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Applying European Emissions Trading and Renewable Energy Support Mechanisms in the Greek Electricity Sector – ETRES (LIFE03 ENV/GR/000219)

Report on Task 4: Impact of ET & alternative RE support mechanisms in the Greek electricity sector

ELMAS Model Description and Preliminary Applications

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Athens, June 2004

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The current report is divided into two parts. The first part focuses on the mode of utilisation of the quantitative tools, to provide the quantitative analysis within the ETRES project. Two major tools interact for this purpose: PRIMES for longer term considerations and ELMAS as a real time simulator. Since ELMAS was specifically built within the ETRES project special attention is given to presenting its key features.

Finally by way of illustration of the process of quantitative analysis and the properties of ELMAS model some scenarios were constructed; an indicative reference case and two alternatives around it. These scenarios are presented in the second part of the report.

The Use of Quantitative Models for Analysing the Impact of alternative Trading and Support Schemes on the Greek Electric Power System

In the context of the ETRES project two distinct quantitative tools (models) are used jointly in order to cover the quantitative aspects of the analysis.

The first model is PRIMES, which has already been developed and used extensively by the Commission of the European Union, national governments and companies to examine among other things the role of flexibility instruments in meeting environmental targets (including specific targets on renewable energy forms). PRIMES is used to provide long term (10 to 20 years) projections of the Greek overall energy and electricity sectors as well as provide the essential input with regard to alternative international permit trade conditions.

In order to enable a detailed and realistic representation of electricity markets a very high resolution (in terms of time) much more detailed Electricity Market Simulator (ELMAS) has been developed allowing hourly load representation and individual plant and operator identification using detailed data obtained from actual operation. In this sense ELMAS allows to simulate “real time” operation of the market.

1. Utilisation of the PRIMES energy model

The PRIMES energy model performs two major types of analytical task:

- It provides an outlook and possible alternative scenarios for the Greek energy system and in particular detailed projections of the Greek electricity and steam system. Such projections are based on assumptions regarding overall and sectoral activity projections, the assumed evolution of internationally traded fossil fuel prices, demographic factors, developments of consumer preferences and energy policy considerations. The starting point for the projections is the outlook for Greece as it emerges from a major study carried out for DG TREN [1] covering long- term energy prospects for Europe. Some modifications to this outlook have been effected in order to take into account recent trends in different electricity end use demand categories as well as recent developments on the supply side (plans for capacity expansion, decommissioning of old plants) as monitored by RAE (the Regulatory Authority) who also participate in the project. The possibility exists for project participants and in particular the Regulatory Authority to alter some or all of these assumptions and obtain a different reference case as well as a series of alternative simulations. Output from PRIMES is mainly directed to the Electricity Market Simulator (see below) and consists of installed power capacity by plant type and electricity demand by type of consumer and use identifying for some important cases specific equipment and thus providing essential input for the construction of annual and daily load duration curves.

- PRIMES is also used for the determination of equilibrium prices for internationally traded GHG emission permits and Green Certificates. Various possibilities of international flexibility mechanisms can be examined involving essentially EU 15 countries, the 10 new member states as well as Turkey, Switzerland and Norway in any combination and with alternative restrictions on the options qualifying for credit as well as participating sectors. In addition the possibility exists for the analysis of exchange potential and prices of permits between the power generation sector and other energy intensive sectors in Greece.

2. The Electricity Market Simulator (ELMAS)

The main output of the ELMAS model consists of electricity balances, operation rates for different types of plant, security of supply considerations (adequacy of capacity), prices and traded volumes of permits and certificates for scenarios involving flexibility instruments applied within the Greek electricity system, trade of permits and certificates between operators and outside agents, spot prices for different loads, system operation costs and longer term viability indicators.

The main input to the model consists in installed capacity by plant type, load characteristics derived from disaggregated demand categories, technical and economic characteristics of different plants, prices of internationally traded permits and certificates, various exogenous factors affecting daily load and plant availability (e.g. atmospheric conditions) as encapsulated in the detailed databases and market configurations including institutional parameters.

The main characteristics of ELMAS are:

- A very high temporal resolution (hourly) with load patterns and plant availability parameters obtained from actual data. This feature is particularly important for the study of renewable electricity generation which is often intermittent, displaying strong seasonal, regular daily as well as random variation. In constructing ELMAS early consideration was given to the possibility of its evolution to a full stochastic representation of electricity demand and supply.
- A capability for identifying individual plants (for major units) or meaningful classifications of smaller ones (e.g. wind power plants). This capability is combined with the possibility of identifying individual operators in view of studying the impact of competitive conditions on the main analytical output of the model.
- Detailed representation of costs and technical performance of different types of plant with particular emphasis on fixed and variable operating and maintenance costs but also sunk costs in an effort to represent adequately both short term and long term profitability.
- A mechanism for representing spot electricity markets assuming variants of the Nash-Cournot oligopolistic behaviour model to determine price offers and short-

term power commitments. This feature, apart from an adequate and realistic framework for integrating flexibility mechanisms such as tradable permits and green electricity certificates, also provides a capability for analysing the impact of liberalisation in the Greek electricity market with multiple future uses particularly in the area of market regulation.

The ELMAS model is a new tool (unique in its type in Greece) and is likely to interest many potential users within Greece especially in view of liberalisation, evaluation of potential for renewable sources, adequacy of power plant commitments, investment risks, and many issues regarding market regulation. Following is a flow chart outlining the interaction of the two models for the purposes of the ETRES project indicating the main types of input and analytical output.

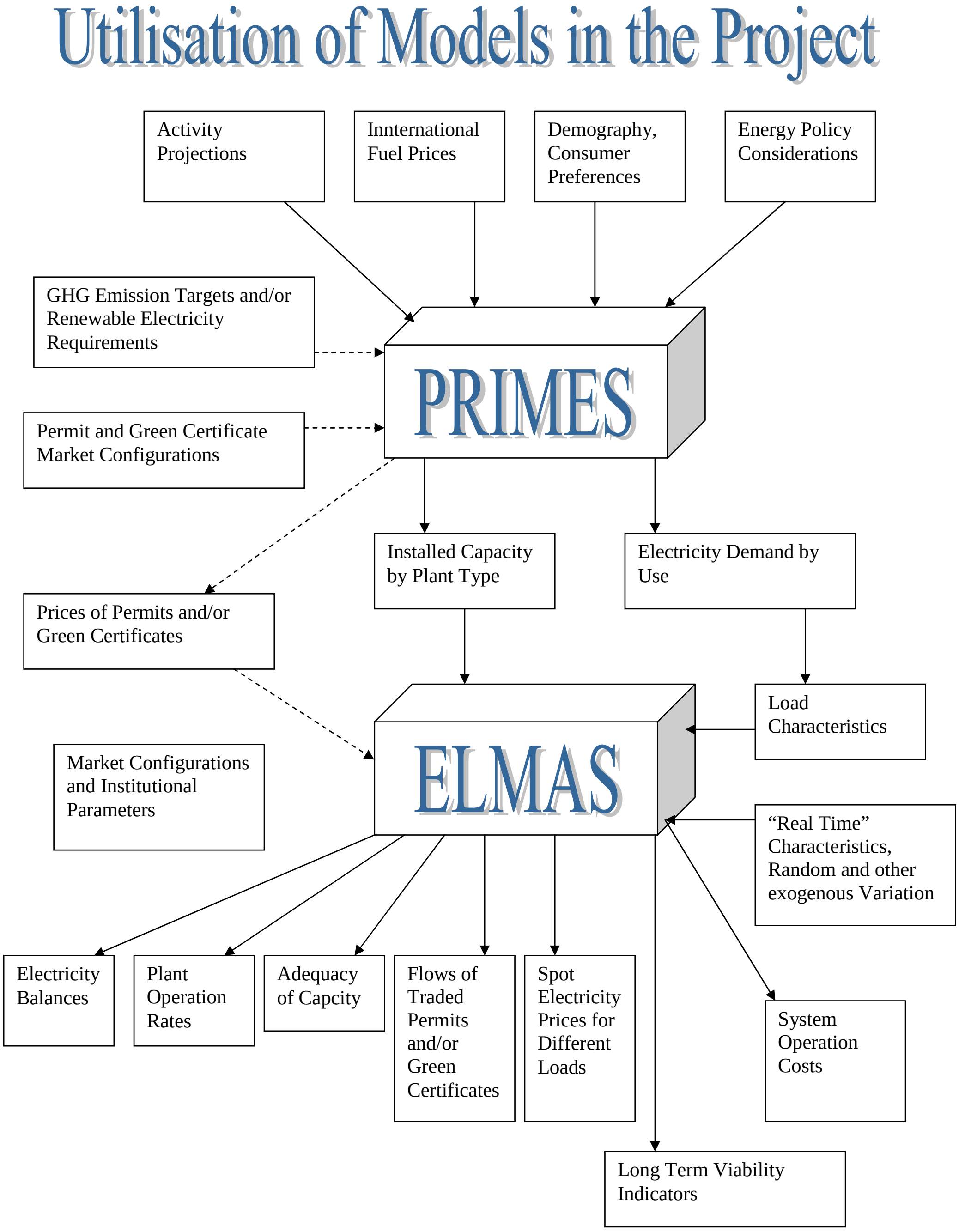

Figure 2-1: The interaction between PRIMES and ELMAS

3. Key Features of the ELMAS model

The ELMAS model has been specifically designed and built within the ETRES project. This section gives some of the key features of the model highlighting its general philosophy and indicating the modelling solutions adopted in overcoming specific challenges. A subsequent chapter presents some preliminary results from applications of the model designed in order to illustrate some of its features.

3.1. General Features

The construction of the model was deemed necessary in view of the imminent liberalisation of Greek electricity market. Currently the Greek market is dominated by PPC constituting virtually a state monopoly with a market share of around 97 per cent. This situation is expected to be radically transformed in the immediate future with the opening up of the market to independent producers of considerable size in view of eventually creating a fully liberalised market. The pace and scope of such liberalisation is still somewhat uncertain and therefore it is important to possess a tool capable of analysing different market configurations.

Market liberalisation could change the context within which renewable electricity sources penetrate with possible modifications in the policies promoting them. Assuming the introduction of a short term spot market for electricity, price volatility could also be influenced by different degrees of RES penetration.

In representing the future market structure a Nash type oligopolistic competition formulation was adopted. It identifies individual players of different sizes and distinct capacity and cost structures.

Each player tries to exploit whatever market power is possible in order to maximise operating profits subject to a number of technical constraints (see below supply sections) and very significantly subject to the actions of other market players assumed to also try to optimise under similar conditions. Perfect short term (24 hour) foresight on all market parameters (including cost structures and operational availability of competitors, their optimising behaviour as well as market demand reactions and atmospheric conditions) for each player is assumed.

The version of this “Game Theoretic” formulation adopted in ELMAS yields an equilibrium i.e. a point where any action by a player (notably any increase or decrease in plant operation) will lead to a deterioration of their profitability given the reaction of other players. Some key characteristics of the specification are:

- Size and cost structures of market agents are important in determining their behaviour.
- There is a clear emergence of market leaders and effective price takers. This tendency is not assumed and results directly from specification but also happens to be a long-standing empirical observation in the field of oligopolistic competition.
- Only “short-term” marginal conditions (variable operating and maintenance costs) are considered. Long-term economic viability taking into account full costs can be examined “ex-post”. This ex-post analysis is important both in assisting market regulation and investment decision making.
- Since it is important for each player to optimise considering the whole set of plants at his/her disposal the model solves in two stages: first using an approximation of each player’s aggregate marginal cost curve to identify the neighbourhood of the solution and subsequently by iteration among more accurate marginal cost curves to determine specific plant operation. ELMAS

solves over a vast hourly sample (containing 61320 time periods) designed to represent the interaction of all relevant market parameters. This sample is created by using and analysing “real time” historical data and by design is both realistic and contains a host of typical as well as “extreme” configurations. This feature carries the analysis beyond average conditions and well into the domain of risk considerations which are crucial in market design and operation.

The model is implemented in the GAMS software using mixed complementarity techniques. Due to the enormous amount of data manipulated even a simple (“myopic”) simulation requires 15 minutes of solution time(large but still manageable).

3.2. Demand: The construction of the hourly load curve

The major demand sectors considered are the Residential, Services, Agriculture, Industry and Transport. There is a detailed representation of the demand side in the model, which includes the decomposition of the major sectors into subsectors and then into end uses. In total, ELMAS considers 43 electricity end uses as shown in Table 3-1. Each demand category is characterised by its own basic load pattern for every month and every hour of the day (also depending on whether a day is a normal working day, a Sunday/public holiday or a Saturday). The methodology employed for arriving at these individual load curves has been the following:

- For each category assume a pattern using extraneous information and “common sense.
- Statistically estimate relations linking a part of demand for heating and cooling purposes to heating and cooling degree hours calculated from the sample (using different thresholds depending on the hour of day).
- Compare the estimated total load with average loads for a given month and hour. This comparison is an important check for the validity of the a priori assumed patterns. In the case of ELMAS the highest deviation has been around five per cent.
- Fine tune the estimates by applying a bi-proportional method reproducing average total loads as they occur in the sample as well as ensuring that annual consumption by category is satisfied.
- Using the calibrated average patterns, temperature data and the maximum (high temporal resolution sample) calculate irregular white noise components.
- Automate the whole path in order to enable the construction of the load (61320 sample hours) for any given vector of demand.

The inclusion of explicit temperature data is important in determining load variability characteristics under conditions where temperature sensitive demand grows differentially to total demand. Figure 3-1 summarises the load projection methodology.

Sector	Subsector	End Uses
Households	**Households**	Cooking
		Water Heating
		Air conditioning
		Space Heating
		Washing machines
		Dish washing
		Drying
		Lighting
		Refrigeration
		TV etc
Services	**Offices**	Space Heating
		Electric Air Cooling
		Lighting
		Electrical uses
		Water heating furnaces and cooking
	Public Buildings	Space Heating
		Electric Air Cooling
		Lighting
		Electrical uses
		Water heating furnaces and cooking
	Trading Sector	Space Heating
		Electric Air Cooling
		Lighting
		Electrical uses
		Water heating furnaces and cooking
Agriculture	**Agriculture**	Direct electricity for space heating
		Lighting
		Electrical uses
		Agricultural pumping
		Motor drive
Transport	**Transport**	Electric motor engines
Industry	**Iron & Steel**	Electrical uses
	Non-ferrous	Electrical uses
	Chemicals	Electrical uses
	Low energy Chemicals	Electrical uses
	Non Metallic Minerals	Electrical uses
	Paper & Pulp	Electrical uses
	Food, drink & Tobacco	Electrical uses
	Engineering	Electrical uses
	Textiles	Electrical uses
	Others	Electrical uses
Energy Sector	**Refineries**	Electrical uses
	Mines	Electrical uses

Table 3-1: The end-uses considered in ELMAS

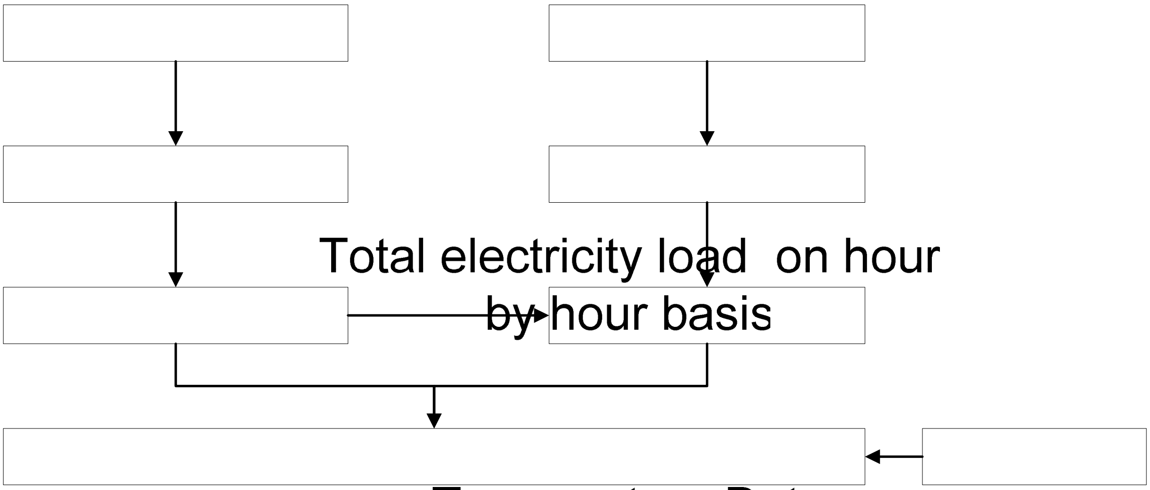

Figure 3-1: The methodology followed in order to construct the national annual load curve.

3.3. Exports

Transmission capacity exists for exports both towards Italy and Greece's northern neighbours. Exports to the North are small and sporadic in character and are likely to remain so given low electricity prices in the countries involved. On the other hand exports to Italy are important (for Greece) and transmission capacity has been expanded recently in order to take advantage of differences in load patterns in the two countries (demand in Greece tends to peak during summer afternoons and evenings while in Italy higher peaks occur in winter months and plenty of export opportunities arise in the autumn when demand is particularly low in Greece and already higher in Northern Italy).

Modelling exports properly would have necessitated the construction of an ELMAS equivalent for Italy a large task disproportionate to the 500MW of existing export capacity. However seasonal time patterns as estimated from high frequency export data have been built into ELMAS in order to capture realistically exports and their potential in smoothing out spot price variation. Otherwise ELMAS treats exports to Italy as a demand category arising from an agent exercising slight (given the relatively limited capacity) oligopsonistic market power.

3.4. Hydro power

Hydro power is the dominant renewable electricity form in Greece although the prospects for its expansion are limited. Due to hydrological conditions (dry summers) and the relatively small size of the river basins average utilisation rates are low at around 16%-17% and vary considerably from year to year following the variability of rainfall during the wet season. Such variability is further accentuated by the fact that 80% of capacity feeds from a relatively small area in North-western Greece which admittedly receives ample rainfall on average which however is subject to considerable variation.

Hydro Power in combination with pumped storage present some of the greatest challenges for models assuming optimising behaviour of economic agents as it is done in ELMAS. Unlike almost all other supply options it is amenable to dynamic considerations and full optimisation would have increased model complexity enormously and given the high temporal resolution of the model would have required totally impractical solution time. In the case of Greece the problem is further compounded by the fact that hydro power is very often linked to irrigation and flood control projects (often a necessary condition for making this generation option economically viable given the low utilisation rates).

The solution adopted in ELMAS has been to assume that:

- Hydro production occurs in the hours of a given month when spot prices are highest subject to sample monthly production constraints.
- Pumped storage occurs in the hours of a given month when spot prices are lowest subject to sample monthly pumping constraints.
- Concerning the monthly constraints on both PPC (Public Power Corporation) management in the seven year sample period was optimal taking into account hydrological factors and irrigation needs.

Otherwise short term hydro-electric supply is treated normally in the model ensuring however that it is notionally distributed to a sufficiently large number of market players in order to avoid its utilisation in deliberate price manipulation.

3.5. Wind and Solar Electricity

Special care is given to modelling wind and solar supply. Wind power has considerable under-utilised potential in Greece and is likely to play a key role in meeting renewable energy and carbon emission targets. One of the main tasks of the model is to provide credible analysis of the feasibility and likely impact of a large-scale introduction of wind power in the Greek electricity market.

Unlike Hydro power, Wind power is experiencing high utilisation rates (around 27% on average). As the best sites are gradually exhausted it could be expected that these rates would tend to fall. On the other hand there is considerable scope for further technological improvement and better understanding and management of local conditions opening the way to perhaps higher utilisation rates. Most of the good sites are situated in and around the Aegean Sea which makes for strong correlations in wind availability on different sites. This correlation tends to accentuate the overall variability of wind power availability. While wind speed variability would tend to introduce additional variability in spot prices in cases of increased reliance on wind power, some characteristic seasonal patterns in wind intensity would tend to blunt the effects: winds in the region tend to be more intense in the afternoon hours especially in summer when some of the highest demand loads are likely to occur. This effect is operative at the average level for these hours and a combination of high dependence on wind capacity and atmospheric calm (usually associated with very high temperatures in summer) could in fact accentuate some of the most extreme spot price events.

Wind production is simulated on an hourly sample of 61320 hours (built from data recorded on a ten minute basis) accounting for wide range of correlations: between sites, across neighbouring hours and with other variables included in the model such as demand load, solar radiation, air temperature, hydro availability etc. This makes ELMAS particularly suitable for studying the risks associated with alternative wind power penetration levels.

Wind power producers are treated exclusively as price takers and are allowed no possibility of deliberately influencing spot price outcomes. Their production in the short term is determined uniquely by physical conditions and is known in advance to other market players.

Solar power (photovoltaic) is treated symmetrically to wind, the main difference consisting in the main driver (solar radiation). Solar electricity is currently making an insignificant contribution to the Greek electrical system, a situation unlikely to change in the medium term due to very high installation costs. Production of electricity from biomass for the purposes of the model is treated like production from fossil fuels (see below) though of course allowance is made for the use of policy and market instruments designed to encourage its penetration.

3.6. Production from fossil fuels

Fossil fuel plants provide the bulk of electricity production in Greece, a situation unlikely to change in the medium term according to all available projections (including PRIMES). Their preponderance combined with the relative flexibility in their operation mean that they constitute the main components in the market and their use is subject to the optimisation behaviour adopted leading to Nash equilibria under oligopolistic market conditions. ELMAS identifies individual plants of many different types and fuels (see presentation of reference case below). In its standard version the model resolution goes down to plant level. An additional module enables the identification of operation of different units (if such detail is required).

It is important to note here that an allocation of the different plants to different companies is not neutral: the same set of plants allocated differently may produce a radically different simulation in terms of most of the important output variables of the model (spot prices, demand, imports, exports and individual plant operation in different hours). This is an intrinsic feature of ELMAS and constitutes a major capability. On the other hand it is clear that in constructing a full scenario great attention has to be devoted to plant allocation issues

Some features incorporated in this part of the model are as follows:

- Marginal cost curves are constructed for every hour allowing for the incorporation of planned or unplanned disruptions as well as seasonal and other time variation of variable costs (notably fuel costs e.g. natural gas).
- Ramping and minimum operation levels are taken into account myopically or with an option to perform dynamic optimisation over 24 hours. Such dynamics increase solution times very substantially and in practice do not often produce significantly different results than the myopic version.
- Forced outage rates for different units are handled through Monte Carlo methods. Some refinement in the parameters of the relevant distributions is still required since it is believed that the statistical analysis performed has not yet properly identified planned and unplanned unit interruptions especially in “grey” cases: a forced closure which is known in advance.

3.7. Imports

Imports, mainly from Greece’s northern neighbours are treated in a similar way to domestic production. The implicit assumption is that exporters to Greece are oligopolistic agents “owning” transmission capacity and participating under the same terms as domestic producers. The availability of power for imports into Greece, apart from line capacity is also constrained by load parameters pertaining in the countries of origin. Such parameters have been statistically determined over a historical sample.

Preliminary Applications

Having designed and implemented ELMAS, the model was run for three applications in order to test it and illustrate its features:

- a reference scenario, which assumes partial liberalisation of the Greek electricity sector,
- a higher wind scenario and finally,
- a scenario assuming a more liberalised market, in order to examine the role of enhanced competition between market players.

These preliminary applications were run for 2010. In the presentation below the main indicator used for evaluating the different scenarios is the spot price and its distribution. ELMAS assumes the existence of such a market and the resulting prices are considered to provide the main market clearing mechanism as well as the ultimate barometer for the competitive regime and adequacy of supply versus demand.

4. The reference scenario

The reference scenario is a projection of electricity demand and supply in Greece for the medium term (2010). It is conceived as an indicative development of the energy system in the future in the context of testing and calibrating the model and it forms the basis for assessing the policy scenarios. No assessment of the likelihood of this scenario is made. Its role is primarily to illustrate the features of the model.

The electricity demand and supply forecasts were obtained from the PRIMES model. The PRIMES projections used have been already published in the study "European energy and transport – Trends to 2030", which constitute the latest official energy baseline of DG TREN.

4.1. Reference scenario assumptions

ELMAS takes annual electricity demand exogenously. The main sources of the projections are PRIMES forecasts with some modifications in order to bring them up to date. The key hypotheses that affect the evolution of the energy demand in the PRIMES model are population, macroeconomic developments and the level of imported fuel prices.

4.1.1. Demographic issues and economic growth

Population is an important determinant both of overall economic performance and of energy trends, especially in the transportation, household and services sectors. For the period from 2000 to 2010 the population in Greece is expected to increase by 0.5 million people, reaching the value of 11.1 million in 2010.

Household size in Greece (i.e. inhabitants per household) is assumed to decrease from 2.8 in 2000 to 2.7 in 2010 reflecting the changing age structure of the population as well as changes in lifestyles.

Regarding economic growth, the PRIMES baseline scenario as described in the study "Trends to 2030", assumes a GDP annual growth rate of 4% p.a. for the period from 2000 to 2010, reaching the level of 181.4 million Euro2000 in 2010.

The long established trend of restructuring the economy away from the primary and secondary sectors and towards services is assumed to continue. Thus, following the period of substantial restructuring of the past 20 years, the industrial sector's share in GDP is assumed to remain stable at around 10.7%. On the other hand, the service sector share in GDP will exceed 65% in 2010.

				Annual % Change
	2000	**2005**	**2010**	**'00 - '10**
Population (Millions)	10.6	11.0	11.1	0.5
Household size (inhabitants/household)	2.8	2.8	2.7	-0.4
Household income (in Euro00/capita)				
GDP (BEuro'00)	122.9	152.5	181.4	4.0
Energy Intensive Manufacturing (Beuro'00)	4.3	5.7	6.7	4.6
Non - Energy Intensive Manufacturing (BEuro '00)	8.5	10.7	12.6	4.0
Services (BEuro '00)	78.8	100.2	121.1	4.4
Agriculture (BEuro '00)	9.8	11.3	13.2	3.0

Table 4-1: Demographic and macroeconomic assumptions used in "Trends to 2030"

4.1.2. Fuel prices

The assumptions on fuel prices for power generation are crucial for ELMAS, because fuel costs constitute the largest part of electricity production variable costs. In the study "Trends to 2030", the fuel prices are expected to decrease in 2010 compared to 2000 levels.

Fuel prices for power generation (Euro'00 per toe)

				Annual % Change
	2000	**2005**	**2010**	**00 - 10**
Lignite	69.6	68.6	67.3	-0.3
Fuel Oil	257.3	174.9	189.9	-3.0
Natural Gas	238.0	130.9	144.3	-4.9

Table 4-2: Fuel prices assumptions used in "Trends 2030"

The natural gas price evolution is important since, according to current investment plans in the Greek power generation sector, most new installations will be based on gas powered technologies. Greece imports natural gas mainly from Russia, which implies that in winter gas prices tend to be higher than in summer. In the preliminary applications, the seasonal variation of gas prices was not taken into account, assuming the same price levels for both winter and summer. However a credible scenario for the gas price evolution is important in order to derive more accurate model results and ELMAS is capable of incorporating price variations.

4.2. Electricity demand in 2010

Electricity demand from final consumers is expected to increase in the next 10 years as a result of the economic growth, the increase of real income and the improvement of living standards. Reference scenario results project an increase in total electricity demand for the period 2000-2010 of about 21.2 TWh with an average annual growth rate of 4%, which is higher than the corresponding EU-15 growth rate. In absolute terms, electricity demand in Greece increases from 44.7 TWh in 2000 to 65.9 TWh in 2010. Figure 4-1 and Figure 4-2 present the average annual growth rate of each electricity end-use.

Industrial consumption of electricity grows at an average rate below 2% p.a. The low annual growth rate of electricity is mainly due to technological modernisation which takes place in industrial activities, in the context of incorporation of Greek industry in the single internal market of EU. It is also due to reformations in favour activities which are characterised by higher value added and lesser energy consumption per unit of product. Electricity in transport increases at an average growth rate of 3.8% p.a. reflecting the continuation of the diesel substitution with electricity in rail transport. It is also due to the continuing penetration of metro and tram in public transportation.

Electricity consumption in the residential and services sectors increases on average at a higher growth rate than the growth rate of the total electricity demand. This is a consequence of both of the expansion of these sectors and the improvement in living standards. With the exception of lighting in households and offices, which increases on average 2% p.a. due to the introduction of more efficient lighting equipment, electricity consumption in all other end-uses registers high growth rates.

Total air-conditioner installations are increased substantially in the forthcoming 10 years, reflecting the continuing penetration of low cost air conditioners in the market. This is particularly marked for households and the trading sector.

The utilisation of electric and electronic equipment also expands in the context of the reference scenario. In 1995 the number of electric appliances in an average Greek household corresponded to 68% of the EU-15 average. Due to the rapid increase of new electric appliances purchases by the Greek households, the ownership of the electric appliances begins to converge to the average EU-15 level. As a result, electricity consumed by TV sets, increases by 7% p.a., while electricity consumption in dish washers and dryers increases more than 10% p.a. Electricity consumption in cooking and water heating, which are already mature uses, shows a modest growth of about 4.5%.

As Figure 4-3 shows, nearly 20% of the total increase in electricity demand is due to air-cooling. A collateral effect is the increase in electric heating, since many air-conditioners can be also used as heaters in winter; the cumulative increase of both air-cooling and heating counts for one fourth of the total increase in electricity demand. An obvious consequence of the above is an accentuation of peaking characteristics of the load curve and an increased vulnerability to extreme temperature phenomena.

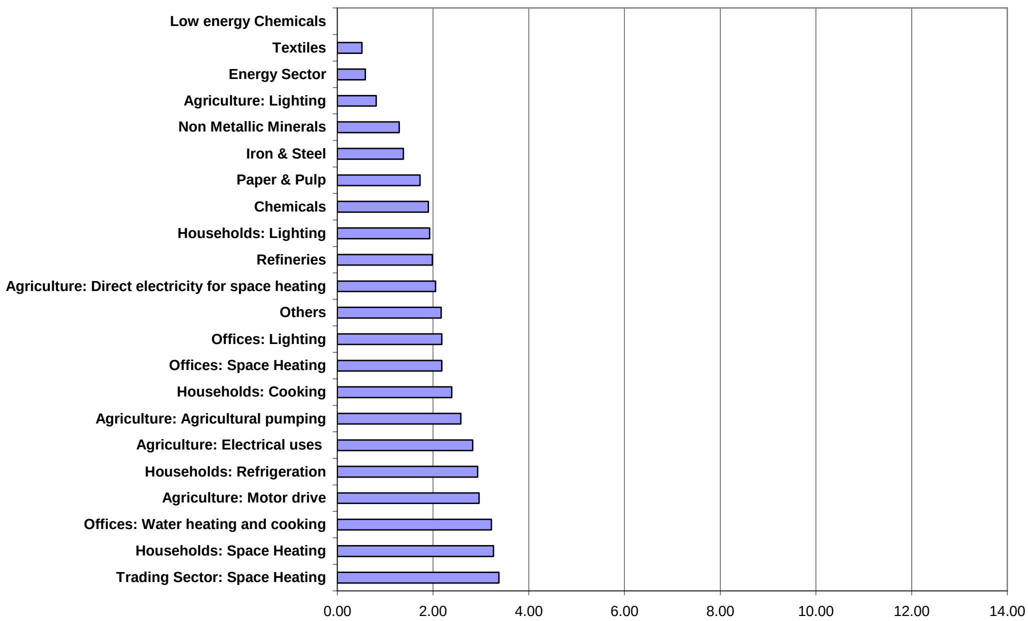

Figure 4-1: Average annual growth rates from 2000 to 2010: less dynamic uses.

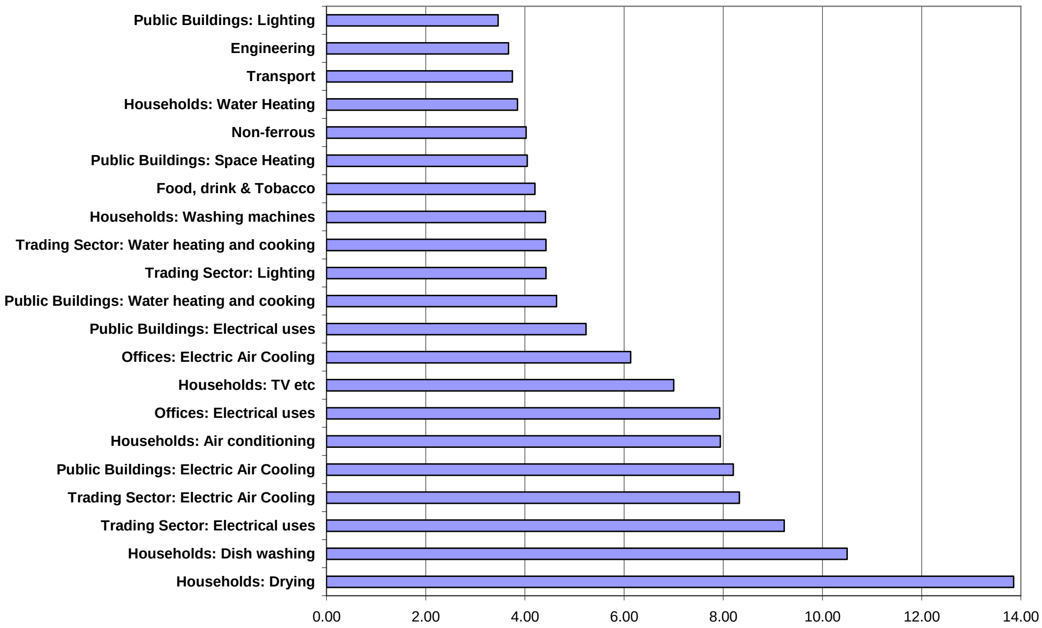

Figure 4-2: Average annual growth rates from 2000 to 2010: dynamic uses.

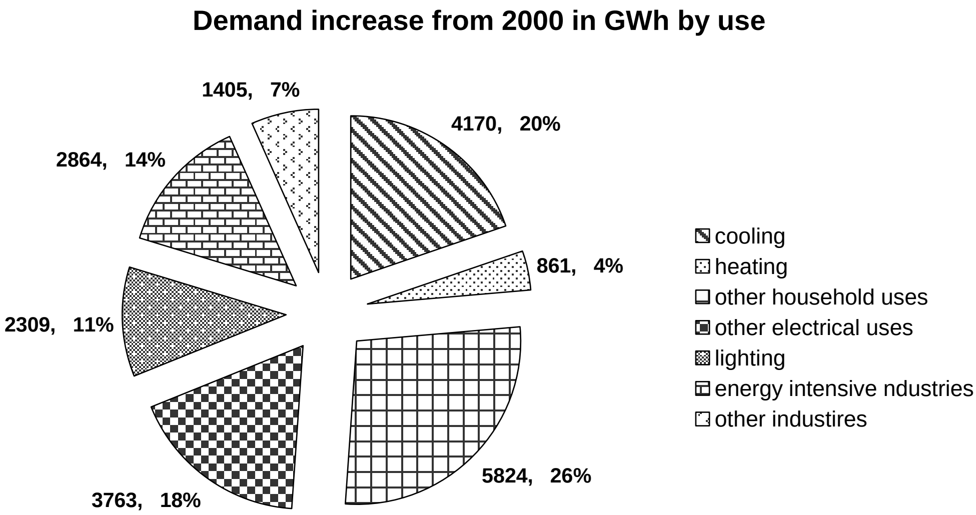

Figure 4-3: Electricity demand increase in reference scenario.

4.3. Annual load curve in 2010

The national load curve is estimated directly from individual load curves pertaining to different end uses. Electricity consumption in industry is mainly base load, while electricity uses in residential and tertiary sectors are characterised as peak load and are affected by population habits. Figure 4-4, shows a comparison of the annual load curves between 2000 and 2010. According to the projection, the highest peak increases by about 62% from its 2000 level, while the base load generally increases by almost 33%.

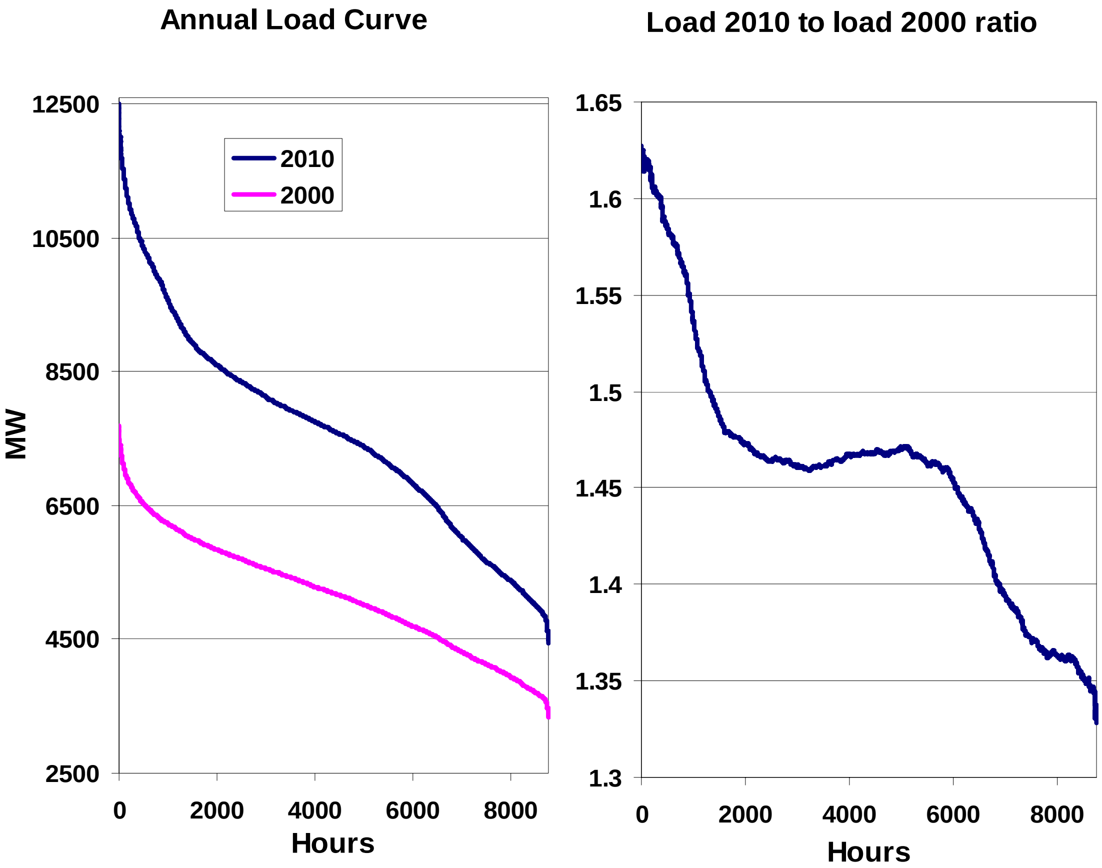

Figure 4-4: The projection of annual load curve.

Figure 4-5 shows the load in a typical working day in July and January. As shown in the figure the peak hours occur in the afternoon (12 to 15 hours) and the evening (20 to 23 hours). Due to the increased share of air-conditioners in overall demand, the highest peaks occur in summer unlike patterns in most European countries in which the highest peaks occur in winter. In addition, the peak hours in summer at night present a lead of about 2 hours compared to winter; thus in summer the night peak hours lie between 21and 23 hours, while in winter the night peak hours lie between 19 and 21 hours. This is explained by the seasonal population life-styles.

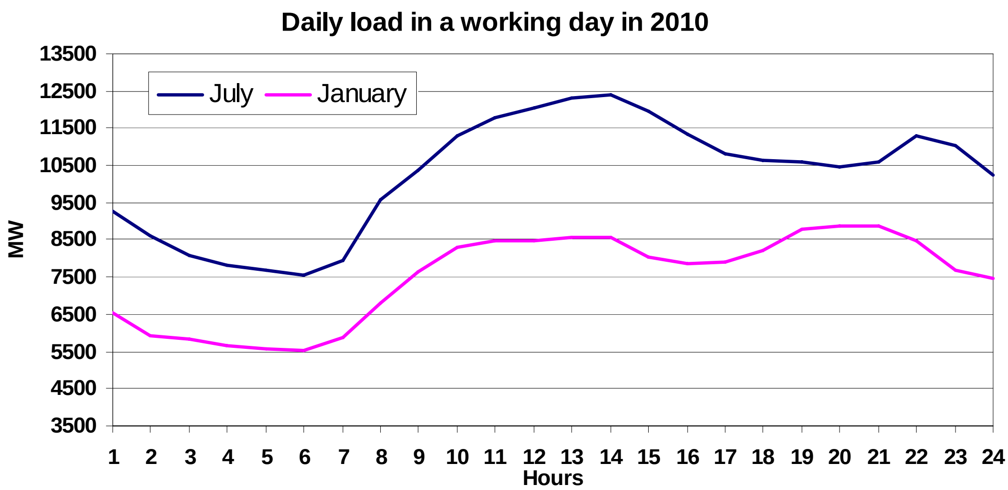

Figure 4-5: Daily load curve in a typical working day.

The reference scenario assumes that the total installed thermal electricity capacity in 2010 will be around 10.9GW, according to current investment plans in Greek power generation sector. However, since the peak load increases about 62% from its 2000 levels, it is interesting to examine the probabilities of observing an electricity load grater than 11GW. The analysis showed that the probability of having a peak load more than the total thermal capacity in July is around 60% (Figure 4-6). It can be expected that there is a significant probability of having high electricity prices in these hours. This issue is discussed in detail in the section of electricity spot prices.

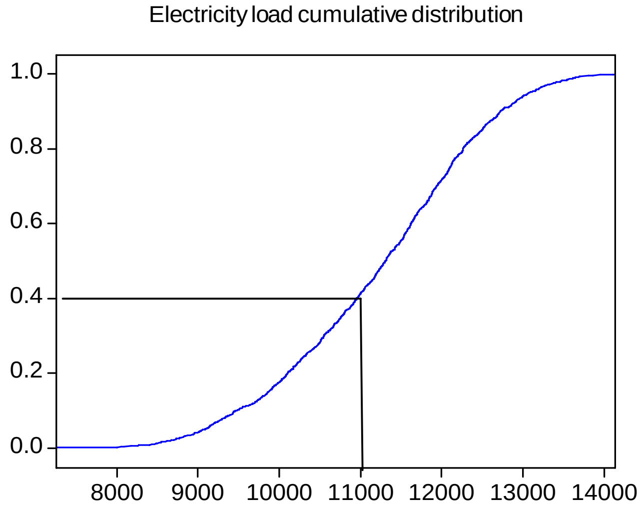

Figure 4-6: The cumulative distribution of electricity load in July 2010 peak hours (12-15 & 21-23).

4.4. The electricity market structure in 2010

4.4.1. The market players

In principle the Greek electricity market is undergoing rapid liberalisation. This liberalisation should cover all generation activities and around one third of consumption (right to choose supplier).

However, the Public Power Corporation (PPC) still remains the only distributor and currently controls 97% of the production. The PPC's power generation system consists of thermal and hydroelectric stations, as well as a small number of units using renewable energy sources (mostly wind energy).

New players are expected to enter the market after 2004. Two of them are already known and are TERNA and Hellenic Petroleum (Helpe). These two companies have already submitted their investment plants to RAE (the Greek Regulatory Authority for Energy) and they have obtained RAE's approval. RAE also estimates that there will be additional investments in new power generation plants, either as TERNA/Helpe investments or as a third independent producer investments. It was decided, for the purposes of reference scenario, to assign 40% of these unallocated investments to TERNA and Helpe and let the rest 60% to be owned by an unknown player, called X1.

Given these developments PPC will still hold almost 70% of the total thermal electricity capacity in 2010, leading to a kind of oligopoly where the market will be controlled by a huge generator. In the context of ELMAS specification this would have given it excessive market power. A more realistic scenario would involve treating PPC outside the main framework of the model. Such a scenario would however blunt the model demonstration qualities of the case which constitute the main purpose of the exercise. It was therefore preferable to construct an alternative where PPC was broken down into smaller companies, by assuming that four companies will own the thermal power plants and another four players will control the hydroelectric stations. For the purposes of the current presentation the players who own the thermal plants are called PPC1…PPC4, while the players owning hydroelectric stations are called HYDRO1...HYDRO4. Another independent producer was also assumed, called DIESEL, owning diesel generators which are used as peaking devices.

Wind turbines and photovoltaic plants were assigned to a separate independent player, called WIND, who was excluded from market competition. The main reason is that the production costs from wind turbines and solar are negligible compared to the production costs of thermal stations. So electricity production from renewable sources is not influenced by the price variation but by the availability of the corresponding intermittent source. In the model, the production from wind and solar energy was subtracted from the total electricity demand according to the hourly availability of the source.

In total 13 players compete for electricity production in 2010 in the reference scenario, namely PPC1...PCC4, HYDRO1...HYDRO4, TERNA, Helpe, X1, WIND and DIESEL.

4.4.2. The power plants and the allocation to market players

Today the electricity production is based mainly on lignite-fired stations. The country's main lignite centre is located in Northern Greece (Ptolemaida, Kardia, Agios Dimitrios, Amyntaio and Florina), having a total installed capacity of 4016MW (at the end of 2003). The southern lignite centre is located in Megalopolis, Peloponnese, with a total installed capacity of 766MW (at the end of 2003). There are also two Gas Turbines Combined Cycle (GTCC) units, one in Komotini of 476MW and one in Lavrio (near Athens) of about 550MW. In addition there are 430MW of conventional oil fired stations located in Lavrio. Finally, diesel turbines of about 212MW are also installed. All these stations are currently controlled by PPC. Before the end of 2010 PPC plans to construct a supercritical lignite unit in Florina of about 330MW, a GTCC unit in Komotini of about 400MW and a GTCC unit in Lavrio of about 400MW. Moreover in the reference scenario it was assumed that another 221MW of diesel generators will be also be available. Finally, the total capacity of hydroelectric plants in 2010 was assumed to stand at 2988MW.

TERNA's investment plan involves the construction of a GTCC unit of about 400MW and a gas turbine open-cycle unit of 150MW before 2010. In the reference scenario, it was also assumed that TERNA will construct one more GTCC unit of 400MW.

Helpe current investment plan includes the construction of one GTCC unit of 400MW before 2010. For the purposes of reference scenario it was also assumed that Helpe will construct one more GTCC unit of 400MW. Moreover PPC plans to construct a gas turbine open-cycle unit of 120MW, which in the reference scenario were allocated to Helpe. Finally concerning the unknown player X1 it was assumed that he will construct 3x400MW GTCC until 2010.

The installed wind capacity in 2002 was about 366MW. According to the latest RAE annual report the applications having received approval or a positive assessment amount to 3GW, although according to RAE a possible contribution by 2010 would stand at around 1.8GW. GARI estimates that a more realistic outcome for 2010 would be, around 1.2 GW. Thus, for the purposes of reference scenario the installed wind turbines capacity in 2010 was assumed at 1.2GW. Finally, photovoltaic capacity was assumed at 5.2MW, according to the estimations for 2010 presented in the RAE annual report.

The allocation of plants to market players in the reference scenario is presented in Table 4-3. According to this scheme four companies will own about the 12% of the total capacity each, two companies will control about 8% and another four will posses about the 6.3% of the total capacity each.

TYPE	NAME	PPC 1	PPC 2	PPC 3	PPC 4	TERNA	HELPE	X1	DIESEL	HYDRO 1	HYDRO 2	HYDRO 3	HYDRO 4	WIND	**TOTAL**
LIGNITE THERMAL	FLORINA SUPERCRITICAL			330											**330**
	FLORINA			300											**300**
	KARDIA	1144													**1144**
	AGIOS DIMITRIOS		1456												**1456**
	AMYNTAIO	546													**546**
	PTOLEMAIDA		570												**570**
	MEGALOPOLI			766											**766**
FUEL OIL	LAVRIO 1&2			430											**430**
DIESEL	DIESEL CONVENTIONAL								212.1						**212.1**
	DIESEL ADVANCED								221						**221**
GTCC	KOMOTINI				476										**476**
	KOMOTINI 2				400										**400**
	LAVRIO 4				550										**550**
	LAVRIO				400										**400**
	GTCC Type 1					800	400	1200							**2400**
	GTCC Type 2						400								**400**
GAS TURBINE	GAS OPEN CYCLE					150	120								**270**
HYDRO	HYDROELECTRIC									913.2	552.7	979.8	542.3		**2988**
RENEWABLE	WIND													1200	**1200**
	PHOTOVOLTAIC													5.2	**5.2**
	TOTAL	**1690**	**2026**	**1826**	**1826**	**950**	**920**	**1200**	**433.1**	**913.2**	**552.7**	**979.8**	**542.3**	**1205.2**	**15064.3**
	% OF TOTAL CAPACITY	**11.2**	**13.4**	**12.1**	**12.1**	**6.3**	**6.1**	**8.0**	**2.9**	**6.1**	**3.7**	**6.5**	**3.6**	**8.0**	**100.0**

Table 4-3: The players in the Greek electricity market in 2010 according to reference scenario. All capacities are expressed in MW.

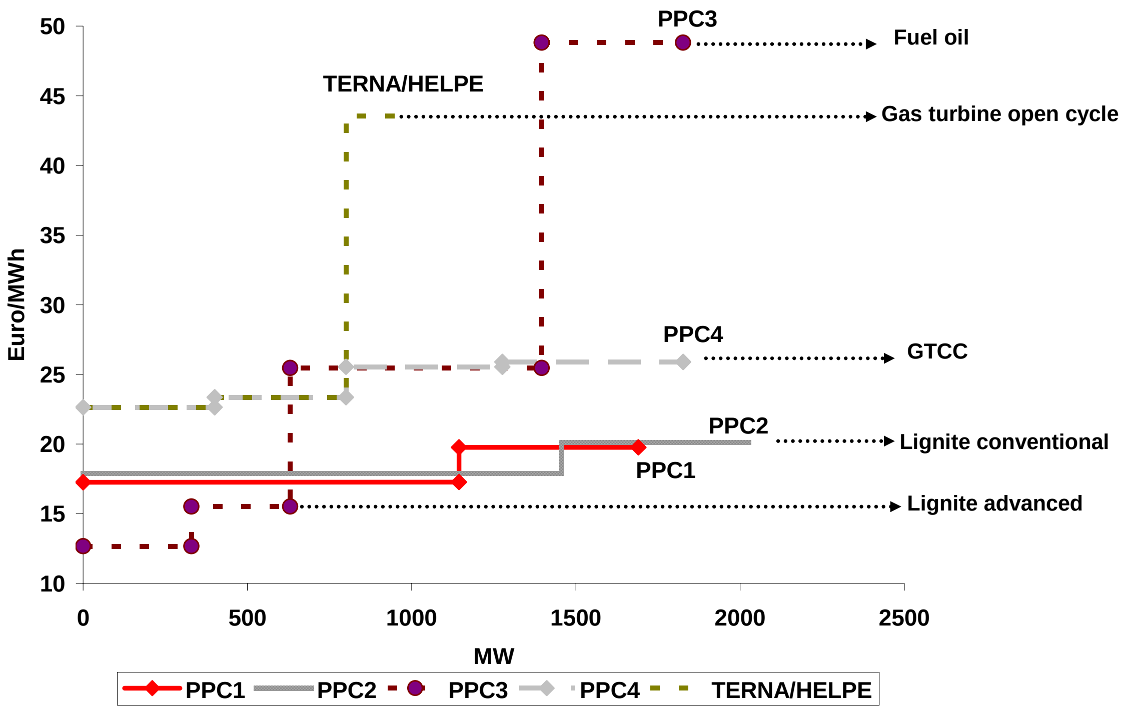

Figure 4-7: The variable production cost curves of some indicative players with thermal plants.

4.5. Electricity production and electricity spot price in 2010

4.5.1. Electricity production

In pool based electricity markets, producers tend to become either "price leaders" or "price takers". Price-leaders are large players, who try to control their production in order to achieve higher prices. On the other hand, small players usually produce their maximum capacity, whenever they cover their variable production costs. As a result the market is characterised by the dominant behaviour of "price leaders" producers that attempt to modify market-clearing prices for their respective benefits. Table 4-4 shows that the large lignite-based producers play the role of the "price leaders" by utilising their plants below 60%. On the other the GTCC-based producers are the "price takers" and they are utilising their plants almost 75% of their capacity. As a result, the production from GTCC units accounts for more than 45% in total domestic electricity production.

	PRODUCTION		UTIL. RATE
	TWh	%	%
HYDRO	4.2	6.5	16.1
LIGNITE	26.6	41.2	59.3
GTCC	30.0	46.5	74.0
GAS OC	0.4	0.6	16.2
OIL	0.6	0.9	8.1
WIND	2.8	4.3	26.3
DOMESTIC PRODUCTION	64.5	100.0	48.9
IMPORTS	3.5	-	52.6
TOTAL PRODUCTION	**68.0**	-	-

Table 4-4: A general view of the electricity production in 2010 under the reference scenario.

The base load is clearly covered by lignite and GTCC thermal plants, while gas open cycle and oil-powered stations are used as peak devices. Regarding the intermittent sources hydro and wind, their utilisation rates are around 16.1% and 26.3% respectively, which are in line with the statistical data provided by EUROSTAT. As a result, wind turbines cover only 4.3% of total domestic production.

The international transmission line capacity was assumed to be around 750MW in 2010, by taking into account a 150MW capacity extension. Imports are expected to represent on average about 5.1% of total electricity supply and the utilisation rate of the international transmission line will be nearly 53%.

Figure 4-8 shows the average electricity production in typical days by plant type. The production is presented for a typical working day in July, a typical working day in January and a Sunday in May. In July, lignite and GTCC plants are utilised in the peak hours almost at their maximum capacity, which is 5.1 and 4.6GW respectively. Hydro electric plants save water at night in order to produce electricity during the peak hours. Oil and gas powered turbines operate only in the peak hours as expected. Imports are also higher in July than in January and May and the average utilisation rate of the international transmission line is near 90%. Wind turbines on average produce more electricity in the afternoon where the average wind velocity is higher. The hourly average wind production accounts for 2.7-3.7% of the total domestic electricity production, depending on the hour of day.

On the other hand a working day in January is characterised by an easier supply situation. Hydroelectricity comes at larger quantities since there is a surplus of water in reservoirs, reducing the need of using the expensive oil and gas peak devices. Electricity imports are lower than July, because electricity demand in the northern neighbour countries is higher in the winter than in summer, which makes imports expensive. Moreover, during the peak hours, the electricity imports remain constant at their highest guaranteed levels. Wind production increases in afternoon and at night where the wind velocity is higher than the morning hours, and covers on average the 3-5.1% of total domestic electricity production (depending on the hour of day).

Finally a typical Sunday in May is characterised by a reduced hydroelectric production, since hydro producers conserve their potential for peak hours during the summer months. For climatic reasons wind energy is also in its lowest levels. Electricity imports rise in peak hours in order to cover the gap in hydro and wind electricity.

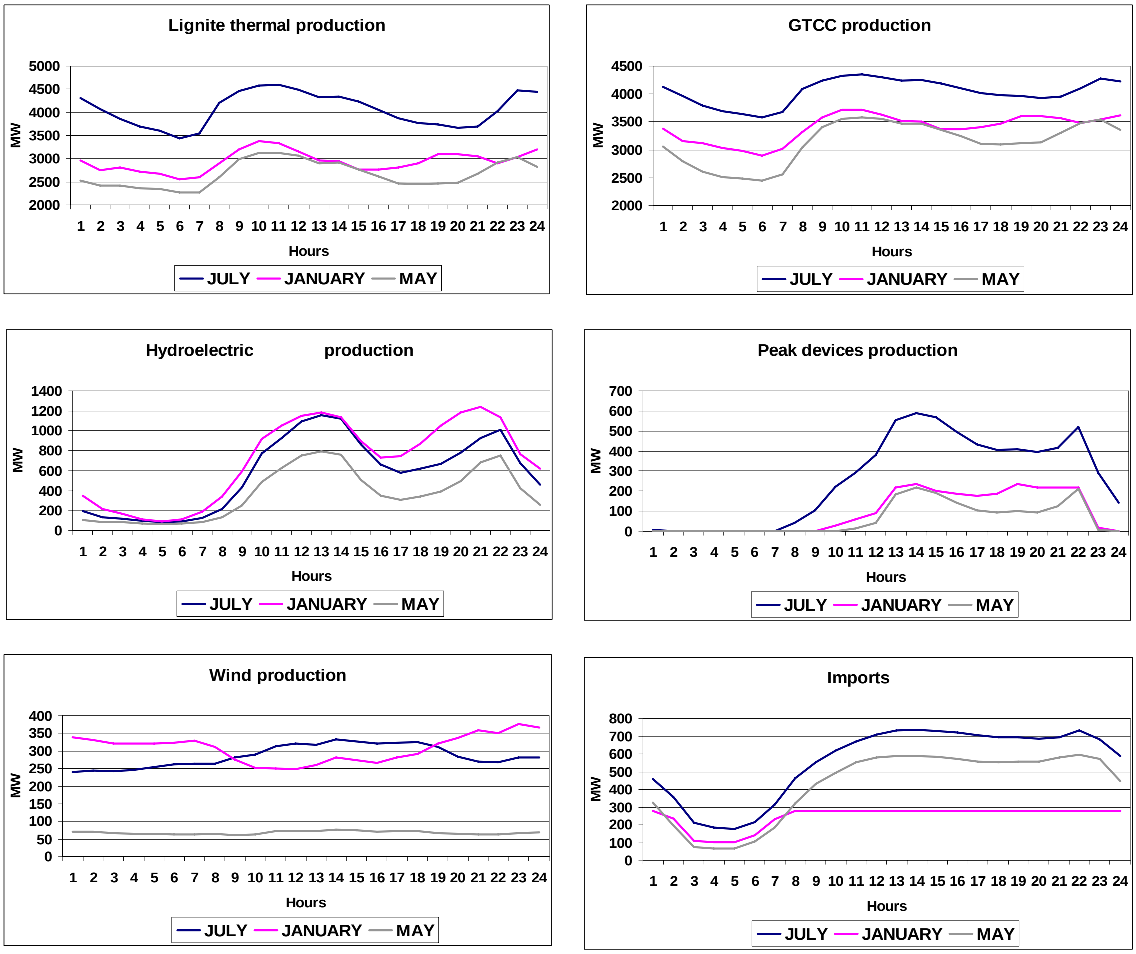

Figure 4-8: Average electricity production in typical days (working days in July and January, Sunday in May) by plant type in 2010

4.5.2. Electricity spot price

Reference scenario results confirm and accentuate the fact that unlike patterns in most European countries spot prices in summer will be considerably higher than in winter, especially during peak hours, because of the importance of air-conditioning. The lowest prices are observed mainly in May and October, when little air-cooling or electric heating takes place.

Figure 4-9 presents the distribution of electricity spot price over the sample in 2010. The distribution is multi-modal with a mean value of about 89 Euro/MWh and a standard deviation of nearly 39 Euro/MWh. There are two main “hills” in the distribution. The first corresponds to base load spot prices and lies in the range between 35 and 60 Euro/MWh, while the second corresponds to peak load spot prices and lies in the range between 100 and 160 Euro/MWh. The rest of the values are either extreme base load and peak load values or spot prices that correspond to intermediate hours.

As shown in the cumulative distribution graph, 5% of the electricity prices are below 36.8Euro/MWh and another 5% above 139.06 Euro/MWh. In extreme high price cases, it is evident that the projected demand is higher than the available power generation capacity.

July has been proved to be the month with the higher electricity spot prices. As Figure 4-10 shows, the probability that the electricity spot price in the peak hours in July (12-15 & 21-23 hours) will exceed the level of 150 Euro/MWh is nearly 15%.

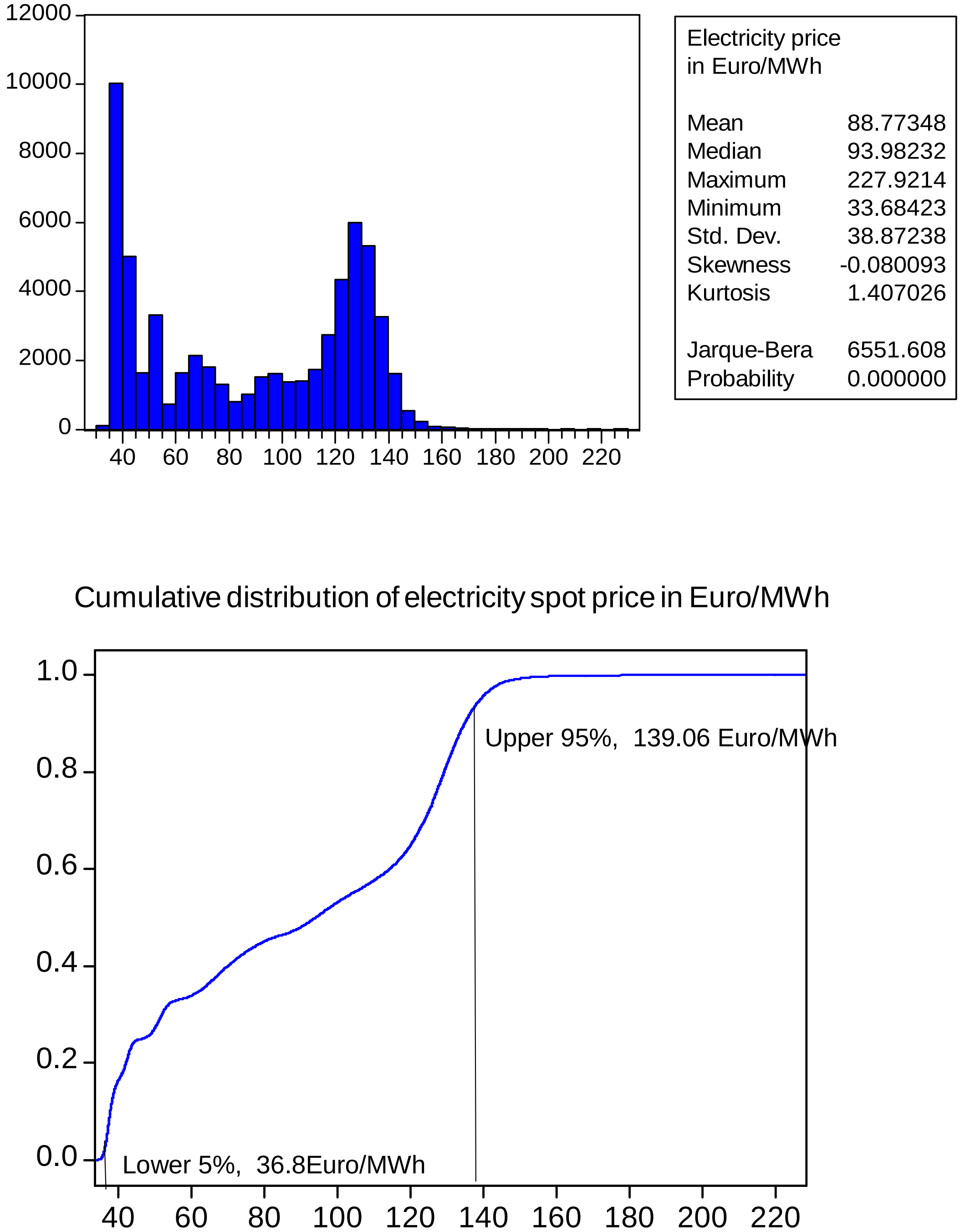

Figure 4-9: Electricity spot price distribution and cumulative distribution in 2010.

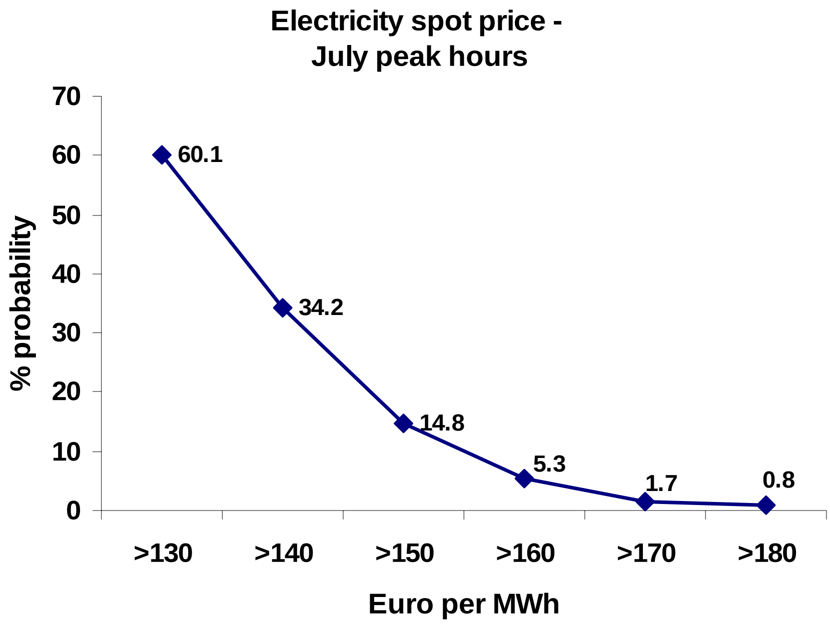

Figure 4-10: Probability that the electricity spot price will exceed a certain level in July peak hours.

The electricity prices are characterised by high volatility. Such volatility can be caused by a number of factors – changing weather conditions such as a heat wave pushing demand to unexpected levels, outage of a major power plant or transmission network congestion. Figure 4-11, presents the average spot price in each hour and the lower and upper 5% quantiles. The small price variation that is observed in base load is due both to lower seasonality in base load demand but also to easier supply conditions (smaller vulnerabilities to extreme events). On the other hand in peak hours the price variation is higher. This is due both to seasonal effects and to random situations that can occur.

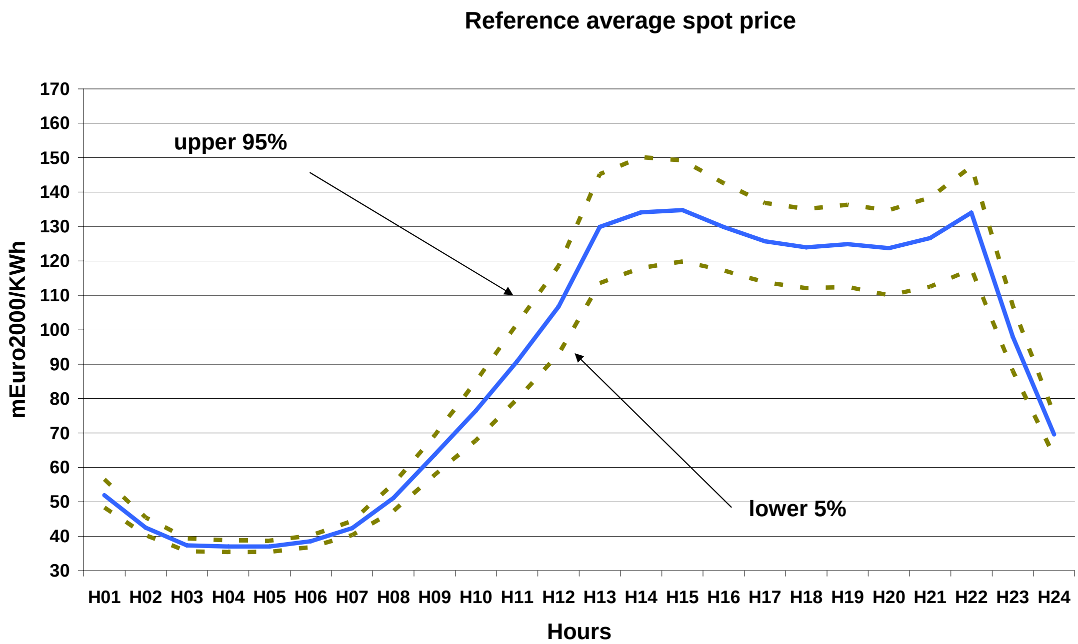

Figure 4-11: Average electricity spot price in 2010 by hour.

The following figures present the average electricity spot prices in typical days, which illustrate the seasonality effects. The figures also present the 5% lower and upper quantiles. The graphs clearly show that the price volatility in July is higher than in December, reflecting the increased demand in summer. In intermediate hours (19-21) spot prices in July tend to fall while they are maintained at high levels in December due to load considerations (lighting, electric heating).

On the other hand, the electricity spot price variation is small in a typical Sunday in May Sunday, reflecting the narrow variation of electricity demand.

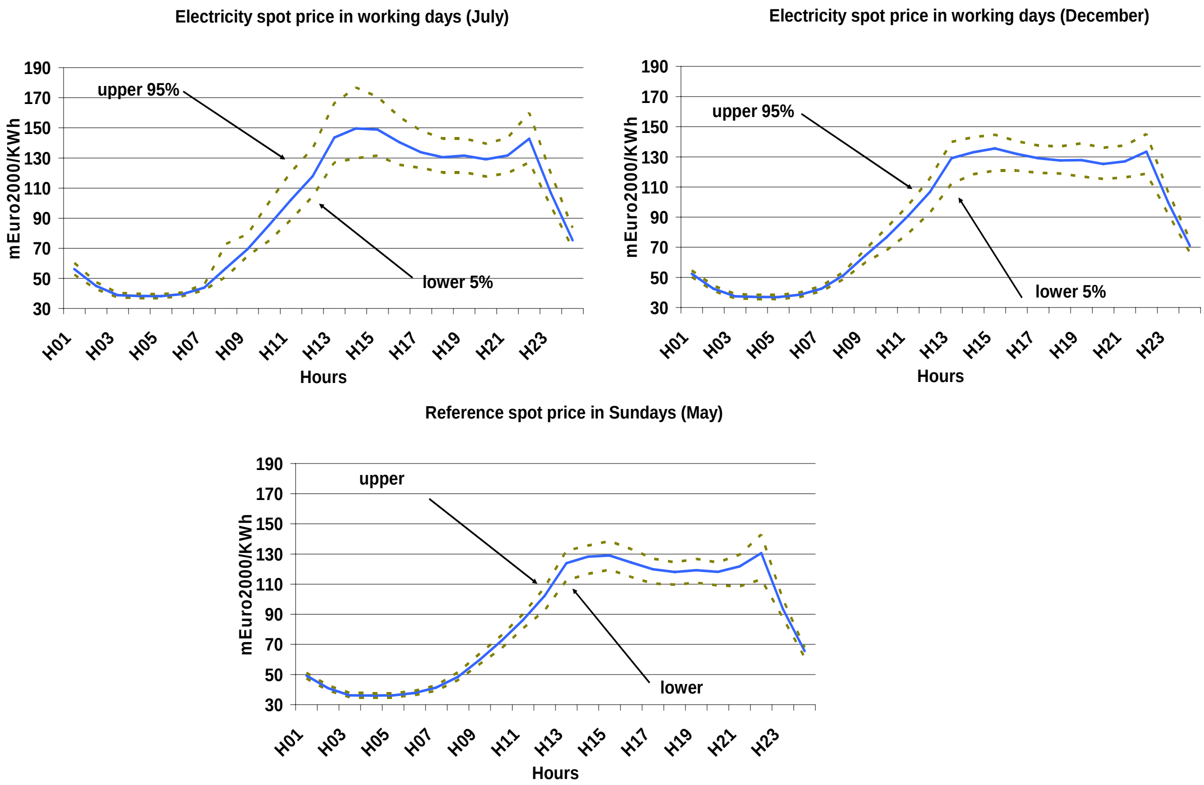

Figure 4-12: Average electricity spot price in typical days (2010).

5. Higher wind scenario

The scope of the higher wind scenario is to study the effects both on electricity production and on spot prices in the case of increased penetration of wind turbines. For the purposes of the scenario it was assumed that all applications for new investments in wind energy that have received approval or a positive opinion from RAE become operational by 2010. Such high capacity at such an early date is clearly unrealistic and was retained in this purely illustrative case. Thus, in the higher wind scenario the total installed wind capacity in 2010 reaches the level of 3GW, in order to highlight the effects of the increased wind penetration on main model variables (production, spot prices, etc.). It was assumed that consumers pay an additional fee of 2.4Euro/MWh as subsidy for wind electricity, consistent with current practices and the enhanced role of wind power in the scenario.

It was important, for obtaining comparable results and avoiding bias into the analysis, to maintain productive capacity comparable to that pertaining in the reference case. For this purpose, the total installed thermal capacity was reduced in order to counterbalance the additional electricity production from wind turbines, by subtracting 600MW of GTCC from the total capacity of player X1.

5.1. Electricity demand and electricity production

The electricity prices are slightly higher in this scenario, which leads to a decline in total electricity demand by 0.45% from its reference levels. Moreover the electricity production from thermal power plants is lower than in the reference case as expected. So, the production from lignite is 2.4% lower compared to reference, while GTCC production declines by nearly 12%. On the other hand, gas open cycle and oil-fired power plants maintain their share in the total domestic production, implying that there is an increased need of peeking devices in this scenario. Hydro electricity remains at the same levels as in reference scenario while imports declining by 3.1% (Table 5-1).

	PRODUCTION		UTIL. RATE	% DIFFERENCE IN PRODUCTION
	TWh	%	%	FROM REFERENCE
HYDRO	4.2	6.5	16.1	0.0
LIGNITE	25.9	40.3	57.9	-2.4
GTCC	26.3	40.9	74.7	-12.1
GAS OC	0.4	0.6	16.9	4.4
OIL	0.6	0.9	7.5	-7.6
WIND	6.9	10.8	26.4	149.7
DOMESTIC PRODUCTION	64.4	100.0	48.8	-0.2
IMPORTS	3.4	-	51.0	-3.1
TOTAL PRODUCTION	**67.7**	-	-	-0.4

Table 5-1: An aggregate view of the electricity production in the higher wind scenario.

5.2. Electricity spot price

The electricity spot price in this scenario is slightly higher than in the reference case. As shown in Figure 5-1 the mean value increases about 1%. Moreover the absolute maximum increases by 12% while the absolute minimum is almost 6% lower than in the reference scenario. The standard deviation of electricity price increases due to the higher uncertainty in electricity supply.

The cumulative distribution shows that 90% of the results lie into the range from 37.7 to 143.9 Euro/MWh, increasing the probability of having an electricity price higher than 144 Euro/MWh to 5%, 2.5 times more than the corresponding probability in the reference scenario.

The comparison of cumulative distributions shows that by excluding a number of price outliers, the electricity spot prices in wind scenario are almost at the same levels as in reference scenario. As an example, the probability of obtaining a spot price less than 110Euro/MWh in the higher wind scenario is nearly 59%, while in the reference scenario it is around 58%. These results imply that the average electricity price paid to producers in the wind scenario will be almost the same as the average price in the reference scenario.

However when focusing on the boundaries of the distributions, the effects of wind on energy prices become more evident. On the one hand the higher wind penetration increases the need of peeking devices, and in turn the electricity prices tend to be higher, but on the other hand it can also reduce the system's production costs and the electricity prices in these cases where there is high wind availability.

Figure 5-2 shows that in summer peak hours the probability of observing an electricity spot price greater than 150 Euro/MWh is about 27.9%, 12.7% higher than in the reference case. Looking at the extreme events the probability that the electricity price will exceed the level of 170Euro/MWh is 3 times higher than in the reference scenario. However there are cases in which the higher wind production produces lower prices. As shown in Figure 5-2, in April afternoon the probability of lower electricity prices is higher in the wind scenario than in the reference scenario.

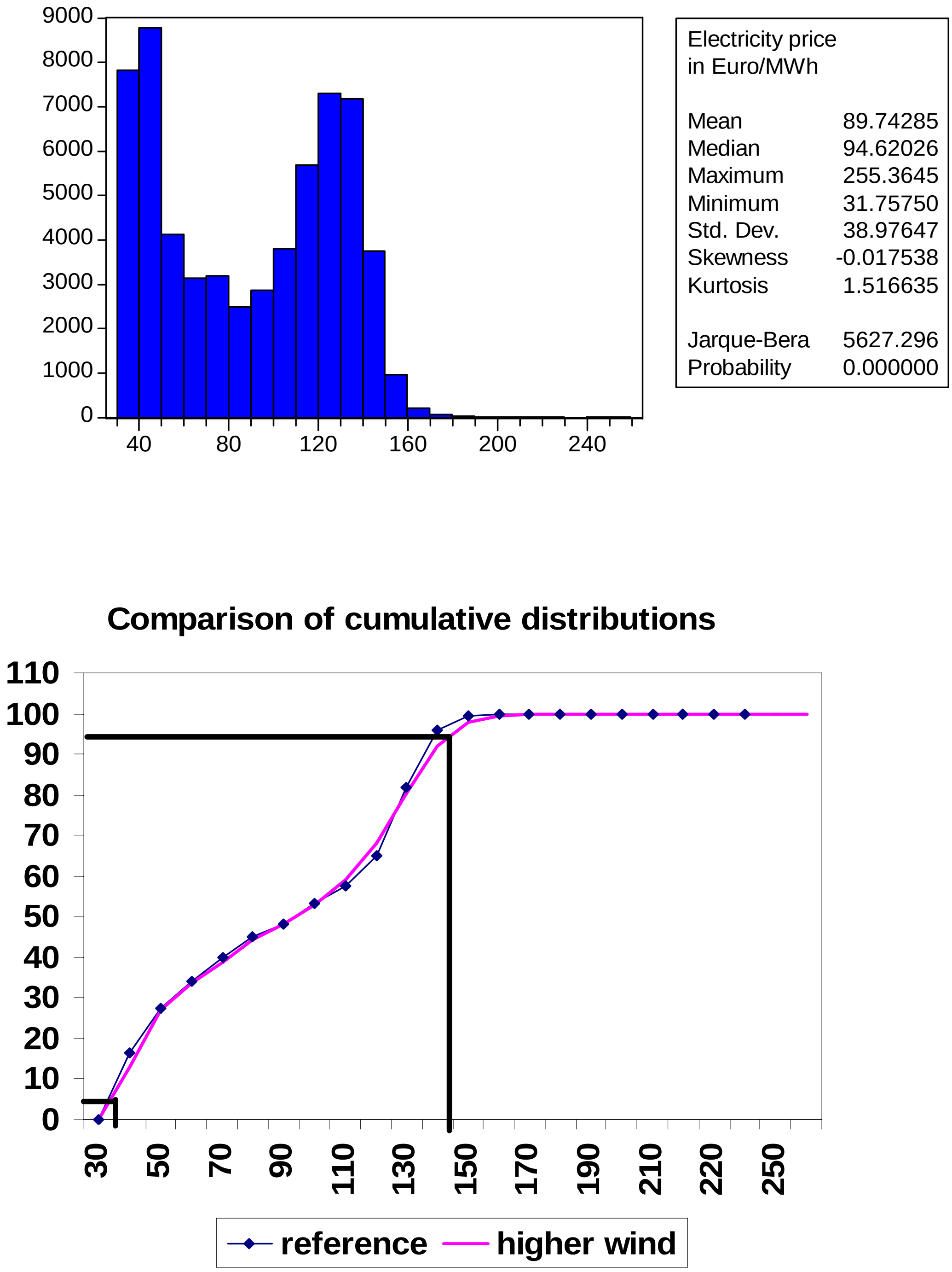

Figure 5-1: Electricity spot price distributions in 2010.

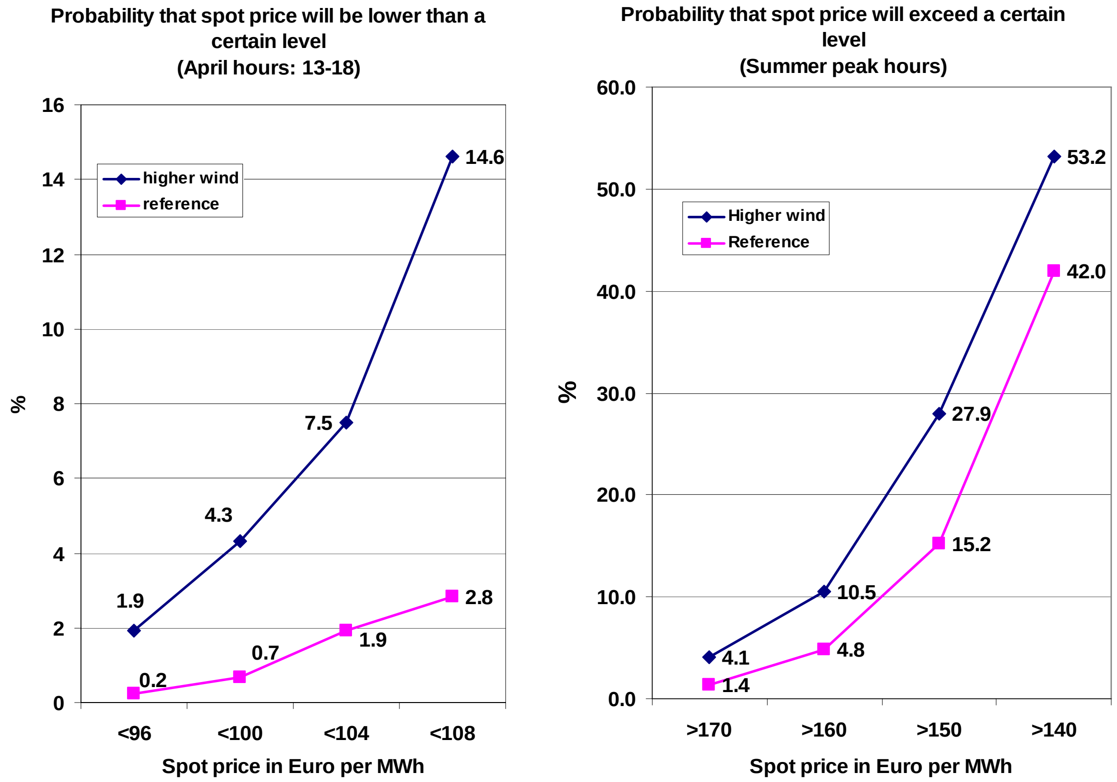

Figure 5-2: Spot price probabilities.

5.3. Conclusions

The higher wind scenario showed that on average there is a negligible increase on electricity spot prices, as a result of peaking devices utilisation in those cases where the electricity production from wind turbines is small due to weather conditions. However the analysis showed that in peak hours there is a considerable increase in the probability of obtaining very high electricity prices. Wind speed variability tends to introduce additional variability is spot prices due to the increased reliance on wind power; although winds in a region tend to be more intense in the afternoon hours especially in summer, when some of the highest demand loads are likely to occur, a combination of high dependence on wind capacity and atmospheric calm (usually associated with very high temperatures in summer) accentuates some of the most extreme spot price events.

The change in electricity production structure has some positive effects on the environment. The higher wind scenario showed that total production from fossil fuels declined by 7.5%, implying a CO_2 abatement of around 2Mtn of CO_2 (around 5% of total CO_2 emissions from power generation).

6. The role of enhanced competition

Despite market liberalisation in the reference scenario, the model results suggest high profit rates for the companies originating from PPC. In fact, the ratio of the total profit to total sales for the eight companies that formed PPC was nearly 26%. This result implies that the market was not fully liberalised and an oligopoly regime was established in the reference scenario.

The third preliminary application focuses on the effects of market liberalisation. In this scenario it was assumed that the Public Power Corporation is broken down into a large number of smaller companies. The new market structure is presented in Table 6-1.

The thermal and hydroelectric plants of PPC are allocated to 13 different companies, in such a way that the total profit ratio does not exceed 11.7%. There are now 18 different players in the new market structure, in which no player holds more than 8% of total electricity capacity, resulting in a more enhanced competition.

The wind capacity assumed is 1.2 GW, while photovoltaics stand at around 5.2MW.

TYPE	NAME	PPC 1	PPC 2	PPC 3	PPC 4	PPC 5	PPC 6	PPC 7	PPC 8	PPC 9	TERNA	HELPE	X1	DIESEL	HYDRO 1	HYDRO 2	HYDRO 3	HYDRO 4	WIND	**TOTAL**
LIGNITE THERMAL	FLORINA SUPERCRITICAL					330														**330**
	FLORINA			300																**300**
	KARDIA	1144																		**1144**
	AGIOS DIMITRIOS		1456																	**1456**
	AMYNTAIO							546												**546**
	PTOLEMAIDA				570															**570**
	MEGALOPOLI									766										**766**
FUEL OIL	LAVRIO 1&2									430										**430**
DIESEL	DIESEL CONVENTIONAL													212.1						**212.1**
	DIESEL ADVANCED													221						**221**
GTCC	KOMOTINI			476																**476**
	KOMOTINI 2						400													**400**
	LAVRIO 4								550											**550**
	LAVRIO					400														**400**
	GTCC Type 1										800	400	1200							**2400**
	GTCC Type 2											400								**400**
GAS TURBINE	GAS OPEN CYCLE										150	120								**270**
HYDRO	HYDROELECTRIC														913.2	552.7	979.8	542.3		**2988**
RENEWABLE	WIND																		1200	**1200**
	PHOTOVOLTAIC																		5.2	**5.2**
	TOTAL	**1144**	**1456**	**776**	**570**	**730**	**400**	**546**	**550**	**1196**	**950**	**920**	**1200**	**433.1**	**913.2**	**552.7**	**979.8**	**542.3**	**1205.2**	**15064.3**
	% OF TOTAL CAPACITY	**7.6**	**9.7**	**5.2**	**3.8**	**4.8**	**2.7**	**3.6**	**3.7**	**7.9**	**6.3**	**6.1**	**8.0**	**2.9**	**6.1**	**3.7**	**6.5**	**3.6**	**8.0**	**100.0**

Table 6-1: The new market structure for enhanced competition.

6.1. Electricity demand and electricity production

The extreme market liberalisation leads to a sharp decline in average spot electricity prices. As a result electricity demand is higher about 4.7% compared to the reference case. Lignite and GTCC account for the 90% of total domestic production and their utilisation rates are now higher. This can be explained partially by the higher demand and partially by elimination of restrictive practices of the main market players who in the reference case happened to be predominantly lignite base.

	PRODUCTION		UTIL. RATE	% DIFFERENCE IN PRODUCTION
	TWh	%	%	FROM REFERENCE
HYDRO	4.2	6.1	16.1	-0.1
LIGNITE	32.9	47.7	73.5	23.8
GTCC	29.0	42.0	71.5	-3.3
GAS OC	0.1	0.1	2.5	-84.5
OIL	0.1	0.1	0.8	-90.6
WIND	2.8	4.0	26.3	0.0
DOMESTIC PRODUCTION	69.0	100.0	52.3	6.9
IMPORTS	2.5	-	38.3	-27.2
TOTAL PRODUCTION	**71.5**	-	-	5.2

Table 6-2: A general view of the electricity production structure.

Table 6-2 shows that the total domestic production has been increased by almost 7% from reference scenario. GTCCs show lower production from reference, as a result of the higher willingness to produce from lignite.

6.2. Electricity spot prices

Electricity prices are significantly lower compared to the reference scenario. As shown in Figure 6-1, the mean value is 65.5 Euro/MWh, about 12 Euros less than the reference scenario. In addition 90% of the results lie in the range from 31.9 to 100.7 Euro/MWh (smaller variability).

Very high price frequencies remain virtually the same as in the reference scenario, implying that very high spot prices persist as they represent cases where demand is equal to available capacity. However, the comparison of the cumulative distributions shows that in this scenario the probabilities of obtaining above average peak demand prices are much lower than in the reference scenario.

Figure 6-3, presents the probability that the electricity price will be lower than a certain level. As shown in the graph the probability that the electricity spot price is lower than 40Euro/MWh is 27%, instead of 16.5% in the reference scenario. Moreover the 99.4% of prices were below 120Euro/MWh.

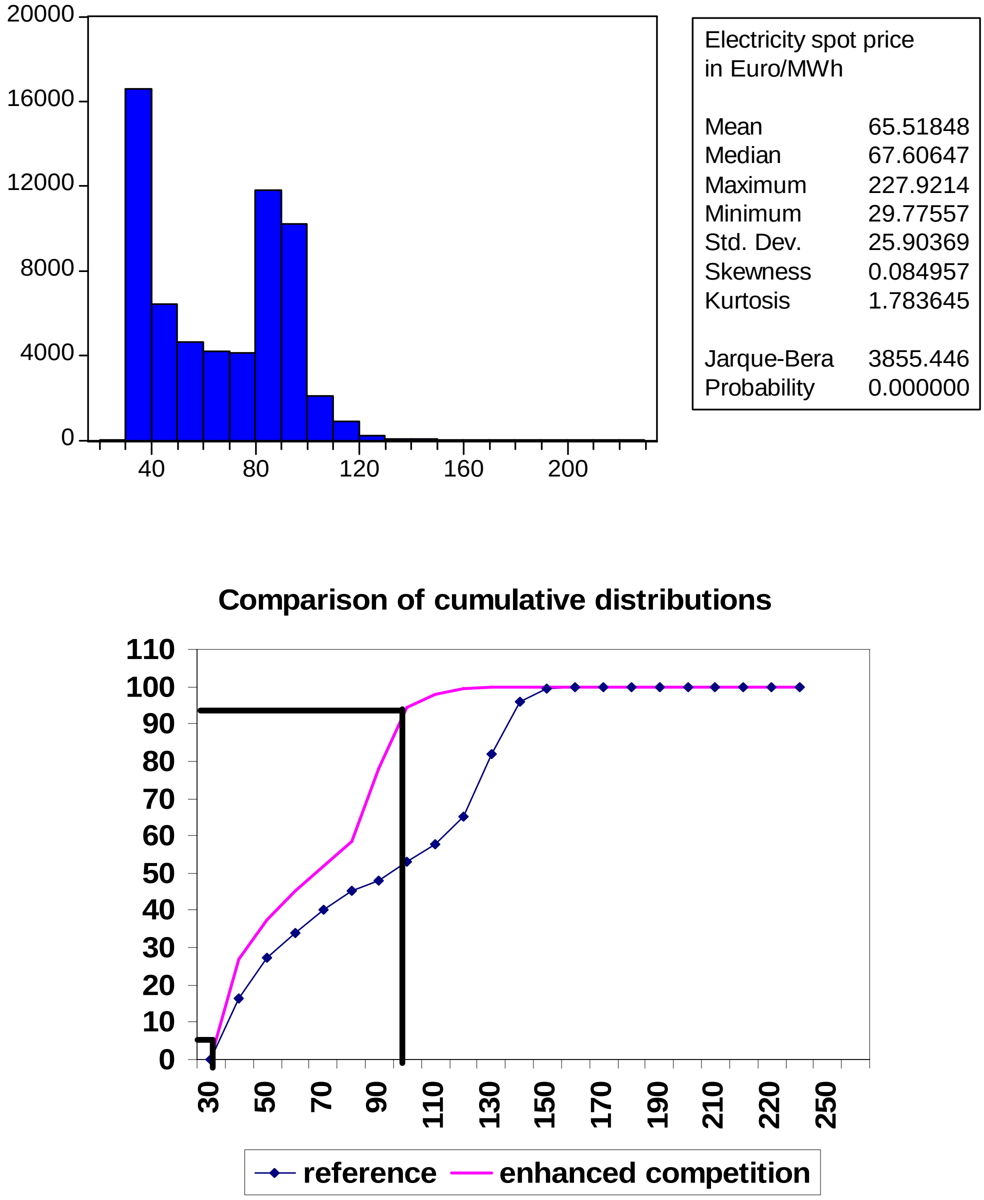

Figure 6-1: Electricity spot price distributions.

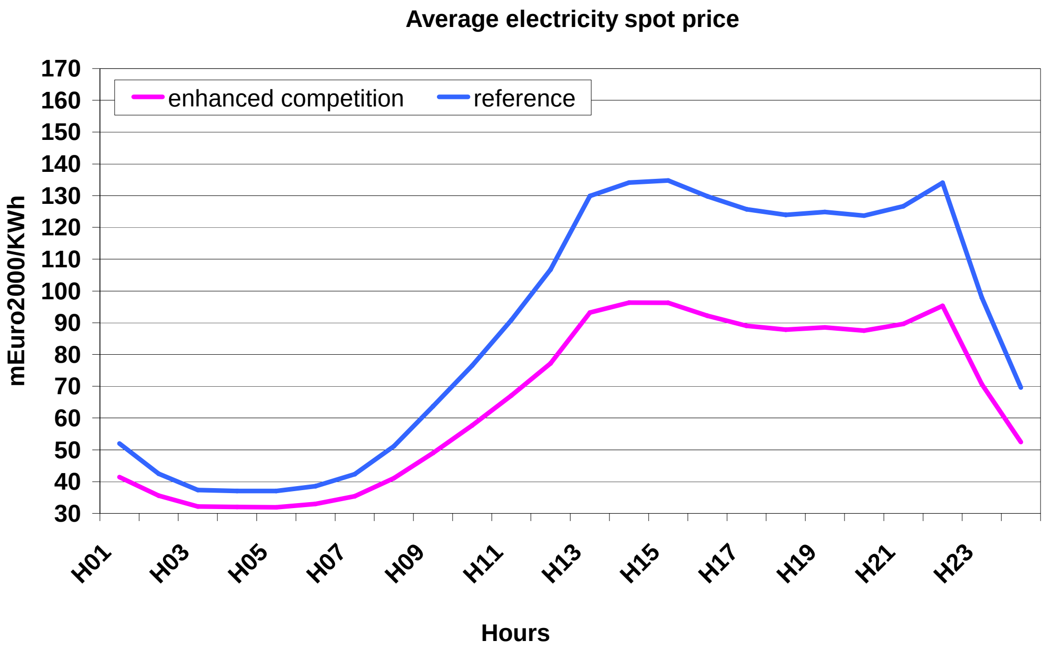

Figure 6-2: The average electricity spot price in reference scenario and in the scenario with enhanced competition.

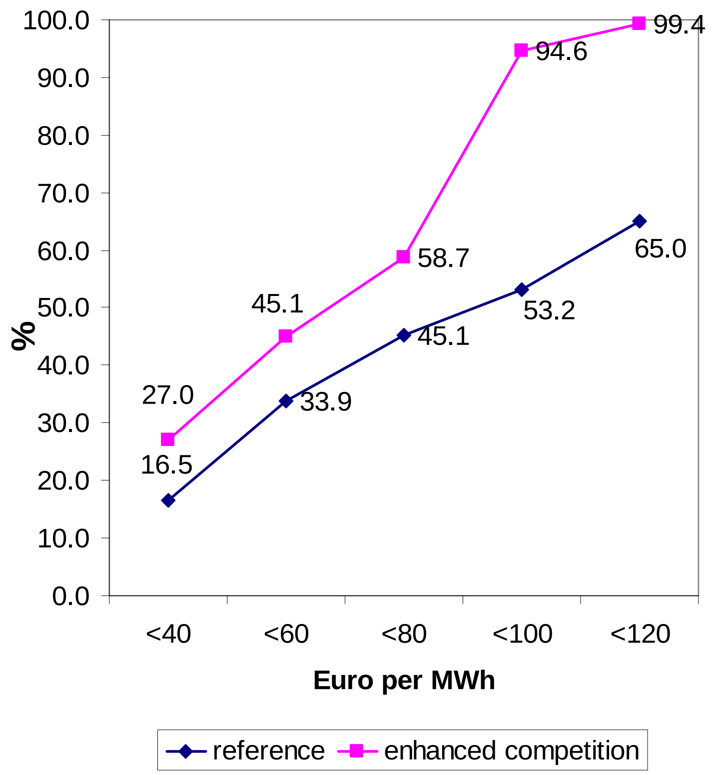

Figure 6-3: Probability that the electricity spot price will be lower than a certain level.

6.3. Conclusions

By enhancing competition, the distinction between “price leaders” and “price takers” is blurred. All producers have fewer profits than in the reference scenario, which is the result of the lower electricity spot prices. While high prices still persist, reflecting situations where high spikes occur in electricity demand, in most cases competition has produced much lower prices. This is particularly the case of peak load pricing where most of the market power is exercised in an oligopolistic market structure.

This scenario clearly illustrates the importance of the allocation of the different plants to different companies: the same set of plants allocated differently may produce a radically different simulation in terms of most of the important output variables of the model (spot prices, demand, imports, exports and individual plant operation in different hours).

7. References

1. *European energy and transport – Trends to 2030*, Directorate General Energy and Transport, ISBN 92-894-4444-4, January 2004.
2. *RAE Report from July 2002 to December 2002*, Greek Regulatory Authority for Energy, ISBN 960-336-036-8.