	617	648	618	652	643	660	689	719	740	761
per fuel											
Solid Fuel	0	0	3	4	4	4	4	4	4	4	4
oil products	253	337	221	178	165	155	156	164	172	176	181
natural gas	12	60	124	137	151	161	160	166	170	174	177
biomass-waste	0	0	0	0	0	0	0	0	0	0	0
solar systems and other RES	3	4	6	7	8	9	10	11	12	13	14
electricity	1052	1416	1515	1470	1545	1541	1587	1670	1755	1814	1871
cogeneration steam	0	5	9	11	10	11	11	12	12	13	14
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	785	1549	1150	935	926	921	921	962	1001	1026	1050
CH_4 (kt)	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N_2O (kt)	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CO_2 eq (kt)	**786**	**1552**	**1152**	**961**	**950**	**945**	**945**	**987**	**1027**	**1053**	**1077**
INDEXES											
energy intensity (toe / M€ 2010)	10.31	11.57	11.60	13.37	12.75	12.33	11.90	11.37	10.92	10.67	10.45
energy consumption per inh. (toe / inh.)	0.12	0.17	0.17	0.17	0.17	0.17	0.17	0.18	0.19	0.20	0.21
emissions intensity (t CO_2 / M€ 2010)	6.1	9.8	7.1	6.9	6.3	6.0	5.7	5.4	5.1	5.0	4.9

Table 3-8. Energy Consumption and Indexes in the Residential Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
GNP per inh. (€ 2010/inh.)	17416	20947	20328	16989	18708	19116	20124	22058	24046	25466	26983
Private consumption (M€ 2010)	126461	153952	156803	127077	137192	140864	148598	162873	177188	186715	195856
Private consumption per household (€ 2010/hh)	35791	40844	38374	30744	31913	31662	32362	34443	36456	37488	38568
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
Household size (residents/household)	3.09	2.91	2.72	2.63	2.55	2.48	2.40	2.33	2.27	2.20	2.14
FINAL ENERGY CONSUMPTION (ktoe)	**4364**	**5294**	**4863**	**4351**	**4432**	**4439**	**4523**	**4686**	**4871**	**5026**	**5170**
per energy use											
heating	3053	3846	3311	2805	2840	2823	2869	2990	3131	3239	3337
cooking	291	287	295	298	310	320	331	340	350	358	365
hot water	557	632	639	624	629	630	631	630	629	626	619
air-conditioning	38	62	94	132	148	169	190	211	236	266	299
electrical appliances and lighting	426	467	524	493	506	497	503	513	526	538	550
per fuel											
Solid Fuel	13	5	5	5	5	5	5	5	5	5	5
oil products	2484	3186	2333	1643	1654	1568	1593	1694	1806	1878	1945
diesel	2354	3124	2280	1580	1579	1486	1510	1614	1730	1804	1872
other oil products	130	62	53	62	75	82	83	80	76	75	73
natural gas	6	72	255	287	368	443	459	495	535	563	590
biomass-waste	579	463	581	777	740	743	740	711	680	667	650
solar systems and other RES	81	99	140	162	191	225	232	238	243	247	249
electricity	1187	1454	1519	1446	1443	1423	1463	1511	1570	1634	1699
cogeneration steam	13	15	31	31	31	31	31	31	31	31	31
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	7653	9960	6742	5714	5933	5840	5952	6350	6789	7077	7345
CH_4 (kt)	5.0	3.4	3.6	10.6	10.2	10.2	10.2	9.8	9.4	9.2	9.0
N_2O (kt)	0.2	0.1	0.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1
CO_2 eq (kt)	**7830**	**10089**	**6871**	**6276**	**6479**	**6380**	**6494**	**6890**	**7328**	**7619**	**7888**
INDEXES											
energy intensity (ktoe / M€ 2010)	0.035	0.034	0.031	0.034	0.032	0.032	0.030	0.029	0.027	0.027	0.026
energy consumption per inh. (toe / inh.)	0.40	0.48	0.44	0.40	0.40	0.40	0.41	0.42	0.44	0.46	0.48
emissions intensity (kt CO_2/ M€ 2010)	0.061	0.065	0.043	0.045	0.043	0.041	0.040	0.039	0.038	0.038	0.038
CO2 emissions per inh. (t / inh.)	0.70	0.91	0.61	0.53	0.54	0.53	0.54	0.58	0.62	0.65	0.68

4. Results for the Energy Saving (EE) Scenario

Table 4-1. Energy Balance Summary

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
PRIMARY GENERATION (ktoe)	**9845**	**10026**	**9710**	**8630**	**7992**	**7757**	**7526**	**6422**	**6619**	**6820**	**6982**
solid fuel	8296	8490	7494	6015	4874	4012	3299	1649	1633	1623	1613
Oil products	261	91	50	0	0	0	0	0	0	0	0
RES	1289	1444	2167	2615	3118	3745	4227	4773	4986	5197	5369
Natural Gas	0	0	0	0	0	0	0	0	0	0	0
NET IMPORTS (ktoe)	**18221**	**21058**	**18984**	**16529**	**16018**	**13993**	**13664**	**14414**	**14646**	**14628**	**14611**
solid fuel	823	499	344	249	250	273	285	285	300	319	340
Oil products	15740	17966	15203	12751	11675	10138	9544	9757	9851	9775	9684
RES	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	1659	2268	2947	3375	3938	3427	3680	4217	4340	4379	4432
Electricity	-1	325	490	154	154	154	154	154	154	154	154
GROSS DOMESTIC CONSUMPTION (ktoe)	**28067**	**31083**	**28694**	**25159**	**24010**	**21750**	**21190**	**20836**	**21265**	**21448**	**21593**
solid fuel	9119	8989	7838	6264	5125	4285	3584	1934	1934	1942	1953
Oil products	16001	18057	15253	12751	11675	10138	9544	9757	9851	9775	9684
RES	1289	1444	2167	2615	3118	3745	4227	4773	4986	5197	5369
Natural Gas	1659	2268	2947	3375	3938	3427	3680	4217	4340	4379	4432
Electricity	-1	325	490	154	154	154	154	154	154	154	154
NET ELECTRICITY GENERATION (ktoe)	**4200**	**4686**	**4504**	**4597**	**4739**	**4364**	**4538**	**4797**	**5051**	**5266**	**5460**
Lignite	2601	2726	2364	1962	1582	1353	1134	594	587	584	581
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	651	629	394	343	314	186	51	51	51	51	51
Natural Gas	567	746	813	1077	1245	887	1007	1252	1285	1292	1308
RES	382	585	934	1214	1598	1938	2346	2901	3128	3339	3520
FINAL ENERGY CONSUMPTION (ktoe)	**18514**	**21156**	**19403**	**16698**	**16553**	**16187**	**16510**	**17052**	**17510**	**17755**	**17970**
per sector											
agricultural	1130	1157	899	791	796	806	817	812	807	800	794
industrial	5246	5342	4658	3920	3874	3816	3978	4190	4402	4579	4758
residential	4364	5294	4863	4351	4432	4257	4334	4461	4581	4614	4634
tertiary	1320	1821	1878	1807	1883	1763	1807	1891	1973	2021	2065
transportation	6453	7541	7105	5829	5568	5545	5574	5698	5747	5741	5719
per fuel											
solid fuel	815	461	292	232	243	272	290	304	319	338	358
oil products	12681	14729	12203	9542	8971	8493	8539	8781	8945	8956	8956
electricity	3747	4429	4435	4241	4353	4014	4179	4405	4636	4827	5007
thermal energy	19	34	172	184	201	203	204	205	207	207	208
RES	894	827	1180	1338	1399	1646	1720	1711	1698	1697	1688
natural gas	358	676	1121	1161	1387	1559	1579	1646	1705	1730	1753
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	94078	103605	90421	75755	69490	61324	57064	50479	51121	51210	51318
CH_4 (kt)	69.5	73.4	62.6	58.5	49.7	43.1	38.3	26.7	25.9	25.4	24.8
N_2O (kt)	3.1	3.4	2.6	4.1	4.0	3.8	3.8	3.7	3.7	3.7	3.6
CO_2 eq (kt)	**96742**	**106443**	**92765**	**78447**	**71923**	**63537**	**59145**	**52257**	**52882**	**52945**	**53024**
INDEXES											
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
GNP (M€ 2010)	189901	229785	226032	184468	205133	210623	222188	243533	264935	279181	292849
Gross Domestic Cons./GNP (ktoe/M€ 2010)	0.15	0.135	0.127	0.136	0.117	0.103	0.095	0.086	0.080	0.077	0.074
Gross Domestic Cons./inh. (toe / inh.)	2.57	2.83	2.58	2.32	2.19	1.97	1.92	1.89	1.93	1.96	1.99
Gross Final Energy Consumption (ktoe)	19299	21949	19794	17539	17724	17544	18073	18802	19479	19833	20160
RES in the final energy consumption	7.7%	6.4%	11.2%	15.4%	19.3%	23.7%	26.6%	29.5%	30.5%	31.3%	32.0%
Coal intensity (kt CO_2/M€ 2010)	0.50	0.45	0.40	0.41	0.34	0.29	0.26	0.21	0.19	0.18	0.18
CO_2 emissions / inhabitant (t CO_2 / inh.)	8.63	9.44	8.13	6.98	6.34	5.57	5.17	4.57	4.64	4.67	4.73
CO_2 emissions / Gross Energy Cons. (t/toe)	3.35	3.33	3.15	3.01	2.89	2.82	2.69	2.42	2.40	2.39	2.38
Dependence on imports (%)	65%	68%	66%	66%	67%	64%	64%	69%	69%	68%	68%

Table 4-2. Electricity generation

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ELECTRICITY DEMAND (TWh)	**43578**	**51509**	**51579**	**49323**	**50625**	**46683**	**48602**	**51230**	**53917**	**56138**	**58231**
Industry	14654	15049	13200	11932	11909	10118	10572	11072	11572	11967	12351
Transportation	186	209	337	361	675	977	1396	2047	2687	3256	3780
Agriculture	2698	2873	2768	3117	3280	3442	3547	3501	3442	3408	3361
Tertiary	12235	16468	17619	17096	17968	16794	17317	18213	19120	19736	20294
Residential	13805	16910	17666	16817	16782	15352	15770	16398	17084	17771	18445
NET ELECTRICITY GENERATION (TWh)	**50579**	**60115**	**60906**	**55905**	**57557**	**53196**	**55219**	**58231**	**61185**	**63686**	**65942**
Lignite	30250	31703	27493	22818	18399	15735	13188	6908	6827	6792	6757
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	7571	7315	4582	3989	3652	2163	593	593	593	593	593
Natural Gas	6594	8676	9455	12526	14479	10316	11711	14561	14945	15026	15212
Hydroelectric systems	3989	5350	7385	4815	5862	6036	6036	6036	6036	6036	6036
Wind systems	454	1314	3012	4826	6862	8932	12688	17061	18154	19248	19911
Biomass	0	140	279	361	779	1023	1023	1023	1023	1023	1023
Geothermal energy	0	0	0	0	0	58	58	58	58	58	58
Photovoltaic systems	0	0	186	4117	5082	6501	7490	9560	11107	12467	13921
Imports	1733	5617	8513	2442	2442	2442	2442	2442	2442	2442	2442
INSTALLED POWER CAPACITY (MW)	**10931**	**12716**	**14911**	**19279**	**20484**	**21015**	**22315**	**24581**	**26111**	**27641**	**29224**
Lignite	4457	4746	4746	3912	3912	2856	2345	1231	1231	1231	1231
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	2114	2289	2201	1810	1404	980	532	532	532	532	532
Natural Gas	1062	2063	3208	5188	5188	5188	5188	5188	5188	5188	5188
Hydroelectric systems	3072	3106	3215	3389	3389	3580	3580	3580	3580	3699	4016
Wind systems	226	491	1298	2182	3088	3925	5522	7522	8022	8522	8822
Biomass		20	41	52	112	147	147	147	147	147	147
Geothermal energy		0	0	0	0	8	8	8	8	8	8
Photovoltaic systems	0	1	202	2746	3391	4332	4993	6373	7404	8314	9281
LOAD INDEX (%)											
Lignite	77%	76%	66%	67%	54%	63%	64%	64%	63%	63%	63%
Coal											
Oil products	41%	36%	24%	25%	30%	25%	13%	13%	13%	13%	13%
Natural Gas	71%	48%	34%	28%	32%	23%	26%	32%	33%	33%	33%
Hydroelectric systems	15%	20%	26%	16%	20%	19%	19%	19%	19%	19%	17%
Wind systems	23%	30%	26%	25%	25%	26%	26%	26%	26%	26%	26%
Biomass	77%	79%	79%	79%	79%	79%	79%	79%	79%	79%	79%
Geothermal energy						75%	75%	75%	75%	75%	75%
Photovoltaic systems	41%	0%	10%	17%	17%	17%	17%	17%	17%	17%	17%
FUEL CONSUMPTION (ktoe)	**11652**	**12156**	**10637**	**9356**	**8449**	**6486**	**5563**	**4370**	**4418**	**4423**	**4442**
Solid Fuel	8303	8526	7527	6014	4864	3995	3276	1613	1597	1587	1577
Oil products	2047	2038	1284	1128	1035	622	186	186	186	186	186
Natural Gas	1302	1592	1826	2214	2551	1869	2101	2571	2635	2649	2679
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	51532	54311	48319	38318	32845	25486	20964	13561	13621	13603	13620
CH_4 (kt)	0.6	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
N_2O (kt)	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.3
CO_2 eq (kt)	**51719**	**54507**	**48487**	**38493**	**33010**	**25618**	**21082**	**13655**	**13717**	**13699**	**13716**
INDEXES	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
RES share in generation (%)	9.1%	12.5%	20.7%	26.4%	33.7%	44.4%	51.7%	60.5%	61.9%	63.4%	64.5%
RES share in gross electricity consumption (%)	9.1%	11.7%	18.7%	25.6%	32.7%	42.9%	50.0%	58.6%	60.1%	61.6%	62.7%
RES share in installed power capacity (%)	30.2%	28.5%	31.9%	43.4%	48.7%	57.1%	63.9%	71.7%	73.4%	74.9%	76.2%
Domestic electricity generation (%)	71.0%	70.7%	73.2%	69.1%	67.1%	75.4%	76.7%	72.8%	73.6%	74.5%	75.1%

Table 4-3. Cost of Electricity Generation

	2015	2020	2025	2030	2035	2040	2045	2050
A. Investments (M€ 2015)		**2515**	**4262**	**3462**	**5061**	**3250**	**5480**	**3904**
A.1 RES		***2239***	***2873***	***3462***	***5061***	***3250***	***5480***	***3904***
Wind systems		1223	1167	2425	3058	1764	1868	1628
Large photovoltaic systems		439	353	583	1180	995	2663	977
Residential photovoltaic systems		439	802	85	164	158	444	432
Hydroelectric systems		0	438	0	0	0	274	729
Geothermal energy		0	32	0	0	0	0	0
Biomass		138	81	0	46	48	25	138
Pumping systems		0	0	368	613	284	207	0
A.2 Conventional		***275***	***1389***	***0***	***0***	***0***	***0***	***0***
Lignite		0	1389	0	0	0	0	0
Natural Gas		0	0	0	0	0	0	0
Oil products		0	0	0	0	0	0	0
Anti-pollution		275	0	0	0	0	0	0
A.3 Total investments (cumulative)		***2515***	***6776***	***10239***	***15299***	***18550***	***24030***	***27935***
B. Levelized cost (€ 2015/MWh)	**87.70**	**91.00**	**105.56**	**103.18**	**103.57**	**103.80**	**102.32**	**101.52**
C. Levelized cost except for investments before 1995 (€ 2015/MWh)	**72.45**	**76.66**	**93.94**	**93.54**	**96.55**	**97.14**	**95.93**	**95.36**

Table 4-4. Energy Consumption and Indexes in the Industry

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	23748	28525	22368	18592	17619	17969	18827	20440	22025	23110	24137
FINAL ENERGY CONSUMPTION (ktoe)	**5246**	**5342**	**4658**	**3920**	**3874**	**3816**	**3978**	**4190**	**4402**	**4579**	**4758**
per sector											
non-metallic minerals	1374	1517	909	821	911	986	1092	1152	1216	1294	1382
cement	1154	1263	801	730	809	872	962	1004	1049	1111	1182
lime	64	79	51	53	50	50	52	56	61	63	66
glass	27	34	30	29	27	27	28	31	33	34	36
ceramic industry	129	141	27	10	25	37	49	61	74	86	98
paper	161	129	141	120	112	113	117	127	137	143	150
non-ferrous	746	834	653	840	838	764	760	758	757	756	757
iron industry	195	220	171	97	108	121	139	153	166	175	185
other industries	2769	2642	2784	2041	1904	1832	1870	2001	2126	2209	2285
per fuel											
solid fuel (coal and lignite)	802	455	284	223	233	263	281	294	309	328	349
oil products	2622	2813	2092	1638	1439	1364	1447	1539	1631	1706	1786
diesel	509	453	314	291	196	151	147	150	152	153	154
fuel oil	852	676	362	301	227	188	185	188	190	190	191
other oil products	1261	1685	1416	1046	1017	1025	1115	1201	1289	1363	1442
natural gas	339	530	727	718	845	948	955	988	1016	1037	1058
biomass-waste	217	233	285	168	167	204	218	247	278	305	328
solar systems and other RES	0	2	4	6	5	6	6	7	8	8	9
electricity	1260	1294	1135	1026	1024	870	909	952	995	1029	1062
cogeneration steam	6	14	132	142	160	162	163	164	165	165	166
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	9952	10226	6862	7734	7758	7922	8249	8507	8769	9038	9344
CH_4 (kt)	0.5	0.6	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8
N_2O (kt)	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4
CO_2 eq (kt)	**10041**	**10331**	**6950**	**7815**	**7852**	**8031**	**8362**	**8627**	**8898**	**9173**	**9486**
INDEXES											
energy intensity (ktoe / M€ 2010)	0.22	0.19	0.21	0.21	0.22	0.21	0.21	0.20	0.20	0.20	0.20
CO2 emissions per energy unit (t / toe)	1.90	1.91	1.47	1.97	2.00	2.08	2.07	2.03	1.99	1.97	1.96
emissions intensity (kt CO_2 / M€ 2010)	0.42	0.36	0.31	0.42	0.44	0.44	0.44	0.42	0.40	0.39	0.39

Table 4-5. Energy Consumption and Indexes in transportation

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
GNP per inh. (€ 2010/inh.)	17416	20947	20328	16989	18708	19116	20124	22058	24046	25466	26983
Private consumption per household (€2010/hh)	35791	40844	38374	30744	31913	31662	32362	34443	36456	37488	38568
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
TRANSPORTATION LOAD											
passenger transportation (Gpkm)	**128**	**160**	**175**	**168**	**170**	**173**	**176**	**180**	**182**	**182**	**182**
road transportation	118	149	164	160	162	165	168	172	173	174	173
cars and motorcycles	98	130	145	144	147	150	153	157	158	159	159
buses	20	20	19	16	15	14	14	15	15	15	15
trains	3	3	4	4	4	4	4	4	4	4	4
domestic aviation	2	1	1	1	1	1	1	1	1	1	1
domestic navigation	5	6	6	4	4	4	4	4	4	4	4
freight transportation (Gtkm)	**27**	**31**	**28**	**21**	**20**	**20**	**21**	**22**	**24**	**24**	**25**
trucks	19	21	20	14	13	13	14	15	16	17	18
trains	0	0	0	0	0	0	0	0	0	0	0
domestic navigation	8	9	8	7	7	7	7	7	7	7	7
FINAL ENERGY CONSUMPTION (ktoe)	**6453**	**7541**	**7105**	**5829**	**5568**	**5545**	**5574**	**5698**	**5747**	**5741**	**5719**
per transportation means											
road transportation	5320	6413	6091	5147	4894	4866	4889	4997	5040	5032	5010
cars and motorcycles	2901	3670	3707	3488	3425	3412	3396	3401	3346	3275	3195
buses	158	152	141	119	105	100	101	102	102	100	99
trucks	2261	2591	2243	1539	1364	1354	1392	1494	1592	1656	1716
trains	49	54	58	55	54	54	56	58	59	59	59
domestic aviation	515	416	244	188	187	189	191	195	196	197	196
domestic navigation	569	658	712	439	434	435	439	448	452	453	454
per type of activity											
passenger transportation	4127	4875	4794	4233	4149	4135	4127	4147	4095	4024	3941
freight transportation	2326	2666	2311	1596	1419	1409	1447	1552	1652	1717	1778
per fuel											
Solid Fuel	0	0	0	0	0	0	0	0	0	0	0
oil products	6437	7508	6938	5614	5256	5010	4958	5025	5019	4964	4897
diesel	2199	2550	2257	1886	1879	1949	1935	2014	2065	2085	2098
fuel oil	253	316	435	252	249	249	251	257	259	260	260
petrol	3403	4126	3901	3039	2671	2338	2294	2270	2211	2136	2059
LPG	26	31	68	227	245	256	258	259	258	256	254
other oil products	556	485	275	211	213	217	220	225	226	227	227
natural gas	0	15	15	19	23	26	26	27	27	27	27
biofuel	0	0	124	164	230	424	470	470	470	470	470
electricity	16	18	29	31	58	84	120	176	231	280	325
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	18427	21192	21991	16559	15529	14837	14686	14897	14891	14736	14546
CH_4 (kt)	4.9	4.8	4.3	5.8	5.1	4.8	4.7	4.7	4.7	4.6	4.4
N_2O (kt)	1.2	1.3	1.1	1.7	1.6	1.6	1.6	1.6	1.5	1.5	1.4
CO_2 eq (kt)	**18899**	**21708**	**22418**	**17221**	**16140**	**15430**	**15272**	**15481**	**15464**	**15294**	**15088**
INDEXES											
energy consumption per inh. (toe / inh.)	0.59	0.69	0.64	0.54	0.51	0.50	0.50	0.52	0.52	0.52	0.53
biofuel share (%)	0.0%	0.0%	2.1%	3.4%	5.0%	9.4%	10.4%	10.3%	10.3%	10.4%	10.6%
coal intensity (kt CO_2 / M€ 2010)	0.10	0.09	0.10	0.09	0.08	0.07	0.07	0.06	0.06	0.05	0.05
CO2 emissions per inh. (t CO_2 / inh.)	1.7	1.9	2.0	1.5	1.4	1.3	1.3	1.3	1.4	1.3	1.3
passenger transportation efficiency (toe/Mpkm)	32.4	30.5	27.4	25.2	24.5	24.0	23.5	23.0	22.5	22.1	21.7
freight transportation efficiency (toe/Mpkm)	85.9	86.4	81.4	74.8	70.5	69.9	69.9	70.1	70.2	70.1	70.0

Table 4-6. Energy Consumption and Indexes in the Agricultural Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	7635	7799	6519	6658	6110	5936	5907	6139	6313	6243	6119
FINAL ENERGY CONSUMPTION (ktoe)	**1130**	**1157**	**899**	**791**	**796**	**806**	**817**	**812**	**807**	**800**	**794**
per energy use											
greenhouses	208	173	176	178	181	184	187	190	194	197	200
other agricultural uses	922	984	723	613	615	622	630	621	613	604	594
per fuel											
Solid Fuel	0	0	0	0	0	0	0	0	0	0	0
oil products	884	885	619	470	456	444	443	440	436	431	425
diesel	811	830	541	391	373	360	359	357	354	349	344
other oil products	73	54	78	79	83	84	84	83	82	82	81
natural gas	0	0	0	0	0	0	0	0	0	0	0
biomass-waste	11	22	37	47	52	59	61	64	66	69	71
solar systems and other RES	3	3	5	6	6	7	7	8	8	8	8
electricity	232	247	238	268	282	296	305	301	296	293	289
cogeneration steam	0	0	0	0	0	0	0	0	0	0	0
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	2612	2705	1682	1443	1400	1365	1362	1352	1341	1325	1308
CH_4 (kt)	0.4	0.4	0.4	0.8	0.9	1.0	1.0	1.0	1.0	1.1	1.1
N_2O (kt)	0.9	1.0	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
CO_2 eq (kt)	**2896**	**3004**	**1876**	**1616**	**1571**	**1537**	**1535**	**1525**	**1514**	**1497**	**1480**
INDEXES											
energy intensity (toe / M€ 2010)	148	148	138	119	130	136	138	132	128	128	130
energy consumption per inh. (toe / inh.)	0.10	0.11	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
emissions intensity (kt CO_2 / M€ 2010)	0.34	0.35	0.26	0.22	0.23	0.23	0.23	0.22	0.21	0.21	0.21

Table 4-7. Energy Consumption and Indexes in the Agricultural Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	128017	157443	161870	135150	147644	152541	161914	178183	194620	205655	216323
FINAL ENERGY CONSUMPTION (ktoe)	**1320**	**1821**	**1878**	**1807**	**1883**	**1763**	**1807**	**1891**	**1973**	**2021**	**2065**
per sector											
offices	101	303	311	287	298	275	284	296	310	319	325
commerce	395	541	588	531	599	561	570	588	606	619	632
hotels	368	463	429	457	477	457	474	502	531	551	570
public sector	455	515	550	532	509	470	480	504	526	532	537
per energy use											
heating	326	470	474	442	444	412	416	428	437	438	436
air-conditioning	536	734	756	747	787	797	823	869	915	946	975
electrical appliances and lighting	459	617	648	618	652	553	568	594	621	638	654
per fuel											
Solid Fuel	0	0	3	4	4	4	4	4	4	4	4
oil products	253	337	221	178	165	146	146	150	152	151	148
natural gas	12	60	124	137	151	150	149	150	150	147	143
biomass-waste	0	0	0	0	0	0	0	0	0	0	0
solar systems and other RES	3	4	6	7	8	9	10	11	12	13	14
electricity	1052	1416	1515	1470	1545	1444	1489	1566	1644	1697	1745
cogeneration steam	0	5	9	11	10	10	10	10	11	11	11
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	785	1549	1150	935	926	864	861	877	885	873	856
CH_4 (kt)	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N_2O (kt)	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CO_2 eq (kt)	**786**	**1552**	**1152**	**961**	**950**	**887**	**884**	**900**	**909**	**896**	**879**
INDEXES											
energy intensity (toe / M€ 2010)	10.31	11.57	11.60	13.37	12.75	11.56	11.16	10.61	10.14	9.83	9.54
energy consumption per inh. (toe / inh.)	0.12	0.17	0.17	0.17	0.17	0.16	0.16	0.17	0.18	0.18	0.19
emissions intensity (t CO_2 / M€ 2010)	6.1	9.8	7.1	6.9	6.3	5.7	5.3	4.9	4.5	4.2	4.0

Table 4-8. Energy Consumption and Indexes in the Residential Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
GNP per inh. (€ 2010/inh.)	17416	20947	20328	16989	18708	19116	20124	22058	24046	25466	26983
Private consumption (M€ 2010)	126461	153952	156803	127077	137192	140864	148598	162873	177188	186715	195856
Private consumption per household (€ 2010/hh)	35791	40844	38374	30744	31913	31662	32362	34443	36456	37488	38568
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
Household size (residents/household)	3.09	2.91	2.72	2.63	2.55	2.48	2.40	2.33	2.27	2.20	2.14
FINAL ENERGY CONSUMPTION (ktoe)	**4364**	**5294**	**4863**	**4351**	**4432**	**4257**	**4334**	**4461**	**4581**	**4614**	**4634**
per energy use											
heating	3053	3846	3311	2805	2840	2711	2747	2830	2903	2887	2862
cooking	291	287	295	298	310	320	331	340	350	358	365
hot water	557	632	639	624	629	629	629	629	628	625	619
air-conditioning	38	62	94	132	148	169	190	211	236	265	299
electrical appliances and lighting	426	467	524	493	506	428	437	450	465	478	490
per fuel											
Solid Fuel	13	5	5	5	5	5	5	5	5	5	5
oil products	2484	3186	2333	1643	1654	1528	1545	1628	1707	1705	1700
diesel	2354	3124	2280	1580	1579	1451	1467	1555	1639	1641	1639
other oil products	130	62	53	62	75	77	77	73	68	65	61
natural gas	6	72	255	287	368	435	449	481	512	520	526
biomass-waste	579	463	581	777	740	690	688	645	596	565	530
solar systems and other RES	81	99	140	162	191	247	260	261	261	260	257
electricity	1187	1454	1519	1446	1443	1320	1356	1410	1469	1528	1586
cogeneration steam	13	15	31	31	31	31	31	31	31	31	31
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	7653	9960	6742	5714	5933	5701	5784	6117	6435	6449	6447
CH_4 (kt)	5.0	3.4	3.6	10.6	10.2	9.5	9.5	8.9	8.2	7.8	7.4
N_2O (kt)	0.2	0.1	0.1	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9
CO_2 eq (kt)	**7830**	**10089**	**6871**	**6276**	**6479**	**6211**	**6295**	**6618**	**6923**	**6922**	**6904**
INDEXES											
energy intensity (ktoe / M€ 2010)	0.035	0.034	0.031	0.034	0.032	0.030	0.029	0.027	0.026	0.025	0.024
energy consumption per inh. (toe / inh.)	0.40	0.48	0.44	0.40	0.40	0.39	0.39	0.40	0.42	0.42	0.43
emissions intensity (kt CO_2/ M€ 2010)	0.061	0.065	0.043	0.045	0.043	0.040	0.039	0.038	0.036	0.035	0.033
CO2 emissions per inh. (t / inh.)	0.70	0.91	0.61	0.53	0.54	0.52	0.52	0.55	0.58	0.59	0.59

5. Results for the Energy Saving & Lignite Phase Out (LPO) Scenario

Table 5-1. Energy Balance Summary

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
PRIMARY GENERATION (ktoe)	**9845**	**10026**	**9710**	**8630**	**7992**	**7340**	**7125**	**6464**	**6711**	**6651**	**6754**
solid fuel	8296	8490	7494	6015	4874	3596	2741	972	963	485	51
Oil products	261	91	50	0	0	0	0	0	0	0	0
RES	1289	1444	2167	2615	3118	3744	4384	5492	5748	6166	6703
Natural Gas	0	0	0	0	0	0	0	0	0	0	0
NET IMPORTS (ktoe)	**18221**	**21058**	**18984**	**16529**	**16018**	**14367**	**13803**	**14064**	**13553**	**13085**	**12380**
solid fuel	823	499	344	249	250	269	281	275	289	276	291
Oil products	15740	17966	15203	12751	11675	10137	9406	9295	8750	8062	7309
RES	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	1659	2268	2947	3375	3938	3806	3962	4340	4360	4593	4626
Electricity	-1	325	490	154	154	154	154	154	154	154	154
GROSS DOMESTIC CONSUMPTION (ktoe)	**28067**	**31083**	**28694**	**25159**	**24010**	**21707**	**20928**	**20528**	**20264**	**19736**	**19134**
solid fuel	9119	8989	7838	6264	5125	3865	3021	1246	1251	760	342
Oil products	16001	18057	15253	12751	11675	10137	9406	9295	8750	8062	7309
RES	1289	1444	2167	2615	3118	3744	4384	5492	5748	6166	6703
Natural Gas	1659	2268	2947	3375	3938	3806	3962	4340	4360	4593	4626
Electricity	-1	325	490	154	154	154	154	154	154	154	154
NET ELECTRICITY GENERATION (ktoe)	**4200**	**4686**	**4504**	**4597**	**4739**	**4366**	**4538**	**4815**	**5038**	**5238**	**5431**
Lignite	2601	2726	2364	1962	1582	1157	892	313	310	145	2
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	651	629	394	343	314	186	51	51	51	51	51
Natural Gas	567	746	813	1077	1245	1085	1155	1324	1345	1479	1500
RES	382	585	934	1214	1598	1938	2440	3127	3332	3562	3879
FINAL ENERGY CONSUMPTION (ktoe)	**18514**	**21156**	**19403**	**16698**	**16553**	**16187**	**16513**	**17195**	**17244**	**17114**	**17150**
per sector											
agricultural	1130	1157	899	791	796	806	817	812	784	759	737
industrial	5246	5342	4658	3920	3874	3817	3978	4268	4461	4457	4586
residential	4364	5294	4863	4351	4432	4257	4336	4526	4277	4195	4100
tertiary	1320	1821	1878	1807	1883	1763	1807	1891	1973	2022	2065
transportation	6453	7541	7105	5829	5568	5545	5574	5699	5748	5682	5661
per fuel											
solid fuel	815	461	292	232	243	272	290	295	309	300	319
oil products	12681	14729	12203	9542	8971	8492	8475	8439	8235	7770	7405
electricity	3747	4429	4435	4241	4353	4017	4182	4420	4628	4808	4977
thermal energy	19	34	172	184	201	203	204	205	207	207	207
RES	894	827	1180	1338	1399	1645	1783	2204	2256	2443	2663
natural gas	358	676	1121	1161	1387	1558	1579	1631	1610	1586	1579
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	94078	103605	90421	75755	69490	60059	54438	46037	44559	41034	37225
CH_4 (kt)	69.5	73.4	62.6	58.4	49.7	40.3	34.6	23.9	23.0	19.2	15.7
N_2O (kt)	3.1	3.4	2.6	4.1	4.0	3.8	3.8	3.8	3.7	3.5	3.4
CO_2 eq (kt)	**96742**	**106443**	**92765**	**78447**	**71923**	**62201**	**56422**	**47777**	**46235**	**42572**	**38630**
INDEXES											
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
GNP (M€ 2010)	189901	229785	226032	184468	205133	210623	222188	243533	264935	279181	292849
Gross Domestic Cons./GNP (ktoe/M€ 2010)	0.15	0.135	0.127	0.136	0.117	0.103	0.094	0.084	0.076	0.071	0.065
Gross Domestic Consumption/inh. (toe / inh.)	2.57	2.83	2.58	2.32	2.19	1.97	1.90	1.86	1.84	1.80	1.76
Gross Final Energy Consumption (ktoe)	19299	21949	19794	17539	17724	17533	18059	18926	19191	19158	19295
RES in the final energy consumption	7.7%	6.4%	11.2%	15.4%	19.3%	23.7%	27.5%	33.1%	35.0%	37.5%	40.3%
Coal intensity (kt CO_2/M€ 2010)	0.50	0.45	0.40	0.41	0.34	0.29	0.25	0.19	0.17	0.15	0.13
CO_2 emissions / inh. (t CO_2 / inh.)	8.63	9.44	8.13	6.98	6.34	5.45	4.93	4.17	4.04	3.74	3.43
CO_2 emissions / Gross Energy Cons. (t / toe)	3.35	3.33	3.15	3.01	2.89	2.77	2.60	2.24	2.20	2.08	1.95
Dependence on imports (%)	65%	68%	66%	66%	67%	66%	66%	69%	67%	66%	65%

Table 5-2. Electricity generation

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ELECTRICITY DEMAND (TWh)	**43578**	**51509**	**51579**	**49323**	**50625**	**46718**	**48637**	**51405**	**53824**	**55917**	**57883**
Industry	14654	15049	13200	11932	11909	10118	10572	11072	11572	11979	12363
Transportation	186	209	337	361	675	977	1396	2047	2675	3256	3768
Agriculture	2698	2873	2768	3117	3280	3454	3559	3501	3454	3408	3361
Tertiary	12235	16468	17619	17096	17968	16794	17317	18213	19131	19736	20306
Residential	13805	16910	17666	16817	16782	15375	15805	16561	16980	17550	18085
NET ELECTRICITY GENERATION (TWh)	**50579**	**60115**	**60906**	**55905**	**57557**	**53219**	**55219**	**58441**	**61034**	**63360**	**65605**
Lignite	30250	31703	27493	22818	18399	13456	10374	3640	3605	1686	0
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	7571	7315	4582	3989	3652	2163	593	593	593	593	593
Natural Gas	6594	8676	9455	12526	14479	12619	13433	15398	15642	17201	17445
Hydroelectric systems	3989	5350	7385	4815	5862	6036	6036	6280	6036	6280	6141
Wind systems	454	1314	3012	4826	6862	8932	13782	18596	19690	20783	22527
Biomass	0	140	279	361	779	1023	1023	1023	1023	1023	1023
Geothermal energy	0	0	0	0	0	58	58	58	58	58	58
Photovoltaic systems	0	0	186	4117	5082	6501	7490	10420	11944	13293	15363
Imports	1733	5617	8513	2442	2442	2442	2442	2442	2442	2442	2442
INSTALLED POWER CAPACITY (MW)	**10931**	**12716**	**14911**	**19279**	**20484**	**20415**	**22215**	**25256**	**26861**	**28264**	**30473**
Lignite	4457	4746	4746	3912	3912	2256	1745	631	631	289	0
Coal	0	0	0	0	0	0	0	0	0	0	0
Oil products	2114	2289	2201	1810	1404	980	532	532	532	532	532
Natural Gas	1062	2063	3208	5188	5188	5188	5188	5188	5188	5188	5188
Hydroelectric systems	3072	3106	3215	3389	3389	3580	3580	3580	3668	4018	4532
Wind systems	226	491	1298	2182	3088	3925	6022	8222	8722	9222	9822
Biomass		20	41	52	112	147	147	147	147	147	147
Geothermal energy		0	0	0	0	8	8	8	8	8	8
Photovoltaic systems	0	1	202	2746	3391	4332	4993	6948	7965	8860	10245
LOAD INDEX (%)											
Lignite	77%	76%	66%	67%	54%	68%	68%	66%	65%	67%	
Coal											
Oil products	41%	36%	24%	25%	30%	25%	13%	13%	13%	13%	13%
Natural Gas	71%	48%	34%	28%	32%	28%	30%	34%	34%	38%	38%
Hydroelectric systems	15%	20%	26%	16%	20%	19%	19%	20%	19%	18%	15%
Wind systems	23%	30%	26%	25%	25%	26%	26%	26%	26%	26%	26%
Biomass		79%	79%	79%	79%	79%	79%	79%	79%	79%	79%
Geothermal energy						75%	75%	75%	75%	75%	75%
Photovoltaic systems		0%	10%	17%	17%	17%	17%	17%	17%	17%	17%
FUEL CONSUMPTION (ktoe)	**11652**	**12156**	**10637**	**9356**	**8449**	**6445**	**5284**	**3828**	**3861**	**3637**	**3238**
Solid Fuel	8303	8526	7527	6014	4864	3575	2713	933	924	443	5
Oil products	2047	2038	1284	1128	1035	622	186	186	186	186	186
Natural Gas	1302	1592	1826	2214	2551	2248	2384	2708	2751	3008	3047
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	51532	54311	48319	38318	32845	24225	18751	10409	10456	8596	6452
CH_4 (kt)	0.6	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5
N_2O (kt)	0.6	0.6	0.5	0.5	0.5	0.4	0.3	0.2	0.2	0.2	0.2
CO_2 eq (kt)	**51719**	**54507**	**48487**	**38493**	**33010**	**24356**	**18863**	**10493**	**10541**	**8676**	**6524**
INDEXES	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
RES share in generation (%)	9.1%	12.5%	20.7%	26.4%	33.7%	44.4%	53.8%	64.9%	66.1%	68.0%	71.4%
RES share in gross electricity consumption (%)	9.1%	11.7%	18.7%	25.6%	32.7%	42.9%	52.0%	62.9%	64.2%	66.1%	69.4%
RES share in installed power capacity (%)	30.2%	28.5%	31.9%	43.4%	48.7%	58.7%	66.4%	74.9%	76.4%	78.7%	81.2%
Domestic electricity generation (%)	71.0%	70.7%	73.2%	69.1%	67.1%	70.9%	73.4%	71.5%	72.3%	70.8%	71.4%

Table 5-3. Cost of Electricity Generation

	2015	2020	2025	2030	2035	2040	2045	2050
A. Investments (M€ 2015)		**2515**	**2873**	**4232**	**6025**	**3412**	**5791**	**5117**
A.1 RES		***2239***	***2873***	***4232***	***6025***	***3412***	***5791***	***5117***
Wind systems		1223	1167	3100	3328	1764	1868	2033
Large photovoltaic systems		439	353	583	1733	983	2649	1332
Residential photovoltaic systems		439	802	85	164	158	444	432
Hydroelectric systems		0	438	0	0	202	805	1182
Geothermal energy		0	32	0	0	0	0	0
Biomass		138	81	0	46	48	25	138
Pumping systems		0	0	463	753	256	0	0
A.2 Conventional		***275***	***0***	***0***	***0***	***0***	***0***	***0***
Lignite		0	0	0	0	0	0	0
Natural Gas		0	0	0	0	0	0	0
Oil products		0	0	0	0	0	0	0
Anti-pollution		275	0	0	0	0	0	0
A.3 Total investments (cumulative)		***2515***	***5387***	***9619***	***15644***	***19056***	***24847***	***29964***
B. Levelized cost (€ 2015/MWh)	**87.70**	**90.78**	**104.63**	**103.05**	**102.90**	**103.96**	**102.33**	**100.97**
C. Levelized cost except for investments before 1995 (€ 2015/MWh)	**72.45**	**76.44**	**93.01**	**93.41**	**95.91**	**97.27**	**96.49**	**95.83**

Table 5-4. Energy Consumption and Indexes in the Industry

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	23748	28525	22368	18592	17619	17969	18827	20440	22025	23110	24137
FINAL ENERGY CONSUMPTION (ktoe)	**5246**	**5342**	**4658**	**3920**	**3874**	**3817**	**3978**	**4268**	**4461**	**4457**	**4586**
per sector											
non-metallic minerals	1374	1517	909	821	911	986	1092	1152	1197	1175	1241
cement	1154	1263	801	730	809	872	962	1004	1032	994	1044
lime	64	79	51	53	50	50	52	56	60	62	64
glass	27	34	30	29	27	27	28	31	33	34	36
ceramic industry	129	141	27	10	25	37	49	61	73	85	97
paper	161	129	141	120	112	113	117	127	136	143	150
non-ferrous	746	834	653	840	838	764	760	750	747	724	723
iron industry	195	220	171	97	108	121	139	153	166	175	184
other industries	2769	2642	2784	2041	1904	1832	1870	2086	2214	2239	2288
per fuel											
solid fuel (coal and lignite)	802	455	284	223	233	263	281	290	304	294	314
oil products	2622	2813	2092	1638	1439	1364	1447	1387	1465	1458	1521
diesel	509	453	314	291	196	151	147	75	81	86	90
fuel oil	852	676	362	301	227	188	185	146	149	148	150
other oil products	1261	1685	1416	1046	1017	1025	1115	1166	1235	1224	1280
natural gas	339	530	727	718	845	948	955	974	990	985	1000
biomass-waste	217	233	285	168	167	204	218	495	534	515	515
solar systems and other RES	0	2	4	6	5	6	6	7	8	8	9
electricity	1260	1294	1135	1026	1024	870	909	952	995	1030	1063
cogeneration steam	6	14	132	142	160	162	163	164	165	165	166
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	9952	10226	6862	7734	7758	7922	8249	8001	8165	7914	8116
CH_4 (kt)	0.5	0.6	0.5	0.6	0.6	0.6	0.7	0.8	0.9	0.9	0.9
N_2O (kt)	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.5	0.5	0.5	0.5
CO_2 eq (kt)	**10041**	**10331**	**6950**	**7815**	**7852**	**8031**	**8362**	**8157**	**8328**	**8073**	**8278**
INDEXES											
energy intensity (ktoe / M€ 2010)	0.22	0.19	0.21	0.21	0.22	0.21	0.21	0.21	0.20	0.19	0.19
CO2 emissions per energy unit (t / toe)	1.90	1.91	1.47	1.97	2.00	2.08	2.07	1.87	1.83	1.78	1.77
emissions intensity (kt CO_2 / M€ 2010)	0.42	0.36	0.31	0.42	0.44	0.44	0.44	0.39	0.37	0.34	0.34

Table 5-5. Energy Consumption and Indexes in transportation

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
GNP per inh. (€ 2010/inh.)	17416	20947	20328	16989	18708	19116	20124	22058	24046	25466	26983
Private consumption per household (€2010/hh)	35791	40844	38374	30744	31913	31662	32362	34443	36456	37488	38568
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
TRANSPORTATION LOAD											
passenger transportation (Gpkm)	**128**	**160**	**175**	**168**	**170**	**173**	**176**	**180**	**182**	**182**	**182**
road transportation	118	149	164	160	162	165	168	172	173	174	173
cars and motorcycles	98	130	145	144	147	150	153	157	158	159	159
buses	20	20	19	16	15	14	14	15	15	15	15
trains	3	3	4	4	4	4	4	4	4	4	4
domestic aviation	2	1	1	1	1	1	1	1	1	1	1
domestic navigation	5	6	6	4	4	4	4	4	4	4	4
freight transportation (Gtkm)	**27**	**31**	**28**	**21**	**20**	**20**	**21**	**22**	**24**	**24**	**25**
trucks	19	21	20	14	13	13	14	15	16	17	18
trains	0	0	0	0	0	0	0	0	0	0	0
domestic navigation	8	9	8	7	7	7	7	7	7	7	7
FINAL ENERGY CONSUMPTION (ktoe)	**6453**	**7541**	**7105**	**5829**	**5568**	**5545**	**5574**	**5699**	**5748**	**5682**	**5661**
per transportation means											
road transportation	5320	6413	6091	5147	4894	4866	4889	4997	5041	5034	5013
cars and motorcycles	2901	3670	3707	3488	3425	3412	3396	3401	3347	3277	3198
buses	158	152	141	119	105	100	101	102	102	100	99
trucks	2261	2591	2243	1539	1364	1354	1392	1494	1592	1657	1717
trains	49	54	58	55	54	54	56	58	59	59	59
domestic aviation	515	416	244	188	187	189	191	195	196	197	196
domestic navigation	569	658	712	439	434	435	439	448	452	392	392
per type of activity											
passenger transportation	4127	4875	4794	4233	4149	4135	4127	4147	4096	3964	3883
freight transportation	2326	2666	2311	1596	1419	1409	1447	1552	1652	1717	1778
per fuel											
Solid Fuel	0	0	0	0	0	0	0	0	0	0	0
oil products	6437	7508	6938	5614	5256	5010	4902	4905	4835	4480	4155
diesel	2199	2550	2257	1886	1879	1949	1889	1943	1970	1844	1718
fuel oil	253	316	435	252	249	249	251	257	259	224	224
petrol	3403	4126	3901	3039	2671	2338	2284	2221	2122	1928	1732
LPG	26	31	68	227	245	256	258	259	258	256	254
other oil products	556	485	275	211	213	217	220	225	226	227	227
natural gas	0	15	15	19	23	26	26	27	27	27	27
biofuel	0	0	124	164	230	424	526	591	656	895	1155
electricity	16	18	29	31	58	84	120	176	230	280	324
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	18427	21192	21991	16559	15529	14837	14516	14537	14342	13286	12327
CH_4 (kt)	4.9	4.8	4.3	5.8	5.1	4.8	4.7	4.7	4.7	4.5	4.4
N_2O (kt)	1.2	1.3	1.1	1.7	1.6	1.6	1.6	1.6	1.5	1.5	1.4
CO_2 eq (kt)	**18899**	**21708**	**22418**	**17221**	**16140**	**15430**	**15102**	**15121**	**14915**	**13842**	**12868**
INDEXES											
energy consumption per inh. (toe / inh.)	0.59	0.69	0.64	0.54	0.51	0.50	0.50	0.52	0.52	0.52	0.52
biofuel share (%)	0.0%	0.0%	2.1%	3.4%	5.0%	9.4%	11.6%	12.9%	14.4%	19.9%	26.0%
coal intensity (kt CO_2 / M€ 2010)	0.10	0.09	0.10	0.09	0.08	0.07	0.07	0.06	0.05	0.05	0.04
CO2 emissions per inh. (t CO_2 / inh.)	1.7	1.9	2.0	1.5	1.4	1.3	1.3	1.3	1.3	1.2	1.1
passenger transportation efficiency (toe/Mpkm)	32.4	30.5	27.4	25.2	24.5	24.0	23.5	23.0	22.6	21.8	21.4
freight transportation efficiency (toe/Mpkm)	85.9	86.4	81.4	74.8	70.5	69.9	69.9	70.1	70.2	70.1	70.0

Table 5-6. Energy Consumption and Indexes in the Agricultural Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	7635	7799	6519	6658	6110	5936	5907	6139	6313	6243	6119
FINAL ENERGY CONSUMPTION (ktoe)	**1130**	**1157**	**899**	**791**	**796**	**806**	**817**	**812**	**784**	**759**	**737**
per energy use											
greenhouses	208	173	176	178	181	184	187	190	194	197	200
other agricultural uses	922	984	723	613	615	622	630	621	591	562	538
per fuel											
Solid Fuel	0	0	0	0	0	0	0	0	0	0	0
oil products	884	885	619	470	456	444	443	440	413	389	368
diesel	811	830	541	391	373	360	359	356	331	308	287
other oil products	73	54	78	79	83	84	84	83	82	82	81
natural gas	0	0	0	0	0	0	0	0	0	0	0
biomass-waste	11	22	37	47	52	59	61	64	66	69	71
solar systems and other RES	3	3	5	6	6	7	7	8	8	8	8
electricity	232	247	238	268	282	297	306	301	297	293	289
cogeneration steam	0	0	0	0	0	0	0	0	0	0	0
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	2612	2705	1682	1443	1400	1365	1362	1352	1272	1197	1133
CH_4 (kt)	0.4	0.4	0.4	0.8	0.9	1.0	1.0	1.0	1.0	1.1	1.1
N_2O (kt)	0.9	1.0	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
CO_2 eq (kt)	**2896**	**3004**	**1876**	**1616**	**1571**	**1536**	**1534**	**1524**	**1436**	**1354**	**1284**
INDEXES											
energy intensity (toe / M€ 2010)	148	148	138	119	130	136	138	132	124	122	120
energy consumption per inh. (toe / inh.)	0.10	0.11	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
emissions intensity (kt CO_2 / M€ 2010)	0.34	0.35	0.26	0.22	0.23	0.23	0.23	0.22	0.20	0.19	0.19

Table 5-7. Energy Consumption and Indexes in the Agricultural Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
Added Value (M€ 2010)	128017	157443	161870	135150	147644	152541	161914	178183	194620	205655	216323
FINAL ENERGY CONSUMPTION (ktoe)	**1320**	**1821**	**1878**	**1807**	**1883**	**1763**	**1807**	**1891**	**1973**	**2022**	**2065**
per sector											
offices	101	303	311	287	298	275	284	296	310	319	325
commerce	395	541	588	531	599	561	570	588	607	619	632
hotels	368	463	429	457	477	457	474	502	531	551	570
public sector	455	515	550	532	509	471	480	504	526	532	537
per energy use											
heating	326	470	474	442	444	413	416	428	437	438	436
air-conditioning	536	734	756	747	787	797	823	869	915	946	975
electrical appliances and lighting	459	617	648	618	652	553	568	594	621	638	654
per fuel											
Solid Fuel	0	0	3	4	4	4	4	4	4	4	4
oil products	253	337	221	178	165	146	146	150	152	151	148
natural gas	12	60	124	137	151	150	148	150	149	146	142
biomass-waste	0	0	0	0	0	0	0	0	0	0	0
solar systems and other RES	3	4	6	7	8	9	10	11	12	13	14
electricity	1052	1416	1515	1470	1545	1444	1489	1566	1645	1697	1746
cogeneration steam	0	5	9	11	10	10	10	10	11	11	11
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	785	1549	1150	935	926	864	860	876	884	872	855
CH_4 (kt)	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N_2O (kt)	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CO_2 eq (kt)	**786**	**1552**	**1152**	**961**	**950**	**886**	**883**	**899**	**908**	**895**	**878**
INDEXES											
energy intensity (toe / M€ 2010)	10.31	11.57	11.60	13.37	12.75	11.56	11.16	10.61	10.14	9.83	9.55
energy consumption per inh. (toe / inh.)	0.12	0.17	0.17	0.17	0.17	0.16	0.16	0.17	0.18	0.18	0.19
emissions intensity (t CO_2 / M€ 2010)	6.1	9.8	7.1	6.9	6.3	5.7	5.3	4.9	4.5	4.2	4.0

Table 5-8. Energy Consumption and Indexes in the Residential Sector

	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
ACTIVITY DATA											
GNP per inh. (€ 2010/inh.)	17416	20947	20328	16989	18708	19116	20124	22058	24046	25466	26983
Private consumption (M€ 2010)	126461	153952	156803	127077	137192	140864	148598	162873	177188	186715	195856
Private consumption per household (€ 2010/hh)	35791	40844	38374	30744	31913	31662	32362	34443	36456	37488	38568
Population (mil.)	10.90	10.97	11.12	10.86	10.96	11.02	11.04	11.04	11.02	10.96	10.85
Household size (residents/household)	3.09	2.91	2.72	2.63	2.55	2.48	2.40	2.33	2.27	2.20	2.14
FINAL ENERGY CONSUMPTION (ktoe)	**4364**	**5294**	**4863**	**4351**	**4432**	**4257**	**4336**	**4526**	**4277**	**4195**	**4100**
per energy use											
heating	3053	3846	3311	2805	2840	2711	2750	2895	2599	2468	2327
cooking	291	287	295	298	310	320	331	340	350	358	365
hot water	557	632	639	624	629	629	629	629	628	625	619
air-conditioning	38	62	94	132	148	169	190	211	236	265	299
electrical appliances and lighting	426	467	524	493	506	428	437	450	465	478	490
per fuel											
Solid Fuel	13	5	5	5	5	5	5	1	1	1	1
oil products	2484	3186	2333	1643	1654	1527	1537	1558	1370	1292	1212
diesel	2354	3124	2280	1580	1579	1450	1459	1546	1358	1281	1201
other oil products	130	62	53	62	75	77	78	12	12	12	11
natural gas	6	72	255	287	368	435	449	481	443	427	409
biomass-waste	579	463	581	777	740	690	696	770	712	675	635
solar systems and other RES	81	99	140	162	191	247	259	260	260	259	256
electricity	1187	1454	1519	1446	1443	1322	1359	1424	1460	1509	1555
cogeneration steam	13	15	31	31	31	31	31	31	31	31	31
GREENHOUSE GAS EMISSIONS											
CO_2 (kt)	7653	9960	6742	5714	5933	5698	5760	5910	5243	4968	4682
CH_4 (kt)	5.0	3.4	3.6	10.6	10.2	9.5	9.6	10.5	9.7	9.2	8.7
N_2O (kt)	0.2	0.1	0.1	1.0	1.0	0.9	0.9	1.0	0.9	0.8	0.8
CO_2 eq (kt)	**7830**	**10089**	**6871**	**6276**	**6479**	**6208**	**6274**	**6462**	**5745**	**5444**	**5129**
INDEXES											
energy intensity (ktoe / M€ 2010)	0.035	0.034	0.031	0.034	0.032	0.030	0.029	0.028	0.024	0.022	0.021
energy consumption per inh. (toe / inh.)	0.40	0.48	0.44	0.40	0.40	0.39	0.39	0.41	0.39	0.38	0.38
emissions intensity (kt CO_2/ M€ 2010)	0.061	0.065	0.043	0.045	0.043	0.040	0.039	0.036	0.030	0.027	0.024
CO2 emissions per inh. (t / inh.)	0.70	0.91	0.61	0.53	0.54	0.52	0.52	0.54	0.48	0.45	0.43

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