# The Impact of Renewable Energy Sources Penetration in Achieving the Energy and Environmental Policy Goals in Greece

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*Abstract:* - An analysis of the measures capable of greenhouse gas control at Greece is presented at this cohort. Greece is a member state of European Union and is situated on the southern end of the Balkan Peninsula. It operates a capitalist economy that produced a GDP of $251.7 billion in 2006. The principal economic activities mainly include the tourism and shipping industries, banking & finance, manufacturing, construction and telecommunications. The legal framework currently governing Renewable Energy Sources (RES) electricity is Law 2773/99, which also sets the rules for the liberalization of the electricity market in the country. Finally the Greek energy system in relation to the energy policy goals is presented.

*Key-Words:* - Renewable energy sources, energy policy, environment, greenhouse gas control

## 1 Introduction

### 1.1 General Data

Greece is a member state of European Union and is situated on the southern end of the Balkan Peninsula. The country has an area of 131,957 sq.km and consists of a large mainland; the Peloponnese, a peninsula connected to the mainland by the Isthmus of Corinth; and around 3000 islands, including Crete, Rhodes, Corfu, the Dodecanese and the Cyclades. Four-fifths of Greece consists of mountains or hills, making the country one of the most mountainous in Europe.

The 2001 census of Greece reported a population of 11 million people, of whom the 66% lives in urban areas. More specifically, the 35.5% of the population lives in the Attica periphery (4 million) and 2.8 million of those live in Athens [1-4].

The country's peculiar geography (vast number of islands, mountainous and craggy mainland) and the resulting lack of uniformity in the distribution of the population, create additional obstacles for the development of the energy infrastructure, necessary for the accomplishment of the national energy policy goals.

Greece being far away from the rest of the European Nations' countries, Italy apart, has developed energy relationships mainly with no European countries like Albania, FYROM, Bulgaria and Turkey.

Greece operates a capitalist economy that produced a GDP of $251.7 billion in 2006. The principal economic activities mainly include the tourism and shipping industries, banking & finance, manufacturing and construction and telecommunications. The country serves as the regional business hub for many of the world's largest multinational companies.

The people of Greece enjoy a high standard of living. Greece has an average per capita income that has been estimated at $27,360 for the year 2007, or around 93% of the EU average.

The shipping and the tourism industries are key elements of the Greek economic activity. Today, the service industry (74.4%) makes up the largest, most

vital and fastest-growing sector of the Greek economy, followed by industry (20.6%) and agriculture (5.1%).

## 1.2 Energy Policy Targets

The energy policy in Greece is exercised by the Ministry of Development. Ministry's recent efforts are concerning the formation of the regulatory and legal framework of the electricity market in the country, the promotion of renewable energy sources, the cogeneration of electricity and heat for energy conservation, and the large international energy interconnection projects.

The principal energy policy targets in Greece are as follows:

- Security of energy supply
- Energy sources differentiation
- Promotion of the productivity and competitiveness through energy investments
- Equal balanced regional development
- Protection of the environment and promotion of renewable energy sources

## 1.3 Legal framework

The legal framework currently governing Renewable Energy Sources (RES) electricity is Law 2773/99, which also sets the rules for the liberalization of the electricity market in the country. Starting in February 2001, any private investor can produce electricity, subject to the issuing of a generation license by the Regulatory Authority for Energy (RAE). This law has incorporated the EU Directive 96/92/EC. Important modifications have been made recently to the national legislation, in relation to the liberalization of the electrical energy and natural gas markets, in order to be in compliance with the EU Directives 2003/54/ EC and 2003/55/ EC [5].

The law 3175 of 2003 set the rules for the liberalization of the natural gas market introducing the legal framework for third party access in the transport network of natural gas. Finally, the law 3426/2005 for the domestic electricity market and the law 3428/2005 for the natural gas market have defined the legal framework for the complete liberalization of the energy markets in Greece.

Specifically for the electricity sector, the new Administration Code of the Electrical Energy Transactional System offers the proper framework for the normal operation of Electrical Energy Transmission System and Daily Market. Additionally, the new law for the liberalization of the market will allow for the operation of an Independent Transmission System Operator and total accounting separation before 2007 ends. In the gas sector, the terms and conditions for connecting the RES station to the grid were published in 2006 Joint Ministerial Decisions (JMD). As for petroleum products storage, the new law 3335/2005 approved the direct import from retail sellers.

***The development of Renewable Energy Sources and Energy Saving are among the majors energy policy lines of Europe and make a substantial contribution to the reduction of CO2 transmissions and the security of energy supply.***

In the above direction, the EU Directive 2001/77/EC for the "promotion of electric energy produced by renewable energy sources in the electric energy domestic market", is used to promote the renewable energy development and also the energy saving based on a number of European Union Directives, like the Directive 2002/91/EK for the "efficient use of energy in buildings", the Directive 2002/31 for the indication of energy consumption on domestic air conditioning devices, the Directive 2003/66 concerning the indication of energy consumption on the domestic refrigerators and freezers and all their combinations, the Directive 2004/8/EK for the "co production of energy an heat", the Directive 2005/32/EK for the "ecological equipment design", and finally, the recent Directive 2006/32EK for the "Energy Efficiency during end use and Energy Services".
In particular, the Directive 2006/32EK for the Energy Efficiency during end use and Energy Services, sets for the member-states as indicative target for energy saving 9% for the following nine years and also obligates member-states to elaborate energy efficiency action plans (EEAP) starting on 30/6/07.

**The great challenge for the renewable energy sources in Greece today is the fulfilment of the European Directive's target for the electricity production from RES (2001/77/EC).** According to this, Greece is invited to increase the contribution of RES in domestic power consumption at the level of 20.1% (large-scale hydroelectric plants including) until 2010. The target, although it is high, is not impossible to reach. The path towards electricity energy production from RES in our country opened with the law 2244/94, followed by the law 2773/99 which, as previously reported, sets the rules for the liberalization of the electricity market in the country, and specify that the Transmission System Operator (TSO) is obliged to grant priority access (priority in load dispatching) to RES electricity-producing installations.

Another important factor of the Greek energy policy during recent years is the promotion of Energy Saving and Rational Use of Energy programs and measures. With the adoption of the European Directives, it was set the legal framework for the publication of ministerial decisions regarding energy indication in Greece, while the legal framework for energy planning was supplemented by the law 3438/06 which specify the formation of National Energy Strategic Council (NESC) for defining the nation's energy strategy and formulating a long-term energy plan. In fact, a vast number of measures have been adopted for transportation, with the passage of law 3423/05 for bio fuels, the replacement of old private vehicles, and the improvement of requirements for road networks and public transportation.

Very significant is also the passage of law 3468/2006 regarding the Generation of Electricity using Renewable Energy Sources and High-Efficiency Cogeneration of Electricity and Heat. The purpose of this law is on one hand, the transposition of Directive 2001/77/EC of the European Parliament and Council of September 27, 2001, on the promotion of electricity produced from renewable energy sources in the internal electricity market and, on the other hand, the promotion, by granting priority to the generation of electrical power from Renewable Energy Sources (RES) and High-Efficiency Co-Generation of Electricity and Heat Plants in the internal electricity market, on the basis of rules and principles.

### 1.4 Economic incentives for energy investments

For the implementation of the energy and environmental policy a number of legal and financial measures have been adopted. During last years, main financial-support instruments that provide substantial public subsidies to RES investment projects (among others) were the Operational Programme for Energy (OPE), the new National Development Law 3299/2004 and the Operational Programme for Competitiveness (OPC). The combined result of the favourable legal framework, the financial incentives and the great potential of RES that are present in the country, was the manifestation, during the last decade, of a strong interest for investments in the sector of energy production from RES. The first important contribution for investments in the above sector was given by the Operational Programme for Energy (OPE) of Ministry of Development (1994-1999), while a good financial instrument was also the Development Law 2601/98 which had a strong regional character, in that the level of public support depended strongly on the particular geographic region, in which the given private investment was planned to materialise.

Following the evolution course of OPE, in 2000 started, related to the Third Community Support Framework, the Greek Operational Programme for Competitiveness. The Measure 2.1 of Subprogramme 2 of the National Operational Programme for Competitiveness (OPC)/CSF III (2000-2006) is devoted entirely to providing State support (grants) to private investments in: a) renewable, b) rational use of energy and c) small-scale (<50 MWe) cogeneration. The total budget of Measure 2.1, for the 2000-2006 period of CSF III, is 1.07 billion Euro, of which 35.6% or 382 million Euro is the public subsidy. Respectively, in 2004, was created a new incentive for the connection of Renewable Energy Sources and High-Efficiency Co-Generation of Electricity and Heat Plants with the System or the Grid from Measure 6.5 “Promotion of RES systems, Cogeneration in the country’s energy system – Energy Saving” with initial budget 50 mil €. Finally, the new Development Law 3299/04 provides development incentives for the RES investments. The level of public support depends strongly on the particular geographic region, in which the given private investment is planned to materialise, and on the corporate form.

## 2 THE GREEK ENERGY SECTOR

### 2.1 General Picture

The energy policies in Greece, after the two petroleum crisis during seventies and their impacts on the domestic economy, were aiming at reducing country’s energy system dependence on petroleum. Basic characteristic of these policies was the exploitation of local energy sources like lignite and hydraulic, building infrastructure projects for energy production and the interconnection with the neighboring countries and finally, the diversification of energy supply with the introduction of natural gas [6].

In 2004 the Primary Energy Supply (PES) in Greece reached 30.6 Mtoe (Fig.1). This is a 38% growth from the 1990’s level when the gross domestic consumption was 22.2 Mtoe. The corresponding growth rate between 1995 and 2004 was 2.7% per year.

The main fuel source is domestically extracted low-calorific-value lignite and is used almost exclusive in energy production. Oil and lignite cover

almost the 86.9% of total energy supply, which shows a constant increase during last years (Fig.1). The natural gas first appeared in 1995 and the renewable energy sources started to be taken into consideration for energy production towards the end of the 90's. Country's energy dependence was 72.7% in 2004, mainly because of the imports in oil and natural gas [7].

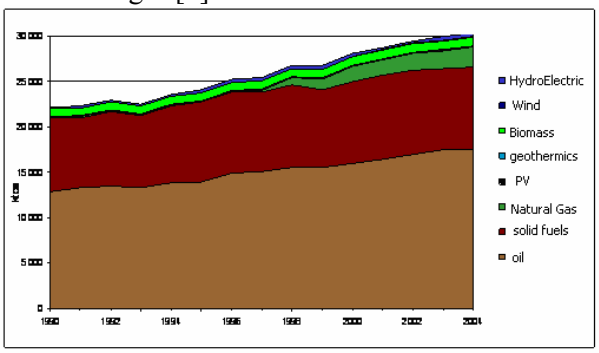


Fig.1 Energy disposal

The most important variation in the gross domestic consumption, during the last years, was the use of natural gas which reduced the use of lignite at 9 Mtoe per year. Solid fuels (mainly lignite) were 8Mtoe in1990 (36% of PES) and reached 9 Mtoe (30% of PES) in 2004. Gas fuels increased from 0.14 Mtoe (0.6%) in1990 to 2.23 Mtoe in 2004 (7.3%). The share of petroleum products increased from 12.8 Mtoe (57.8%) in 1990 to 17.5 Mtoe (57.1%) in 2004. The share of renewable energy sources remain constant at 5% between 1990 (1.1Mtoe) and 2004 (1.6 Mtoe) and presents small variations dependent on the use of large-scale hydroelectric plants.

In the final energy consumption, petroleum products account for 68.5%, electricity 21.1%, while for smaller percentages account the solid fuels especially in industry, the renewable energy sources 5%, and the natural gas 2.3% (Fig.2).

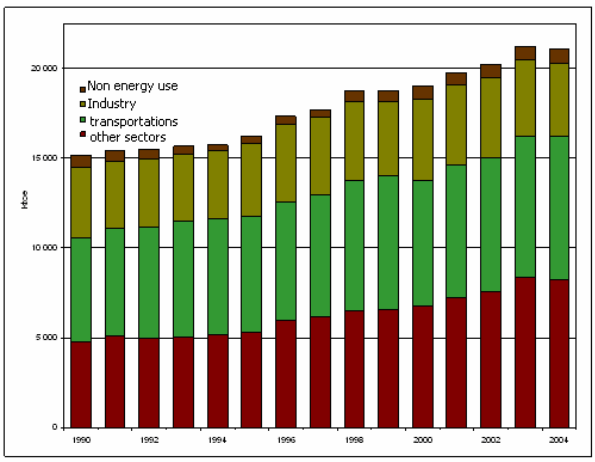


Fig.2 Energy consumption

The transport sector accounts for 39% of the final energy consumption in 2004 (8.1 Mtoe). The final consumption in the transport sector shows an increase of 2.2 Mtoe or 37% since 1990. The transport sector is the one with the largest consumption and is in constant increase.

The domestic sector's percentage has risen significantly, while the tertiary sector presents also a constantly high increase. As a whole, the tertiary, domestic, public, and agricultural sector consumed in 2004 the 39% of energy, while the corresponding percentage of 1990 was 32%. In practical, we are talking about the buildings sector.

The industry shows a constant consumption during the last years, which was 4.4 Mtoe in 2004 with an increase of 0.2 Mtoe or 5% in relation to 1990.

The per capita energy consumption in Greece is average comparing to the world values.

The primary and the final energy intensity have risen by 40% in the period from 1998 to 2000. However, during the last years there are reduction trends caused by the combination of the energy saving measurements and of the high rate increase of GDP. Thus, the primary energy intensity was 0.240 kgoe/ECU95 in 2004, and the final energy intensity was 0.165 kgoe/ECU95, while the per capita energy consumption in the same year was 2.8 toe.

## 2.2 Renewable Energy Sources

**The contribution or the RES to the energy balance accounts for 5%**, in relation to the total supply of primary energy in the country, and about 13-14%, in relation to the domestic production of primary energy. The hydroelectric power from RES in Greece is increasing rapidly during the last years and accounts for 2-2.5% of gross domestic electric energy consumption. It is related mainly to wind energy and small-scale hydroelectric plants and, to a small degree, biomass from which is expected a bigger contribution very soon [8,9].

**Taking into account the large-scale hydroelectric plants (production from drilling is excluded), the hydroelectric power from RES accounts for 10%.** The production of thermal power from RES comes mainly from active solar systems, thermal applications of biomass and geothermal heat pumps. The rapid development of solar collectors' industry during the last decades has given Greece the second position in European level in installed collectors' surface. However, the main heat production from biomass comes either from non commercial biomass burning, in the residential

sector, or from biomass residues in woodworking industries, food processing plants, cotton industry, etc., where it is used for the same purposes. Someone might say that the Greek thermal market from RES is yet in starting phase. The biofuels usage in Greece is also in starting phase and a study regarding their market penetration is soon to be released. At this moment, two biodiesel production plants are under construction, financed by the Operational Programme for Competitiveness.

**The installed capacity of electrical energy production from RES was 3.597 MW in 2004,** while the total installed energy of the Greek electric energy production system was 12435 MW.

Table 1 RES electric energy production installed power (MW)

| RES Technology | 1990 | 1991 | 1992 | 1993 | 1994 |
|---|---|---|---|---|---|
| **Total** | 2411 | 2515 | 2541 | 2552 | 2552 |
| Hydro Electric | 2408 | 2512 | 2523 | 2523 | 2523 |
| Hydro Electric -1 MW | 2 | 2 | 2 | 2 | 3 |
| Hydro Electric 1-10 MW | 28 | 28 | 39 | 39 | 39 |
| Hydro Electric 10+MW | 2063 | 2167 | 2167 | 2167 | 2166 |
| geothermic | 2 | 2 | 2 | 2 | 2 |
| Photovoltaic | 0 | 0 | 0 | 0 | 0 |
| Wind power | 1 | 1 | 16 | 27 | 27 |
| Biogas | 0 | 0 | 0 | 0 | 0 |
| **RES Technology** | **1995** | **1996** | **1997** | **1998** | **1999** |
| **Total** | 2552 | 2551 | 2757 | 2896 | 3068 |
| Hydro Electric | 2523 | 2522 | 2728 | 2856 | 2959 |
| Hydro Electric -1 MW | 3 | 3 | 4 | 5 | 8 |
| Hydro Electric 1-10 MW | 39 | 39 | 39 | 40 | 42 |
| Hydro Electric 10+MW | 2166 | 2165 | 2165 | 2197 | 2294 |
| geothermic | 2 | 2 | 2 | 2 | 0 |
| Photovoltaic | 0 | 0 | 0 | 0 | 0 |
| Wind power | 27 | 27 | 27 | 38 | 109 |
| Biogas | 0 | 0 | 0 | 0 | 0 |
| **RES Technology** | **2000** | **2001** | **2002** | **2003** | **2004** |
| **Total** | 3299 | 3369 | 3388 | 3473 | 3597 |
| Hydro Electric | 3072 | 3076 | 3078 | 3079 | 3099 |
| Hydro Electric -1 MW | 14 | 15 | 17 | 19 | 23 |
| Hydro Electric 1-10 MW | 42 | 45 | 45 | 50 | 56 |
| Hydro Electric 10+MW | 2317 | 2317 | 2317 | 2311 | 2317 |
| geothermic | 0 | 0 | 0 | 0 | 0 |
| Photovoltaic | 0 | 1 | 1 | 1 | 1 |
| Wind power | 226 | 270 | 287 | 371 | 472 |
| Biogas | 1 | 22 | 22 | 22 | 25 |

As indicated in Table 1, the consistency of financial support measurements, of the OPE and of the development law essentially, is the steadily increasing development of the wind energy plants, the small-scale hydroelectric, and the biogas. In particular, the wind energy parks of PPC increased capacity from 27 MW in 1997 to 472 MW with operational license by the end of 2004.

Small-scale hydroelectric were at 80 MW by the end of 2004 starting from 43 MW of PPC in 1997. Finally, the installations of electric power production and coproduction from biogas (mainly in Liosia and in Psitalia) have an electric capacity of 25 MW. The electric power production from RES in 2004 was 6,45 TWh and was produced: 81% from hydroelectric plants (5205 GWh), 17% from wind parks (1121GWh), 2% from biomass (124GWh), and there was also a small amount produced by photovoltaic plants (Table 2). Gross electric power consumption was 62 TWh in the same year. The trend of electric power production from RES is indicated in Diagram 2. In 2004 the total primary thermal production was 44.434 TJ, and was 86% from biomass, 10% from solar energy, and 3.5% from biogas.

**The Primary energy production from RES (Table 2.15) in 2004 was 1.6 Mtoe,** while in the beginnings of the 90's was 1.2 Mtoe. 700 Ktoe of these are due to the non commercial biomass burning in the residential sector, 215 Ktoe to the industrial biomass burning (total percentage of biomass 57%), 448 Ktoe (28%) from hydroelectric production, 96 Ktoe (6%) from wind energy production, 108 Ktoe (7%) from the thermal solar systems production, and 36 Ktoe (2%) from biogas, mainly for electric energy production. The contribution of the RES to the gross domestic energy consumption is constant and fluctuates around the 5-5.5%. The reason is that the primary energy production from RES is due, for the 70%, to non commercial biomass burning and to large-scale hydroelectric which remain constant in percentages and do not get influenced by financial policy incentives. The overall contribution of the RES, excluding the biomass in the residential sector and the large-scale hydroelectric, shows a steady upward trend caused by the financial measurements support. However, given the increasing demand for energy and the consequent increase of gross domestic consumption, this ratio doesn't seem to be changing.

The statistical data of the last years show also a strong fluctuation of the RES ratio in the overall electricity production (5-10%), which is due, mainly, to the operational activity of the large-scale hydroelectric of PPC S.A., while the rest of the RES have a steadily increasing ratio which accounts for 2.5% in 2004. It should be noted that the 10% of

2003-2004, it is not representative for any reason because of:

1. The large-scale hydroelectric plants in Greece are almost exclusively dam projects, which are mainly used for peak loads and their production depends upon the available water amount.
2. In 2003-2004 it was made intensive use of the large-scale hydroelectric plants, given the fact that these were years of good hydraulicity conditions.

Table 2 Electric energy production from RES (GWh).

| RES Technology | 1990 | 1991 | 1992 | 1993 | 1994 |
|---|---|---|---|---|---|
| **Total** | 1999 | 3173 | 2397 | 2588 | 2879 |
| Hydro Electric | 1997 | 3171 | 2389 | 2541 | 2842 |
| Hydro Electric -1 MW | 6 | 5 | 5 | 5 | 8 |
| Hydro Electric 1-10 MW | 54 | 71 | 43 | 77 | 97 |
| Hydro Electric 10+MW | 1709 | 3023 | 2155 | 2200 | 2495 |
| Wind power | 2 | 2 | 8 | 47 | 37 |
| Biogas | 0 | 0 | 0 | 0 | 0 |
| Photovoltaic | 0,1 | 0,0 | 0,1 | 0,2 | 0,2 |
| **RES Technology** | **1995** | **1996** | **1997** | **1998** | **1999** |
| **Total** | 3816 | 4542 | 4132 | 3936 | 4992 |
| Hydro Electric | 3782 | 4504 | 4096 | 3866 | 4829 |
| Hydro Electric -1 MW | 7 | 7 | 11 | 8 | 9 |
| Hydro Electric 1-10 MW | 89 | 119 | 138 | 138 | 160 |
| Hydro Electric 10+MW | 3434 | 4222 | 3733 | 3572 | 4423 |
| Wind power | 34 | 38 | 36 | 70 | 162 |
| Biogas | 0 | 0 | 0 | 0 | 1 |
| Photovoltaic | 0,2 | 0,2 | 0,1 | 0,1 | 0,2 |
| **RES Technology** | **2000** | **2001** | **2002** | **2003** | **2004** |
| **Total** | 4562 | 3560 | 4240 | 6459 | 6450 |
| Hydro Electric | 4111 | 2725 | 3463 | 5332 | 5205 |
| Hydro Electric -1 MW | 26 | 40 | 58 | 76 | 91 |
| Hydro Electric 1-10 MW | 140 | 95 | 92 | 169 | 212 |
| Hydro Electric 10+MW | 3527 | 1962 | 2650 | 4521 | 4369 |
| Wind power | 451 | 756 | 651 | 1021 | 1121 |
| Biogas | 0 | 79 | 126 | 105 | 123 |
| Photovoltaic | 0,2 | 0,2 | 0,5 | 0,6 | 0,8 |

# 3 ANALYSIS OF THE GREEK ENERGY SYSTEM IN RELATION TO THE ENERGY POLICY GOALS

## 3.1 Methodology - basic assumptions - input data

As input data have been used the supply of useful energy and the alternative policies scenarios[10].

So, here have been used statistical data, and also estimations of experts about the expected evolution of the population, industry activity, transport, and the activity of the tertiary sector as well as estimations of market saturation of technologies that are penetrating today (i.e. residential air conditioning).

The basic assumptions used for the estimation of the power demand trend are presented in the following paragraphs:

The industrial sector is expected to present a constant power demand over the next decade, as the forecasts do not indicate a strong increase of industrial activity. Thus, the industrial sectors with low intense power (indicated as Industry in Fig.3) it is estimated that they will present an increase of 2% annual in the final power demand for the period 2000-2015, which corresponds to a similar increase of the entire sector's added value. The power consuming production sectors of cement, bricks, steel and aluminum are analyzed separately in the model. The estimated production for each one of these sectors in thousand tones is shown in Fig.4. Thus, cement production is raised by 1% annual until 2005 because of the increase in the domestic demand (large infrastructural projects), followed by an average increase of 0.2% caused by the saturation of domestic and international market. Brick production is estimated to follow a similar course with an average annual increase of 0.2%. Ammonia production is expected to have an average annual increase of 0.2% following the petrochemical sector's development. Steel production is estimated that will remain constant during the period of study and the aluminum production will continue with the annual increase of 0.22% for the period 2000-2015 [11].

A special characteristic of the Greek energy system is the introduction of natural gas in 1997. The usage of natural gas in the various sectors depends on the distribution network's development and its acceptance from the consumers. In order to take this fact into consideration it has been used a potential penetration curve, based upon the market analysis made by DEPA. Thus, these forecasts have been used as the upper limits of the overall natural gas consumption per sector.

For the power production from RES the main assumption that has been made is that their economic potential is 3 GW and in particular [12]:

- The upper limit of penetration for the Wind Parks has been defined from the limitations of the transport network and is considered to be 2.2 GW.
- The upper limit of penetration of the Small-scale Hydroelectric plants is considered to be 500 MW which is in practical the economic potential of the corresponding investments.

In relation to the energy products prices and their future trend, they have been used the forecasts of the Ministry of Energy of the USA about the international prices of coal and petroleum (Fig.5),

where three different possible trends scenarios are presented. Natural gas prices are estimated according to the ongoing contracts, in connection with the prices of HFO (Heavy Fuel Oil) and LFO (Light Fuel Oil). Natural gas transport costs are estimated according to the present tariffs of DEPA [13].

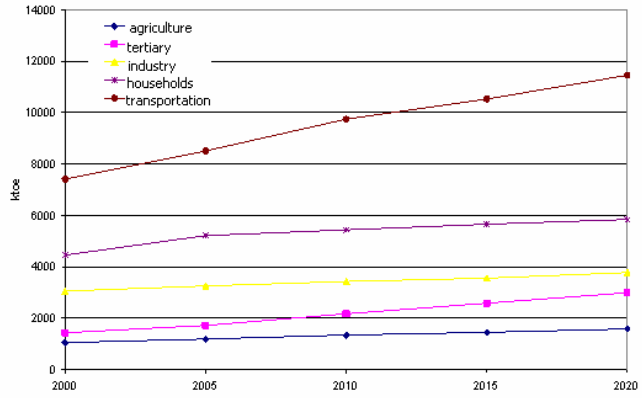


Fig.3 Estimation of the electric energy demand per sector.

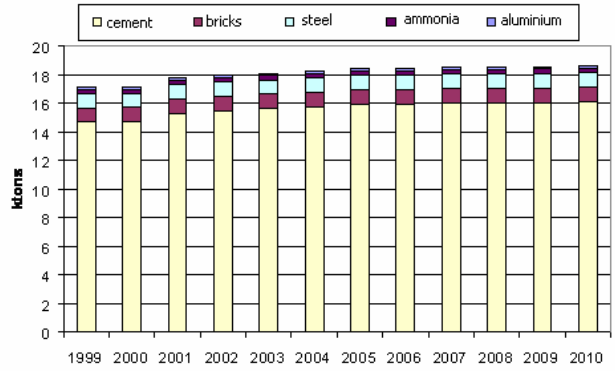


Fig.4 Estimation of the electric energy demand for energy consuming industries.

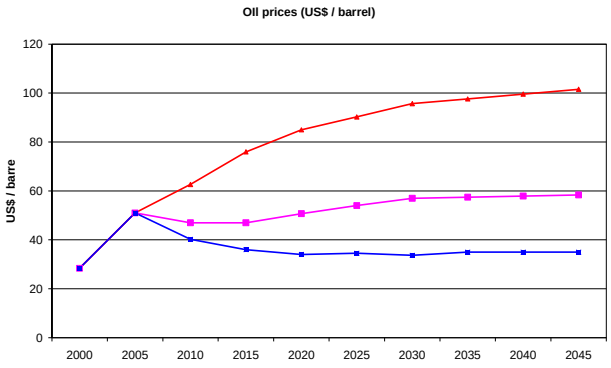


Fig.5 Oil prices estimation according to DOE.

Greenhouse gas emission limitations according to the commitments of Kyoto for the energy sector characterize the energy policy of the recent years and are taking into consideration in the model. Thus, the estimation of the National Observatory of Athens is used, which is included in the Official Gazette Issue 58A 5-3-2003, Ministerial Council Act 5 27-2-2003, according to which the commitments of Kyoto for the energy sector correspond to a +35% increase from the emission levels of 1990 [14].

## 3.2 Final scenarios

Three scenarios have been examined assuming that they present the most interesting trends:

- The first is a reference scenario including only the energy policy resolutions that have been already activated (i.e. investments in course) and does not include emission limitations. It refers to international trends with average petroleum prices. The reference scenario is used in order to determine where the trends will be driven to by the logic of business as usual (if the market proceeds on its own) but also to use it as a yardstick for the scenarios of achieving the Kyoto objectives.
- The second is a scenario of emission limitation and includes the commitments of Kyoto for the energy sector. It refers to international trends with average petroleum prices. The contribution of the RES is considered to the limit of their economic potential. Kyoto's scenario + average petroleum prices tries to determine quantitatively under which conditions the Kyoto objective could be meet with average petroleum prices.
- The third is a scenario of emission limitation and includes the commitments of Kyoto for the energy sector. It refers to international trends with high petroleum prices. The contribution of the RES is considered to the limit of their economic potential. Kyoto's scenario + high petroleum prices tries to determine quantitatively under which conditions the Kyoto objective could be meet with high petroleum prices and represents the worst case scenario [15-18].

## 3.3 Results

As it can be noticed from Fig.6, in the reference scenario the installed capacity of the energy system should be increased by 30.8% until 2010 from 2004 levels, in order to meet the power demand. In the scenario of Kyoto + average p.p. the energy power should be increased by 39.5%, while in the Kyoto + high p.p. by 39% from 2004 levels. The rise is due to the fact that in order to maintain the emissions

under low levels, the lignite plants should operate under their technical capacity. Therefore, new plants of natural gas, wing energy and new technology lignite and coal burning plants should be constructed.

The lignite plants will continue to be the base of the energy grid for the next decade and in the reference model the percentage of the power produced from these stations will rise up to 55% in 2010. In order to meet the Kyoto objectives, the power produced from the conventional lignite plants should be reduced to 45% of the overall capacity in 2010 starting from the 60% of the overall as it was in 2004.

Natural gas will occupy an important share of the energy power production and co-production in the industry and in the tertiary sector. The share of energy power produced from natural gas is 17% in 2010 based on the reference scenario, 22% for the scenario of Kyoto + average p.p. where the co-production in the industry and in the tertiary accounts for 10.6% of the overall power production. In the Kyoto + high p.p. scenario the energy share produced from natural gas should be of 16% due to the fact that the high oil prices imply high natural gas prices.

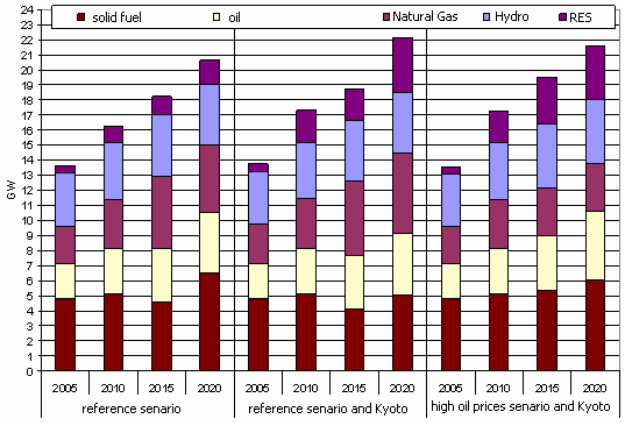


Fig.6 Development of the installed electric power.

In all three scenarios the participation ratio of the oil products in energy production remain constant at 13% and is relating with the islands not connected to the mainland's interconnected system, presenting a small variation from the 14.3% ratio of 2004.

Following their present trend, **the total energy yield of RES electricity stations accounts for 14.9% in 2010 based on the reference scenario.** Regarding Kyoto's scenarios the capacity of small hydro and wind parks rise significantly reaching the limits of their economic potential (about 3 GW) and the corresponding capacity from the RES accounts for 20% in 2010.

The general conclusion for the energy production is that in the **scenario of Kyoto + average p.p.** it is evident the need to reduce the solid fuel plants, increase the natural gas plants, and to **increase the RES plants and co-production in relation to the reference model.** In trends according to the **Kyoto + high p.p. scenario** a smaller development of natural gas plants and introduction of new high performance solid fuel plants is needed in relation to the Kyoto + average p.p. It is also required **the same level of development for RES and co-production.** Regarding the final energy consumption, in the reference model natural gas accounts for 6.6%, while electricity accounts for 23.4% and oil products account for 60% (Fig.7). In the Kyoto + average p.p. scenario the penetration of natural gas in the final energy consumption accounts for 5.9%, while electricity accounts for 23.8% of the overall consumption. The corresponding ratio of the oil products is 60%. In the Kyoto + high p.p. natural gas accounts for 6.1%, while the electricity accounts for 24% and oil products for 57.9%. Even if these ratios are almost the same for all three scenarios the final consumption in the Kyoto's scenarios is reduced due to the energy saving which is included in these scenarios. In particular, in the Kyoto + high p.p. scenario the final energy consumption in 2010 should be reduced by 2.5% in relation to the reference model, natural gas consumption by 9.2%, and the oil products consumption by 5.7%.

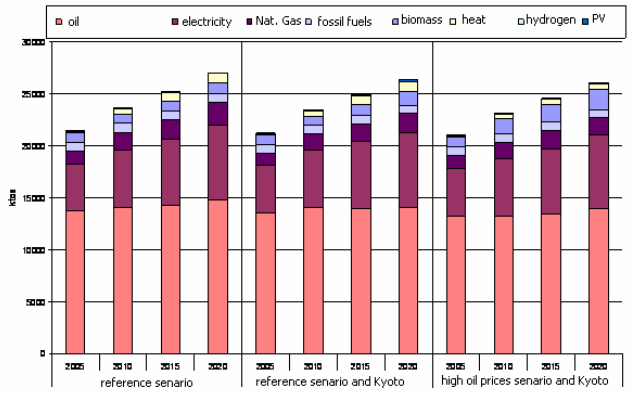


Fig.7 Energy consumption.

The required energy saving in Kyoto scenarios (in the overall energy sector) is also evident in the Fig.8, where the gross domestic consumption is indicated. Thus, for 2010 the Kyoto + average p.p. scenario forecasts, relatively to the reference model, a reduction of the overall gross domestic consumption by 3.7%, a reduction of the gross domestic consumption of solid fuels by 16%, and an increase of the natural gas usage by 7.2%. In the Kyoto + high p.p. it is forecasted, relatively to the

reference scenario, a reduction of the overall gross domestic consumption by 4.3%, a reduction of the gross domestic consumption of solid fuels by 8.2%, and a reduction of the natural gas usage by 1.7% and of the oil products by 7.2%.

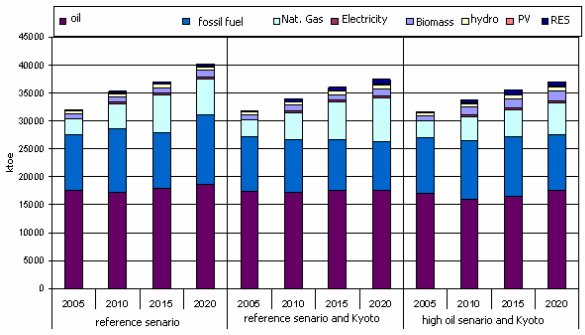


Fig.8 Gross energy consumption

In the reference scenario the CO2 emissions are increasing by 48% in 2010 relating to the 1990's levels. In practical, this ratio indicates the emissions level, if no additional measures are taken. In the Kyoto scenario CO2 emissions are contained to +35% in 2010 relatively to 1990's levels.

## 3.4 Conclusions

The calculations for the reference scenario resulted in an increase of +48% of gas pollutants emissions from the levels in 1990. In order to avoid this situation, a number of additional measurements should be applied, especially during the period 2006-2012.

**The energy sector's emissions in Greece are strongly related to the lignite plants operation of the PPC.** The exploitation coefficient of the old lignite plants should be reduced or it should be taken into account the cost of the additional emissions' licenses. A number of these plants should be modernized in order to reduce their emission levels.

In order to achieve a greater use of natural gas in the production sector, a much more attractive price policy will be required for the use of natural gas for electricity production and for co-production. **The investments in wind parks should come up to an installed capacity of 2100 MW for 2010, while the small-scale hydroelectric should come up to 500 MW.** The co-production from natural gas in the industry and in the tertiary sector should reach the level of 700 MW in 2010 from 220 MW of today or, alternatively, this capacity should be provided by combined cycle technology.

Fig.9 indicates the marginal cost of avoidance of the CO2 emissions in relation to the emissions increase in per cent from the levels of 1990. The curve results from using various CO2 tax values and by giving the possibility to the system to change the combination of technologies and fuels that are used. Thus, considering an increase of +35%, the marginal cost of emissions avoidance (investments) results in 10-15 €/ton.

**Fig.10 indicates an analysis of the marginal cost of emissions avoidance in relation to the penetration of RES.** Independently of the oil prices the marginal cost of emissions avoidance is lower for a higher penetration of the RES. Thus, the mosy important conclusion of this study is that **for the achievement of the environmental targets in Greece and given the usage level of lignite, the effectiveness of the energy policy is the increased penetration of the renewable energy sources** in combination to the penetration of co-production in the industry and in the tertiary sector.

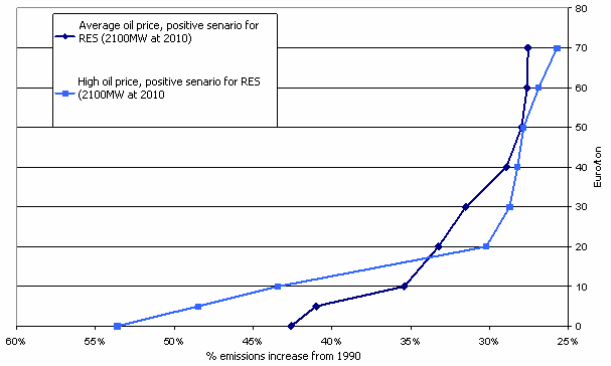


Fig.9 Marginal cost to avoid emissions.

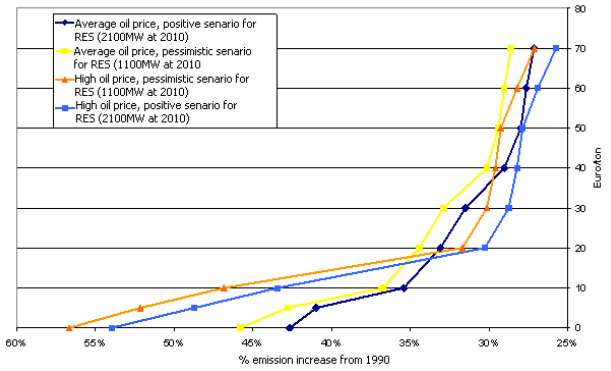


Fig.10 Marginal cost to avoid emissions.

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