Insight into the Greek electric sector and energy planning with mature technologies and fuel diversification

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Abstract

The numerous available options for the development of the Greek electric sector in combination with the various techno-economic and political constraints make energy planning rather complex. Furthermore as full auctioning of CO_2 allowances shall be the rule from 2013 onwards for the electric sector following free allocation, even more uncertainties emerge. This work aims at investigating the main characteristics of the Greek electric system taking into consideration the various allowance allocation schemes, evaluates fundamental energy scenarios and ultimately performs energy planning. The reliability of the algorithm utilised is assessed by predicting successfully key figure energy results for years 2004-2008. Main parameter under investigation in the study is the cost of CO_2 emissions allowances, while expansion scenarios are evaluated according to a newly developed set of indices standing for feasibility, environmental performance, cost effectiveness and energy safety. Many expansion scenarios examined were proved unrealistic as led to extremely high utilization of imported fuels for electricity production, while others proved inefficient on environmental or economic basis. Finally it was proved that if a "conservative" energy planning is adopted, emissions reduction in 2020 can reach 6.3% over 2005.

Keywords: Greek electric sector; energy planning; CO_2 allowances

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1. Introduction

From United Nations Framework Convention on Climate Change and the Kyoto Protocol, the Climate Change seems to evolve into an environmental and economic subject of major importance, which increasingly establishes its position in the political agendas around the globe. In January 2008 the European Commission (EC) outlined an extensive package of proposals for the European Union (EU) 27 Member States (MS), known as "Climate action and renewable energy package", in order to set commitments and objectives by 2020 and effectively fight Climate Change.

Major commitments of EU in the package is the 20% reduction of Green House Gas (GHG) emissions over 1990 and 20% energy use coming from renewables by 2020. The intention of these measures is to transform Europe into a highly energy-efficient and low GHG-emitting economy, and furthermore increase its energy security. The package was adopted in December 2008 by European Parliament and Council transforming the proposal to legally binding targets for the MS. Finally it resulted in EC Directives and Decisions in 2009 (EC, 2009a, 2009b, 2009c).

As base year for the presentation of emissions reductions, the year 2005 was adopted since data for that year is more reliable, including verified emissions of the installations. Calculations over 2005 also make much clearer the efforts that must be carried out by comparing with a more recent situation (EC, 2008a).

Therefore the former EU target of -20% GHG in 2020 over 1990, equivalently becomes -14% over 2005. According to the Directive this will have to be achieved through a 21% reduction in ETS sectors and 10% in non-ETS sectors. For Greece the non-ETS sector target is specifically defined at 4% (EC, 2008a, 2009a).

One fundamental line of the adopted EU strategy is the enhancement of ETS, which was launched in 2005 and now is in its second phase (2008-2012). While in the first two phases of ETS, MS set their own emission target levels, for the third phase (2013-2020) a single EU-wide cup is adopted for the emissions of electric sector and other installation activities included in Appendix of directive 2003/87/EC. For the electric sector specifically, the total amount of the allowances after 2013 will be auctioned, except for the case of useful heat production; the later will be encouraged with free allowances, as it promotes more efficient electricity generation and helps avoid distortions of competition with installations of other sectors which also produce heat (EC, 2009a). As a result of the single EU cap country specific targets are not defined, and reductions are expected to take place based on cost-efficiency.

To meet EU target of 20% by 2020 for renewables, E.C. set individual targets for MS, taking into consideration starting points, renewable energy potentials, energy mixes, past efforts and Gross Domestic Products. For Greece the target was set at 18% RES use in final energy demand by 2020. The accomplishment of the national targets for renewables plays key role in the “Climate action and renewable energy package” as these contribute not only in emissions reductions but also decrease the EU's dependence on foreign energy sources, enhancing thus the energy safety.

The effort which is necessary for the implementation of the above measures and the compliance with the above targets in the case of Greek electric sector, strongly rely on the unique characteristics of the sector and the country itself, which are described by Dagoumas et al. (2007).

The complexity of energy planning is also increased due to the transition after 2013 to "full auctioning" of CO_2 allowances, a transparent and simple allocation mechanism which can reduce competition distortions in energy market (EC, 2008b).

For the analysis of the behaviour of Greek energy sectors, numerous are the recent studies that have been carried out. The total energy system was simulated by Capros and Mantzos (2000), by Mirasgedis et al. (2002) and by Agoris et al. (2004) focusing mainly on the estimation of CO_2 abatement cost for various emissions mitigation measures and technologies, without considering ETS. In the more recent studies of Dagoumas et al. (2007, 2008) allocation of CO_2 allowances and ETS are taken into consideration, for the investigation of electric system expansion. Nevertheless in these later studies, emissions modelling seems to be implemented as a fixed CO_2 constraint on the operation of power plants, rather than a measure which acts through alteration of plants' economic efficiency; for that reason the amount of total procured CO_2 allowances in these studies is predetermined and not estimated. In any of the aforementioned studies full auctioning is not investigated after 2013. On the other hand in the model based analysis of the EU Policy Package concerning all 27 countries, which was carried out by Capros et al (2008), ETS in combination with both grandfathering and full auctioning allocation mechanisms was examined; however this study mainly concerned the implementation of EU measures in all MS, investigating aspects as distributional equity in efforts sharing, rather than focusing on the uniqueness of Greece.

This work adds by modelling ETS in a more realistic fashion, taking into consideration partial free allocation of CO_2 allowances for period 2005-12 and full auctioning after 2013. In this approach power plants operate without predetermined emission constraints, being able to surpass their allocated allowances with additional cost, while are limited only by their economic efficiency; therefore ETS and allocation mechanisms inherently affect the balance of the market and subsequently the annual energy mixes. This more advanced approach is further combined with the new EU package requirements, limitations and targets with focus specifically on Greek electric sector.

With the aid of the model, and after pointing out that one of the basic principles of Greek energy policy is energy safety, the potentials of a "conservative" low risk energy planning for the expansion of Greek electric sector are thoroughly explored, and the roles of domestic lignite and imported coal are examined. Additionally, scenarios of radical changes for the electric system expansion and their impacts and feasibility are investigated. These cases, including the investigation of CO_2 allowances price effects which comprises main parameter in this work, are not covered by any previous studies.

2. Simulation of Greek Connected Electric System

2.1 Modelling methodology

This work looks into various expansion scenarios for the Greek connected electric system towards 2020. The aim is to investigate and evaluate these scenarios according to their environmental performance, economic efficiency, implementation feasibility, energy source diversification in production mix and energy safety towards 2020. For that purpose, the module BALANCE of the Energy and Power Evaluation Program (ENPEP) was used (ANL, 2007). This software, in order to determine the balance between energy supply and demand, uses a non-linear equilibrium approach. The model relies on a decentralized decision-making process in the energy sector, allowing the consideration of factors other than cost, approach which stands for multiple decision makers. In the current study the main basis for the implementation of the calculations is least cost, while other issues, as enforcement of specific energy policies or technological and technical constraints are additionally considered; such parameters are the priority of RES energy in system dispatch and the policy for energy import as a last resort.

2.2 Model setup – Common data and assumptions

ENPEP/BALANCE is a data intensive model. Among its requirements is the initial definition of the structure of the entire system, including all the sectors that will be taken into consideration during simulation as well as their constituents; as such in the current study were considered the electric sector, transport and distribution of electricity, fuel and RES and finally consumption sectors. For the base year of the simulation input parameters must be defined containing energy statistics for all sectors, and more specifically prices and quantities of the energy flows in the system. For the following years, projections about growth of energy demand, energy sources prices as well as technical and policy constraints and assumptions are required and must be defined as well.

In the present study a base case scenario was initially developed including all the components that would be common in the scenarios to be investigated. The first step of the modelling work was a systematic representation of the existing electric connected system which was carried out on a power plant unit basis (Hellenic Transmission System Operator, 2006; PPC); the system is outlined in Table 1 on a plant basis for the ETS reference year 2005. Decommissioning of old fossil fuel units, as well as commissioning of new hydroelectric plants, elements common in all scenarios, were based mainly on PPC's business plan (PPC, 2008) and press releases (PPC) and are outlined in Table 2 and Table 3 respectively. Until 2008 oil, natural gas and coal prices were taken into consideration according to real market prices while for the future period (2009-2020) were assumed unchanged. This was decided since the investigation of fuels price variation influence on energy planning is not in the scope of the present study. In the case of natural gas and lignite, estimations had to be made as their cost to PPC is confidential. For lignite, a mine based approach was followed concerning mainly fuel quality and cost variations (PPC). In addition to price, energy production levels were defined for all power plants for the base year according to existing data of Hellenic Transmission System Operator (HTSO). For hydroelectric plants, hydrologic conditions of 2004 were adopted for all next years as well, assuming in the present study that 2004 was a year of moderate rainfalls.

Table 1. Description of Greek Connected Electric System (2005)

Plant type	Number of Units	Installed Net Capacity (MW)
Pulverised Fuel (Lignite)	22	4,808
ST (Oil)	4	718
CCGT (NGas)	5	1,967
GT & ST (NGas)	3	487
Hydro (Large)	24	3,024
RES (excluding cogeneration)	7	433

Table 2. Retirement plan of PPC existing units

Year of retirement	Total Retired Net Capacity (MW)	Plant type
2010	339	ST (NGas)
2010	173	CCGT (NGas)
2010	226	PF (Lignite)
2011	288	ST (Oil)
2012	430	ST (Oil)
2013	334	PF (Lignite)
2017	274	PF (Lignite)
2018	545	PF (Lignite)
2020	275	PF (Lignite)

Table 3. Commissioning of new Hydroelectric plants

Year of commission	Capacity (MW)
2009	161.6
2010	186.0
2013	285.0

2016	16.5

Regarding base year annual demand, 2004 Load Duration Curve (LDC) was derived from HTSO data. Base and future year demand projections were allocated to the sectors according to 2004 statistics as it is shown in Table 4 (Eurostat, 2008). For demand forecasts towards 2020, a specific per sector annual rate of increase was calculated, based on 2004 over 2003 data (Eurostat, 2008). This rate was kept constant for all years (Table 4), even though data is available for the first years to date, in order to not over-customize the solution.

Table 4. Electricity consumption by sector (year 2004 – Connected system)

Electricity Demand	Electricity consumption by sector (%)	Rate of electricity consumption increase (2004/2003)
Households & Services	71.39%	3.8%
Transportation	0.47%	0.4%
Industry	28.13%	0[a]
Total	100%	2.71%

[a]Zero valued used instead of the negative -1.19%

Techno-economic data as plants capital costs, operation and maintenance fixed and variable costs, as well as planned outages where either assumed (DOE/IEA, 2009) or derived from estimations based on PPC data (PPC). Unplanned outages of PPC power plants were defined according HTSO for period 2006-2007 (HTSO); periods of major unplanned outages were not taken into consideration in order again to not over-customize the solution on past years data. For the same reason outage percentages were kept constant for all years. Emission factors were calculated specifically for each power plant, taking into consideration plants' reported emissions to the European Pollutant Emission Register (EPER) and electricity production (HTSO) for year 2004; for the incomplete oxidation of fuels towards CO_2 typical factor values were adopted (EC, 2004).

2.3 Realistic CO_2 allowances modelling

The investigation of the effects of the quantity and price of CO_2 emissions allowances on the behaviour of Greek electric sector in the various scenarios constitutes a major element of the current study. According to this approach the time period examined in the study is virtually divided into four different regimes. In the first period, the "no ETS period", which takes place in 2004, is assumed that no emission trading related activities take place in the system. National Allocation Plan (NAP) periods, "NAP I" and "NAP II", follow referring to periods 2005-2007 and 2008-2012 respectively. During these, the allocation of CO_2 allowances to the plants is performed as designated by the first and second NAPs (HMEPPPW, 2004, 2006). According to these a specific amount of allowances is allocated for free to each power plant in the system for each period. At the same time the option of a plant to surpass its free allowed allocation and buy additional allowances is left open in the study. The amounts of these allowances for periods "NAP I" and "NAP II" are explicitly defined on a plant and year basis, permitting free transfer among units of the same plant; transfers are not allowed in any other case in the study, including banking or transferring of allowances to next years. Finally the "full auctioning period" is assigned to years 2013-2020, where no free allowances are allocated to the electric sector plants, fully lining to EC "energy package". In this phase each plant has to buy its emission allowances, even for the first tone of CO_2 that will emit.

2.4 Model validation

Prior to scenario investigation, the accuracy of the model was examined against data of the past years. In order to make that feasible, as base year of calculations the year 2004 was selected, while the results were examined through 2008.

Although input data was not over-customized for years 2004-2008, referring to major plants unplanned outages that were not taken at consideration, electricity demand per sector that was set based on 2004 over 2003 data, and hydrologic conditions that were considered same to 2004's, projections seem to agree very well with the reported data. Electricity demand forecasts (Figure 1) seem to deviate no more than +1.3% over HTSO data. Figure 2 illustrates the projected electricity production per plant type for years 2005-2008. As it is shown projections are in reasonable agreement with HTSO data. An exception to this agreement, which again proves the rule of successful predictions capability of the model, occurs in year 2006. In this year the electricity production from lignite plants is predicted substantially higher than the reported one; this can partially be attributed to the actual hydrologic conditions of that year which led to increased hydroelectric energy production. In fact the hydroelectric energy actually generated in 2006 was approximately 28% higher than 2004's, and therefore 28% more than the assumed levels. Part of this additional hydroelectric energy replaced base load and thus decreased lignite plants production. The better hydrologic conditions of 2006 were also combined with two major unplanned outages; SES Ptolemais Unit IV (pulverised lignite combustion technology) with net capacity 274MW, which was out of system for three warm months (28/06/06 – 30/09/06) and SES Lavrio Unit III (combined cycle technology) which was out for two months in the same year (01/01/06 – 01/03/06) (HTSO). The combined effects of the above incidents can provide an explanation for the simultaneous decrease in hydroelectric production projections and increase in the respective lignite and CCGT in relation to HTSO reported values. In the same direction also seem to have affected the several days employee's strike activities in 2008, as well as the maintenance of SES Agios Dimitrios Unit III in combination with additional delays in the integration of the unit in the production system (PPC, 2009). Similarly the underestimation of imported energy in 2007 and 2008 projections is consistent with the overestimation of hydroelectric energy production for these years; as 2007 and 2008 finally proved to be "dry" years with productions decreased 35% and 39% respectively in relation to 2004, the actual need for imports inevitably increased.

Beyond the hydrologic conditions and the isolated facts mentioned above, further discrepancies, as the slight overprediction of electricity production from Combined Cycle Gas Turbine (CCGT) plants can be attributed to other modelling issues. As such it can be considered the shape approximation of annual load curve in the model, which is not precisely fitted to the real data; additional issue is the difficulty to simulate the dual use of hydroelectricity to meet occasionally peak and base demand in Greece.

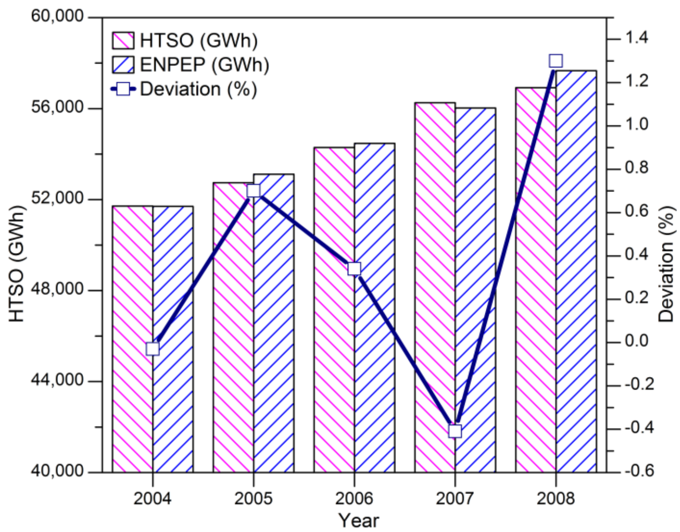

Figure 1. Comparison of projected and measured electric load

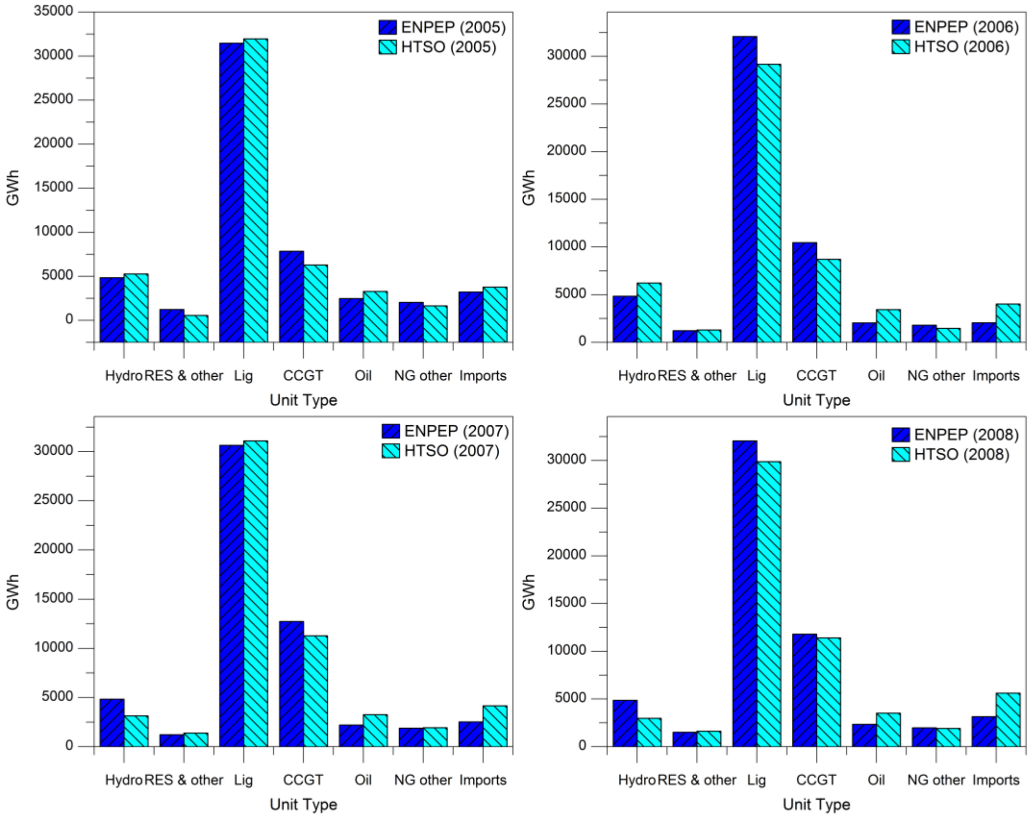

Figure 2. Comparison of projected and produced electricity per plant type – 1 year periods

The aim of the Greek sector simulation in the present study is not to perform electricity production projections with absolute accuracy, but to efficiently identify the trends and behaviour of the electric system and project future energy mix, avoiding significant systematic errors. The opposite would not in any case be feasible as the calculations, which are performed on a year basis, could not sufficiently take into consideration smaller time scale characteristics of the electricity market behaviour, non equilibrium effects and market distortions. For that reason as well as the non over-customization of the model on available data, discrepancies appear in years where statistics is today available and thus could be avoided. However significant unsuccessful predictions do not occur systematically.

2.5 Sensitivity Analysis

In order to investigate the effect of input data uncertainties on projections, a systematic sensitivity analysis was carried out. The parameters examined in the present study are the costs of fuel and imported electricity, aiming to investigate their effect on the price of the produced electricity. Figure 3 illustrates the % variation of electricity price which results from 1% variation of each parameter, for the two periods of the study 2004-2012 and 2013-2020. These results were obtained by ranging parameter values by ±10% for scenario D30 (Table 5). As it is shown the factor which influences most the electricity price at the earlier years is lignite cost, which is consistent with the present and expected near term lignite-oriented structure of the Greek electric system. Natural gas price plays key role in both periods of the study, but becomes dominant at the second half, where full auctioning of CO_2 allowances takes place and lignite use is diminished in electricity production mix. The role of the other fuels price as well as imported electricity price concerning their influence on system price can be considered of secondary importance. It must be pointed out that the results presented in Figure 3 are related to the assumptions and limitations of the current study and the scenario they refer.

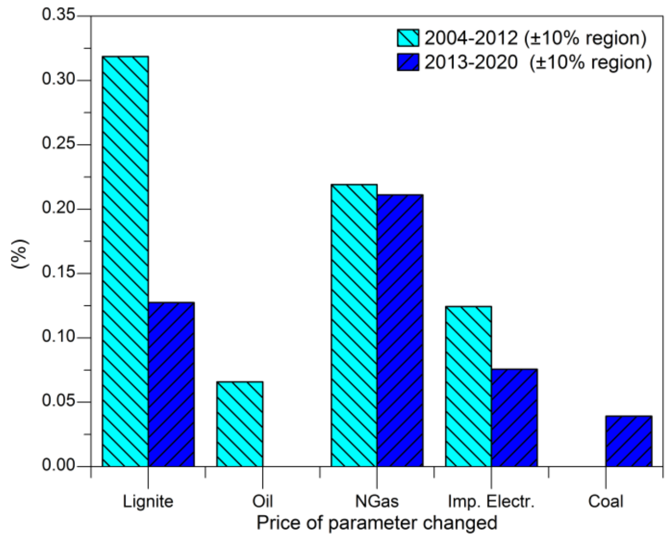

Figure 3. Electricity price variation (%) for 1% variation of each parameter in the +10 and -10 region – 2004-2012 and 2013-2020 average

3 Investigation of Energy Scenarios

After the validation of the model and the examination of its projection capabilities as well as accuracy and sensitivity levels, two groups of scenarios were investigated; a complete list along with a reference to the main characteristics of each scenario is illustrated in Table 5.

Table 5. Description of scenarios investigated in current study

Scenario	Cost of CO_2 ($/t)		Installation of RES (to 2020)	Installation of fossil fuel plants (MW) 2012 - 2020			Group
	2005-2012	2013-2020	GW	PF (Lig)	PF (Coal)	CCGT (NG)	
A00	20	0	3	796	4,089	5,624	1
A15	20	15	3				
A30	20	30	3				
O30	20	30	0	0	0	0	2
B00	20	0	3	0	2,124	1,925	
B30	20	30	3				
C00	20	0	3	0	3,717	1,925	
C30	20	30	3				
D00	20	0	3	796	3,186	1,540	
D30	20	30	3				
E00	20	0	6	796	3,186	1,540	
E30	20	30	6				

3.1 Radical change scenarios

The first group of scenarios aims at investigating the feasibility of possible commissioning of a large number of new power installations, installations that were announced from time to time in the press by electric companies. In addition to these 3GW of RES are installed starting from 2008 until 2020. The expansion of the system per plant type is depicted in Figure 4, while the distribution of RES utilities commissioning through years is considered exponential. As it is evident, this scenario deals with the possibility of an extended increase of installation capacity and system expansion, especially for the case of natural gas CCGT plants. From this scenario a set of very interesting questions arise; which will be the behaviour of this virtual electric system? Which plant types will take increased share of load and gain priority in the system dispatch? Which technology and fuels will prevail in the final mix? What will be the response of the system to high, moderate and zero CO_2 allowances price?

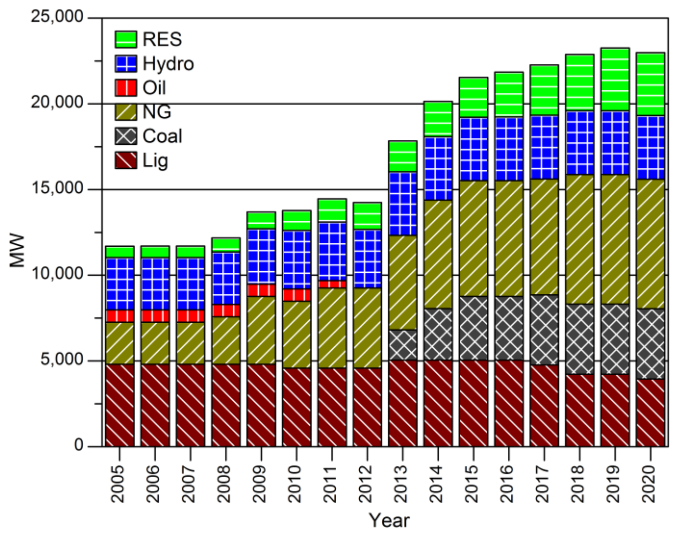

Figure 4. Electric sector expansion – Scenarios A00, A15, A30

3.2 Step-by-step energy planning scenarios

3.2.1 The adopted methodology and its conceptual base

The second set of scenarios in general comprises a sequential effort to develop an efficient but also realistic expansion plan of the Greek electric sector. This is achieved by establishing a "doing nothing" scenario as a basis, on which the insufficiencies, shortages and generally the behaviour of the electric system are evaluated according to certain criteria. This evaluation leads on decisions and corrective actions and consequently on new improved scenarios, the performance of which is evaluated again. This procedure is repeated until reaching a target scenario, which in general may be a solution, compliant with specific constraints. In this study the target is to investigate the possible outcome of a rational and rather conservative energy policy.

3.2.2 Evaluation criteria as energy planning basis

The first step before scenarios development is the establishment of the criteria basis on which the scenarios will be evaluated and improved towards a finally acceptable solution. In the context of the present study, scenario performance is assessed taking into consideration the aspects of

- feasibility and realism,
- cost efficiency,
- fuel diversification,
- energy safety,
- decarbonisation and
- environmental target compliance.

These aspects are particularised in the present study and taken into consideration for evaluation through parameters as

- agreement with technical constraints
- penetration of immature technologies and technologies that lead in high CO_2 avoidance cost
- earlier year of technology penetration
- System Average Price
- total CO_2 abatement cost
- share of imported fuels in final electricity production
- percentage of base load installed capacity over peak load
- levels of imported energy
- emitted CO_2 per MWh of electricity produced
- annual and average annual CO_2 emissions towards 2020 over 2005's emissions
- CO_2 reductions which correspond to equivalent, "ideal" emission paths
- RES percentage in final electric mix

3.2.3 Emission performance and equivalent emission paths

The various scenarios that generally can be developed may perform in a different way concerning their emissions performance. Therefore it is very difficult to efficiently compare them directly as they may differ not only in the final year's emission level over base year, but also in the way they reach there, namely in the intermediate path they follow. A scenario which demonstrates higher emission decrease in 2020 over 2005 levels is not essentially superior to another which results in lower absolute decrease in 2020 but higher total reduction over all years towards 2020. In the same way a scenario with high total emission reduction but very unequal distribution of this reduction over the years or poor performance at the last years, does not necessarily outperform another with lower total emissions reduction but very good distribution through the years.

For the purposes of a thorough and complete scenario comparison regarding emission performance, the concept of equivalent exponential emission path is introduced in the study. The equivalent exponential emissions path for a specific scenario refers to a hypothetical series of annual emissions, which start at the same level and year with the original one and, but extend towards the last year exponentially; this results in the same total emissions with the scenario under investigation but with constant ratio between the emissions of subsequent years. The necessity for calculation and study of the exponential equivalent path is crucial for the successful evaluation and comparison of emission performance among scenarios as this provides information about parameters such as

- the exponential equivalent decrease of emissions in the final year over base year
- the deviation of the specific scenario real emission path from the hypothetical exponential path

The first parameter corresponds to the % reduction of emissions that would have been achieved in the final year of the study, if the reduction rate had been kept constant in all years, over the emissions of the base year. This parameter characterizes the overall efficiency of the scenario and can help to investigate how far away the scenario lies from the compliance with an absolute reduction target at the end of study.

The exponential emissions reduction path can in some aspects be regarded as the ideal path that an energy scenario could have led to; this arises since it leads to the same overall emissions reduction levels with the original path, but shares the reduction burden evenly over the years, avoiding large deviations. From this viewpoint, the second parameter, the deviation of real emissions path from the hypothetical exponential path, reveals information about the consistency, technical and economic efficiency and consequently the feasibility of a scenario. The larger the deviation of a scenario from its corresponding exponential path, the larger will be the mandatory, maximum annual efforts and measures that will have to be implemented in specific years in order to achieve the same total levels of emissions reduction. Another equivalent path that could be considered as optimum, in order to perform emissions comparisons, is the linear equivalent path, in which the absolute annual reduction of emissions is considered constant for all years rather than the reduction rate. An advantage of the equivalent exponential over the linear path is that for the same total emission reduction, the absolute annual effort slightly decreases with the years; this way the total annual effort, aggravated by the emissions increase due to load increase, is merely alleviated. For that reason in the present study the equivalent exponential emissions path is considered as ideal and all the comparisons are performed over it and not the equivalent linear.

The equivalent exponential emission path is not adequate only by itself to characterize emission performance of scenarios as, for example, two different scenarios with the same overall decrease of emissions would lead in the same exponential path. For that reason a set of indices was developed and used in order to supplement the complete evaluation of emission performance. Among these indices, of high importance is the average annual emission reduction over base year's emissions. This index corresponds to the "running average" reduction until each year over base year emissions; reveals thus information about the state of emissions reduction through the years, taking into consideration earlier actions. Certainly this averaging index can also be calculated for the equivalent exponential path as well, providing the average annual equivalent exponential path, which is useful for comparison purposes with the original one. Minimum deviation between these two paths indicates performance comparable to the ideal concerning effort sharing between years. Furthermore, early intersection of the two paths shows strong early actions and quick system response to achieve final target. In general a scenario with superior emissions performance should produce average emissions reduction curve that quickly meets and subsequently closely follows its equivalent exponential.

The total annual emissions of the electric sector may increase or decrease between subsequent years mainly due to two different parameters. The first is the structure and characteristics of the electric sector itself. This parameter can globally be represented by an electricity production “quality” index which represents the quantity of emitted CO_2 per inland produced GWh; obviously the lower this index is the more decarbonised the system gets. The other parameter is the electricity production variation, which is directly linked to demand; increase of power production tends to increase emissions. As the effects of these two quantities combine two other parameters must be defined to provide information about the relative influence each one. These are emissions change due to electricity production quantity and quality change; comparison between these can reveal which the dominant is and eventually helps the analyst substantiate total emission trends.

3.2.4 Energy planning through sequentially improved scenarios

The whole concept of the “step-by-step energy planning scenarios” is to sequentially build or investigate an expansion plan for the electric sector, starting from a “doing nothing” scenario basis. Each new scenario that arises is evaluated according to the aforementioned criteria, and its inefficiencies are spotted. After that, the scenarios are modified properly in order to obtain certain characteristics and attributes on a specific area each time, yielding thus new ones. This procedure is repeated until reaching a target scenario.

The sequence described above is clearly illustrated in Table 5, where the final scenarios E00 and E30 are ultimately reached starting from the "Doing nothing" O30, through four discrete steps. In summary these steps are implemented through increase in CCGT and pulverised coal (PC) capacity, addition of domestic lignite in the fuel mix and increase of RES capacity. Target scenarios E00 and E30 correspond to a possible, conservative and low risk expansion of Greek electric sector. All scenarios are examined under high or zero emissions allowances price in order to look into their effects on the final energy mix and cost efficiency of scenarios.

4. Results and discussion

4.1 "Radical change" scenarios results

This group of scenarios (A00, A15 and A30) concerns new capacity installation, as is it was derived from electric companies' investment plans and announcements in the press. The annual and average annual CO_2 emissions over 2005's levels are depicted in Figure 5 along with their corresponding equivalent exponential emission paths. As it is shown, the emission increase projected in

2020 for zero, moderate and higher CO_2 allowances price are 5.3%, -11.2% and -15.7% respectively. The particularity of these scenarios is that, for moderate and higher CO_2 allowance cost, the reductions they project over 2005's emissions reaches its maximum levels in 2012 and then gradually decrease towards 2020. This set of scenarios can therefore be characterized as "strong early action" scenarios. For that reason and in order to take into consideration this earlier high reduction of emissions, the equivalent exponential emission reduction in 2020 is looked into as well. In the specific case the equivalent exponential emission reduction in 2020 for scenarios A15 and A30 reaches emission reduction of 20.7% and 25.7% over 2005 levels. In other words, the specific scenarios would have reached the latter levels in 2020, achieving the same total absolute emission reduction, if they had accomplished their annual emission reductions from the base to the last year keeping constant annual emission reduction. These equivalent reductions are very close or fully comply, even with the global E.U. target of -21% in 2020 for the ETS sectors (EC, 2009a). On the other hand the zero CO_2 allowances cost scenario A00, clearly demonstrates poor emission performance resulting in final increase of total CO_2, fact which shows the strong effect of the full auctioning mechanism in combination with the ETS.

Figure 5b depicts the average annual emissions of each year over 2005 levels for scenarios A00, A15, A30 along their corresponding equivalent exponential emission paths. As it is a shown, average annual emissions for the whole period until 2020 reach -10.7% and -13.5% over 2005's emissions for moderate and higher CO_2 allowances price respectively. These levels correspond to a virtual emission reduction which if was accomplished from the first year and kept steady until last year, would had resulted in the same total absolute reduction with the original path of emissions. In 2014 the original average annual emissions become lower than the corresponding equivalent exponential (Figure 5b), indicating that the actual total emission reduction to that date has become greater than the ideal (premature actions). Although the good emission performance of scenarios A15 and A30, the large divergence between the real and exponential equivalent curves, for both annual and average annual emissions reduction rates (Figure 5a and Figure 5b), urges further investigation of the economic efficiency and technical feasibility of the scenarios.

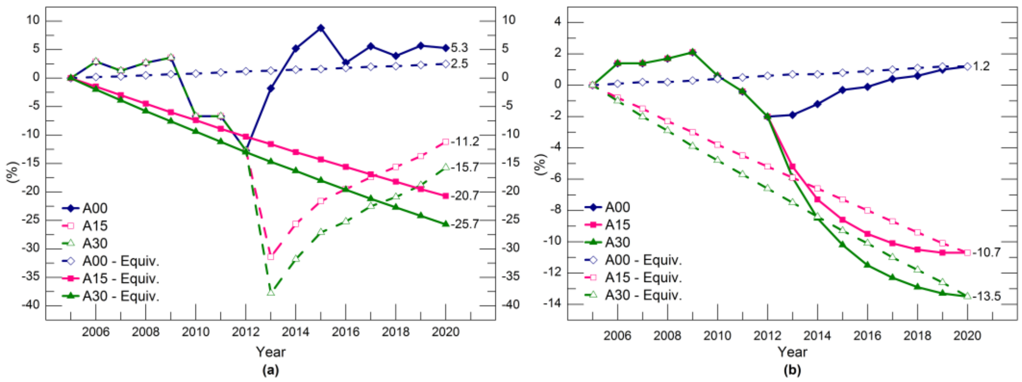

Figure 5. Annual and average annual CO_2 emissions' increase over 2005 (%) - Scenarios A00, A15, A30 and corresponding equivalent exponential paths

Indeed by investigating the variable operating and maintenance costs for all plants included in scenario A30, it comes out that a great number of lignite and CCGT units, present costs higher than System Marginal Price (SMP) (Figure 6); hence these are not utilized in system dispatch scheduling for electricity production at all or are used to meet reserve requirements only. This fact reveals for the scenario excess in capacity installation in relation to demand, and thus diminished realism concerning actual realization.

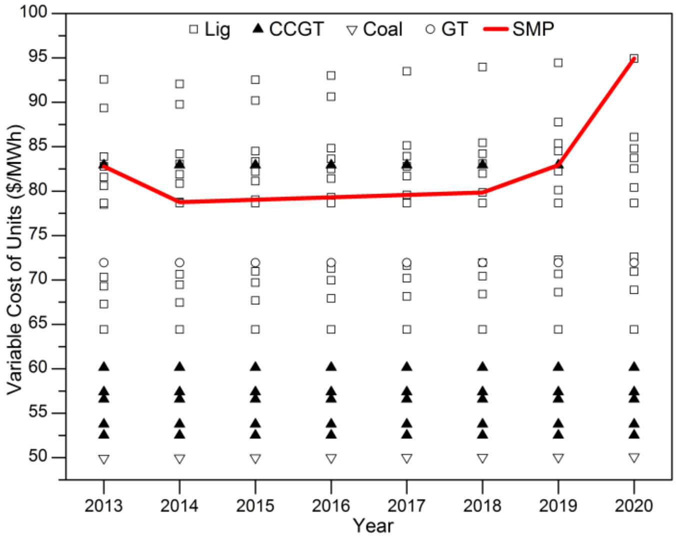

Figure 6. Overinvestment in power capacity - Scenario A30

Taking a deeper look into the scenarios and the final electricity production mix they project in 2020 (Figure 7), many useful observations can be made. Initially the total electricity production from imported coal and natural gas, is extremely high reaching the levels of 79.2% and 82.2% for moderate and higher CO_2 allowances price (A15 and A30). This is followed by the diminishing of domestic lignite use for electricity production, at about 5.1% for medium CO_2 cost and almost zero (2.1%) for higher CO_2 prices. In any case, these high levels of imported fuel use in electricity production mix are undesirable in terms of energy safety for the country. These phenomena seem to be allayed for the case of zero emissions cost, where lignite power plants retain their competitiveness comparing to CCGT or PC plants and thus maintain their priority in dispatch scheduling. Concerning RES penetration in the final electricity production mix, all scenarios present poor performance projecting only 8.5% penetration in 2020.

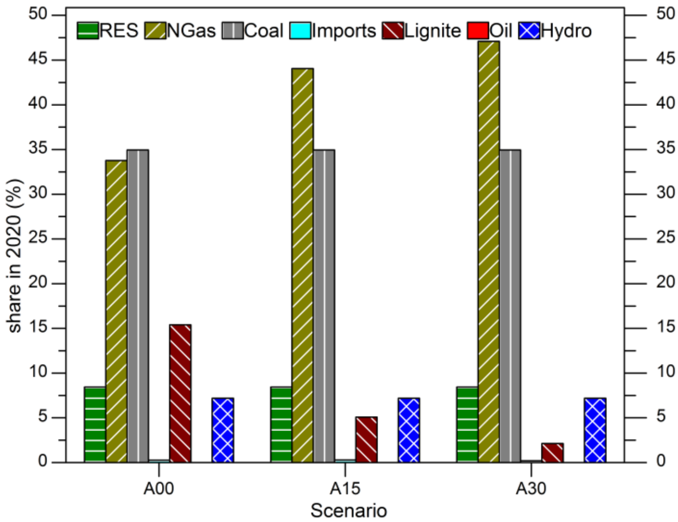

Figure 7. Comparison of electricity production mixture in 2020 for scenarios A00, A15, A30

Beyond energy safety and fuel diversification, the high shares of natural gas in final electric mix that are projected, especially in A15 and A30 scenarios, prompt to technical implementation and feasibility issues. More specifically the question that arises is if the natural gas contracted capacity of Greece will be sufficient of delivering those quantities to the system. As it is illustrated in Figure 8, the annual consumption of natural gas for electricity production reaches levels of 7.11bcm and 7.83bcm in 2013 for scenarios A15 and A30, in order to supply only the electricity production sector. Considering that the use of natural gas for electricity production was about 70% of the total consumption for years 2004-2006 (Council for the National Energy Strategy of Greece, 2008) and assuming this will be also the case for 2013, these projections correspond to total demand of natural gas of 10.16bcm and 11.19bcm. On the other the annual capacity of Greece covered by contracts is currently 4.23bcm (Council for the National Energy Strategy of Greece, 2008). This deviation reveals need for new agreements on natural gas supply of the country in order to make the scenarios under investigation technically feasible. The capacity adequacy of existing transportation network is also under question for the aforementioned quantities of natural gas. The decreased levels of natural gas utilization for electricity production which are projected for 2020 are due to penetration of coal into the production mix; nevertheless natural gas levels remain high.

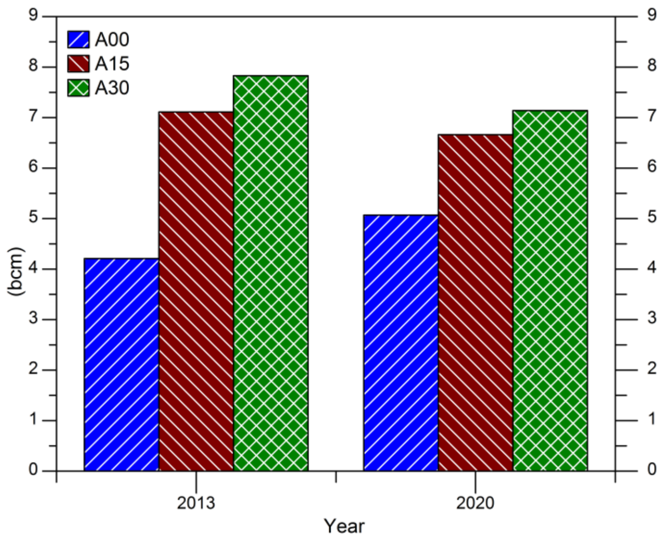

Figure 8. Annual consumption of natural gas for electricity production

4.2 Results of step-by-step energy planning

4.2.1 Intermediate solutions

“Doing nothing” scenario (O30) occurs mainly to reveal the inadequacy of existing electric system to meet future load demand levels towards 2020. The implementation of the sequential improvement over that base scenario resulted in a series of new scenarios. The first of these in the sequence (B00 and B30) deal with the replacement of decommissioned plants with new PF coal and CCGT natural gas power plants, while trying to keep total CO_2 emissions at the same levels. With this scenario it is therefore attempted to increase installed capacity by adding new plants that emit lower CO_2 than the decommissioned, without increasing total emissions. This can undoubtedly be realised since lignite plants of specific capacity emit more CO_2 per produced MWh_{el} than coal or natural gas plants of the same capacity; consequently for the same level of lignite emissions the capacity of coal and natural gas plants will be larger. This is mainly due to the emission factors of coal (92.71 tCO_2/TJ) and natural gas (55.82 71 tCO_2/TJ), which are lower than the respective of lignite (122.0 tCO_2/TJ) (HMEPPPW, 2009). Working on the aforementioned idea of keeping emissions of replaced plants in B scenarios steady, 1,925 MW_{net} of CCGT and 2,124MW_{net} of PC were installed replacing a total of 2,884MW_{net} of decommissioned lignite, oil and natural gas power. To the fossil fuel plants replacements, an additional installation of 3GW of RES was also employed.

It must be pointed out that the substitution of decommissioned lignite plants was carried out by standard typical CCGT and PC candidates, whose technical specifications, including net capacity, were assumed constant for all cases and scenarios. To that assumption can mainly be attributed any discrepancies between the capacities of decommissioned lignite and calculated capacities of the new commissioned PC and CCGT according to the concept of constant emissions. It must be noticed that the improved priority in dispatch scheduling of the PC and CCGT units in relation to the lignite ones, was not taken into consideration; therefore emissions are expected to actually decrease rather than remain constant comparing to O30; this will be further enhanced by the generally lower efficiency of existing (35.6% average 2001-2005) (IEA, 2008) and new lignite plants (42-45%) in relation to new pulverized coal (43-47%) and natural gas combined cycle plants (54-58%) as long as this is efficiency is it associated with Best Available Techniques (BAT) (IPPC, 2006).

Scenarios B00 and B30 improved the initial "Doing nothing" scenario O30 diminishing the shortage of electric energy from 45.8% to 11.6% in 2020, which was represented by "virtual" imports, and also increased RES final share to 8.4% (Figure 9). With next scenario C it is aimed to further decrease electricity production deficiency and at the same time increase the ratio of base capacity over peak load. For that reason an additional capacity of 1,593MW_{net} of PC power plants is commissioned in comparison with B. This results for the case of higher CO_2 allowances price (C30), in the reduction of annual imports from 11.6% to 5.7% and reduction of natural gas share from 35.5% to 33% in 2020; the base capacity over peak load ratio is also increased from 36.8% to 47.9% (Figure 10). It is obvious that with the improvements performed in scenario C30 over B30, energy safety is promoted in every aspect.

The objective of scenario D is to further reduce the use of imported fuels at shares near or lower than 30% in final electricity production in order to further promote energy safety. For that reason the share of domestic lignite is increased in final mix. Therefore in scenario D comparing with C, two lignite power plants are commissioned in place of one PC and one CCGT natural gas plant. Although this does not seem to seriously influence final electric mix in the case of higher

CO_2 allowances price (D30), still reduces natural gas and coal shares in 2020 at 31.2% and 26.7% respectively increasing lignite share at 20.4% (Figure 9). Hence energy safety is improved as electricity production from domestic sources in final mix is enhanced by almost 6 units (36% instead of 30.2%). Furthermore as lignite partially replaces natural gas capacity, the ratio of base load capacity over peak load increases by 2 percentage units as well (Figure 10). Therefore the installation of additional lignite capacity in the existing system, replacing coal and natural gas, seems to enhance energy safety of the country in two ways. The limited increase of lignite share which is observed in D30 can certainly be attributed to the high price of CO_2 emissions allowances.

Scenario D similarly to B and C, results in RES penetration in final electric mix at about 8.4%. The increase of that share is the aim of scenario E, and for that reason the total capacity installation of RES is increased from 3GW to 6GW. This action results in share of RES in final electricity mix of about 15.4% in 2020 which is closer to the E.C. target for Member State Greece of 18% in final energy demand. The additional increase of RES share seems to diminish the utilization of all fossil fuels at shares below 30% in final electric mix in 2020.

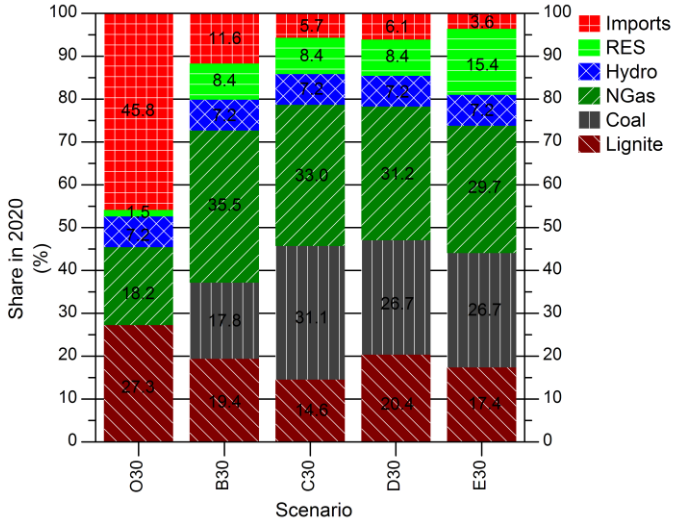

Figure 9. Comparison of electricity production mix in 2020 - Scenarios O30, B30, C30, D30, E30

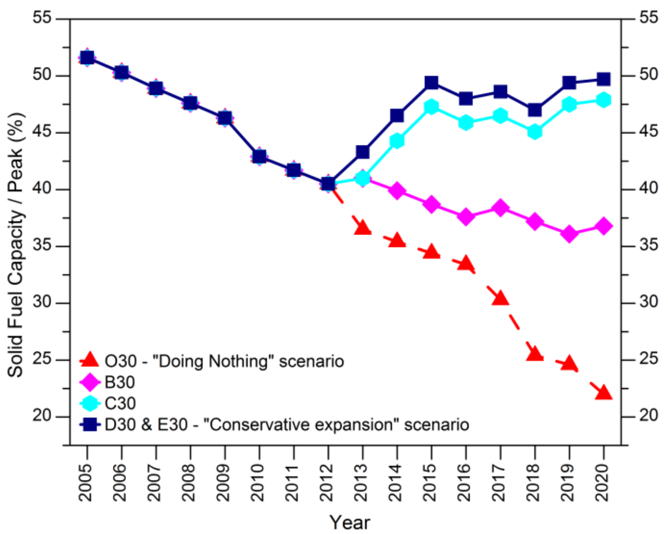

Figure 10. Base load capacity over peak for the intermediate solutions and the final scenario of the step-by-step energy planning methodology.

4.2.2 Final scenario

The step-by-step energy planning methodology led to the final scenario E. The path from 2005 towards 2020 in terms of final electricity mix by origin is illustrated in Figure 11 for the cases of zero and higher CO_2 emissions allowances price (E00 and E30). As it is shown imports are kept at moderate to low levels for all years except of years 2011 and 2012; there the system seems unable to fully meet the demand without increased imports. Near this time period high natural gas shares are also observed, phenomenon which however gradually decreases towards 2020. The final electricity production mix in 2020 is acceptable in terms of energy safety, as all fuel shares remain at levels below than 30%, even for the case of higher CO_2 price, parameter which certainly seems to favour the imported natural gas fuel. Furthermore base installed capacity over peak load ratio is kept at fair and near 2005 levels, although the major decrease that is presented by the scenario in the midterm (Figure 10). This decrease on the other hand seems unavoidable due to the lack of planning for new base load plants installation in the previous period. Power production from lignite is projected constantly decreasing with the years in both cases E00 and E30, but the reduction is more evident for the case of higher CO_2 price. This is certainly attributed to the higher energy efficiency and lower emissions of PC and CCGT natural gas plants which gain priority in dispatch scheduling in place of lignite plants and therefore maximize their annual utilization. Coal penetration into the system seems uncontested for the fuel prices considered in the present scenario, as it maintains its share for both high and low CO_2 price cases, gaining priority over not only lignite but also natural gas. Therefore while CCGT natural gas plants seem to play important role early in 2012 and after, coal power plants appear to steadily gain ground towards 2020.

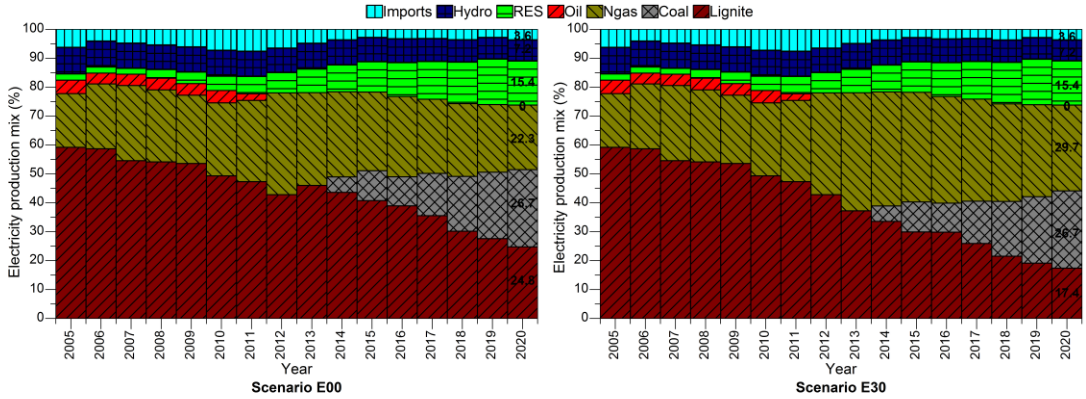

Figure 11. Projections of electricity production mix per year – Scenarios E00 and E30

Concerning emissions performance, scenario E30 seems to achieve its maximum emission reduction over 2005's levels (-9.8%) early in 2013 (Figure 12). After that year, annual emissions are kept at relatively low levels, having an average of 6.8% in the period 2012-2020 over 2005's emissions. In the last two years of the study, reduction is getting weaker reaching finally -3.8% in 2020. This is owing to the additional emissions which correspond to load increase and which for 2019 and 2020 prevail over the emissions decrement due to improvement of electricity production quality (tCO_2/GWh_{el} - Figure 13). Figure 14 demonstrates the discretisation of annual emissions increase rate (%) of each year over its previous, as a total of the emissions increase caused by load increase and the emissions decrease caused by electricity production quality improvement.

In order to take into consideration redundancy of early actions in the final emission reduction of 2020, the equivalent exponential path is determined for annual and average annual emissions reduction over 2005's levels (Figure 12). In the case of annual reduction, the equivalent exponential path, results in 6.3% reduction in 2020 instead of 3.8% of the original path. The deviation between these two rates reveals that the overall performance of the scenario, in terms of total reductions, is superior to what is indicated for 2020; thus 2020's actual reduction rate seems to discredit the total efforts of the scenario and therefore can not be considered representative. Comparing the original and the equivalent exponential annual average emission reductions over 2005's levels (Figure 12b) for the case of higher CO_2 emission allowances price high performance characteristics of E30 are revealed. This can be concluded as the original average emissions curve reaches the equivalent exponential in an almost tangential way and afterwards slightly oscillates around it, which denotes not excessive early actions and potentially high cost efficiency. In year 2017 the two curves intersect indicating that in that year the total emissions of the real and equivalent exponential scenario become equal; in other words in that year the original scenario reaches the performance of the ideal. Finally the average annual emissions increase over 2005 levels reach -3.2%. This, as already mentioned, corresponds to the virtual case where 3.2% reduction is achieved over base year from the first year and then kept constant along all the years, resulting in the same total emissions. In the case of zero emission allowances cost (E00), emissions increase 7.5% over 2005 in 2020 which corresponds to equivalent exponential increase 6%.

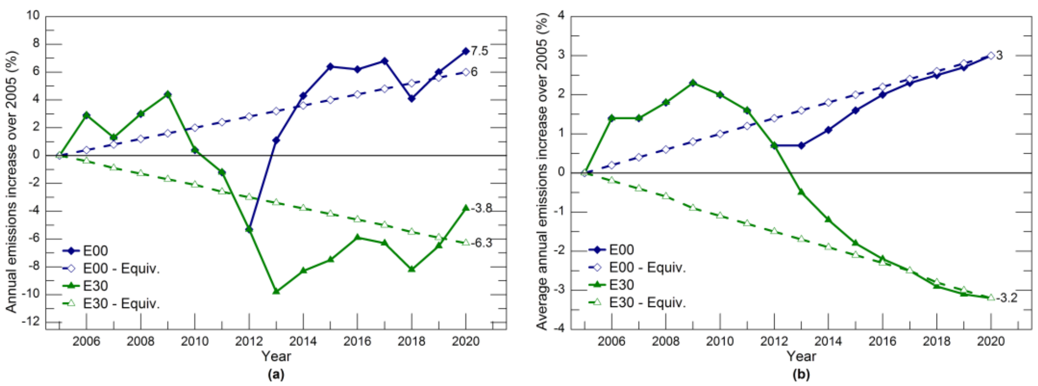

Figure 12. Annual and average annual emissions increase over 2005 (%) - Scenarios E00, E30 and corresponding equivalent exponential paths

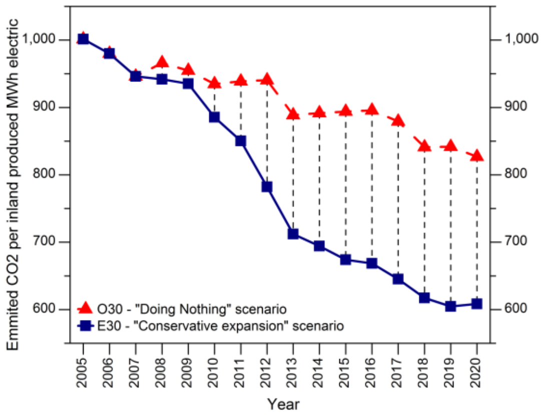

Figure 13. Comparison of system decarbonization for the "doing nothing" and "conservative expansion" scenarios

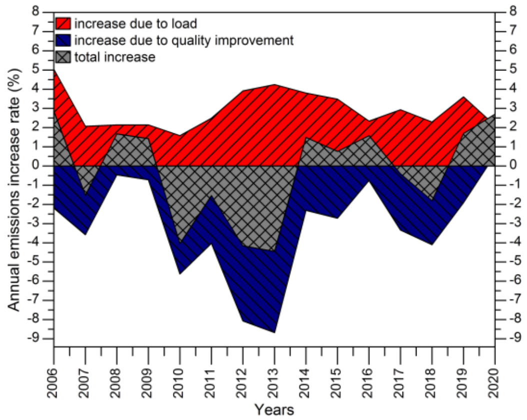

Figure 14. Annual emissions increase rate as a result of load increase and production quality improvement (% over previous year)

4.2.3 Effect of RES increase

RES seem to play important role in the system as they do not only produce CO_2 free electricity but also enhance indigenous power production. With the gradual addition of 3GW RES capacity in the system, the share of RES in electricity production mix increases from 8.45% to 15.40%, while natural gas share and imports are limited from 31.17% to 29.72% and from 6.06% to 3.56% in 2020 respectively (Figure 9); on the other hand, the share of domestic lignite drops from 20.42% to 17.43%. Ultimately the total indigenous electricity production is enhanced in 2020 from 36.07% to 40.02% in the final electricity production mix. At the same time emissions reduction in 2020 reaches 3.8% over 2005 levels (Figure 15), reduction which corresponds to 29Mt CO_2 for the whole period. Even more considerable seem to be the effects of RES capacity increase on emissions for zero CO_2 price.

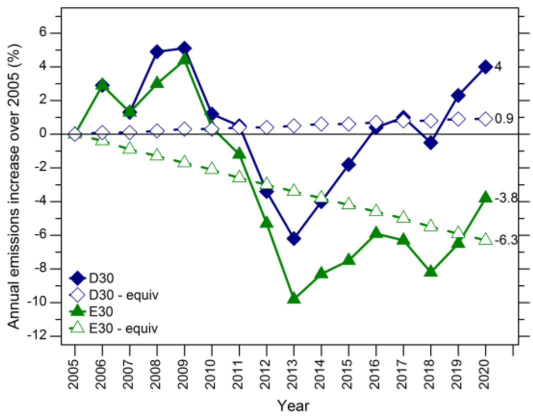

Figure 15. Annual emissions increase over 2005 (%) - Scenarios D30, E30 and corresponding equivalent exponential paths

4.2.4 Effects of “full auctioning” on electricity price

Full auctioning is expected to have significant effect on the average price of the electricity production system (SAP) in Greece. SAP and its increase due to additional CO_2 cost is presented in Figure 16. According to projections, after the initiation of full auctioning mechanism, SAP for high CO_2 prices (E30) seems to instantly increase 39% in relation with the zero CO_2 case (E00) and then gradually decrease to 31.9% until 2020; this continuing reduction is be attributed to the gradual decarbonisation of the system. With the initiation of full auctioning in 2013 SAP increase is projected at 34.7% over 2012. It must be noticed that this increase corresponds to the case that no allocation revenues will be recycled to power producers. The extra cost of electricity production due to CO_2 emission allowances is generally expected to be passed-through to the consumers at high rates in the order of magnitude of 70-90% but to also lead to unavoidable sunk costs for the utilities (EC, 2008b). These high rates are mainly owing to the local nature of demand for electricity as well as due to demand's inelasticity to electricity price. On the other hand for markets with decreased competitiveness, such as the oligopolistic are, the pass-through rates of CO_2 costs into electricity prices are expected reduced (McKinsey and ECOFYS, 2006). In any case, full auctioning through its high influence on SAP will probably give strong incentives for low emission technology investments in electric sector.

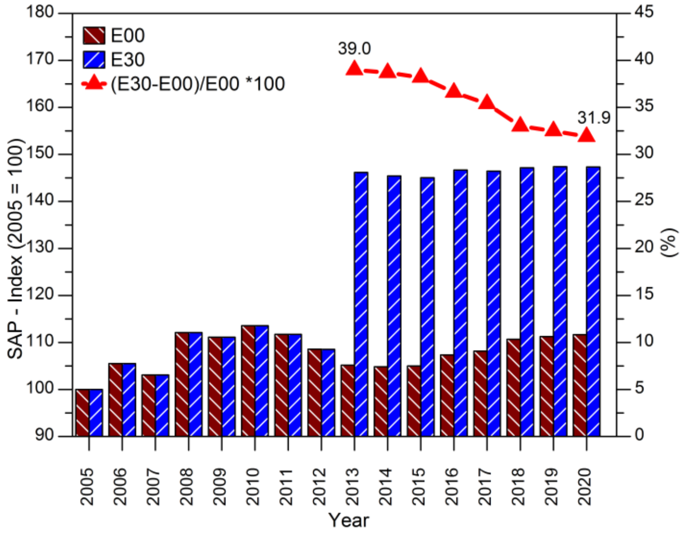

Figure 16. Comparison of System Average Price for scenarios E00 and E30

5. Conclusions

The simulation of the Greek electric sector using ENPEP/BALANCE can provide detailed information about its behaviour and thus make scenarios investigation and efficient energy planning possible.

The investigation of a radical change scenario, where all the installations announced by companies in press were commissioned, resulted in high emission performance due to extended decarbonisation of the system. However in terms of feasibility and promotion of energy safety these scenarios were proved inefficient as they resulted in extremely high utilization of imported fuels for electricity production; furthermore they led to low or zero annual loading of newly commissioned units, which reveals over-investment and is not consistent with the aspect of cost efficiency and feasibility.

Concerning energy planning, a procedure of sequential scenario evaluation and improvement was adopted. For this evaluation a new set of indices was successfully developed and used. The ultimate target in the study was to investigate the best possible outcome of a conservative, low risk and highly feasible energy planning concerning resources utilisation, RES penetration, maturity of technologies adopted, fuel diversification and energy safety. The scenario that was finally designed demonstrated good performance in most of these aspects towards 2020, but fair emissions performance. In that scenario natural gas and coal shares were kept at 29.7% and 26.7% respectively in 2020's energy mix, while RES penetration in energy production reached 15.4%. Solid fuel installed capacity over peak load, index standing for energy safety, was projected 50% in 2020 reaching again 2005's levels. At the same time emitted CO_2 per inland produced electricity, indicator of system decarbonisation, was projected for 2020 at 0.608tCO_2/MWh_{el} which corresponds to 39% reduction in comparison with 2005. Higher CO_2 prices seem to enhance lignite utilisation diminishing, which was also occurring towards 2020 even for zero CO_2 prices, leading finally to lignite shares near 17.4% in 2020; on the contrary zero CO_2 price appear to have milder effect resulting in a corresponding 24.8% share. In any case, the installation of new lignite capacity in the system, replacing coal and natural gas, seemed capable of improving energy safety as enhanced both electricity production from domestic sources in final mix and also the ratio of solid fuels capacity over peak load. RES seem to play well their dual role of CO_2 reduction and indigenous electricity production enhancement, though the later aspect is slightly weakened by the simultaneous reduction of domestic lignite. Finally with relatively conservative energy planning, emissions reduction can reach in 2020 3.8% over 2005's levels (or 6.3% equivalent exponential path) if CO_2 prices are high. Certainly this reduction is far away from the global E.C. target of -21% for the ETS sector.

Concluding, and in the context of conservative energy planning, while CCGT plants seem to play important role early in 2012 and after, PC power plants will probably gain steady ground towards 2020. This shows to be inevitable in order to simultaneously have natural gas share limited, electricity demand met with safety and emissions reduced, proving the multiple roles of coal. A future without coal in Greek electric sector, assuming conservative energy planning and taking into serious consideration energy safety will be very hard to realize; a way out can possibly be provided by large scale measures and actions, such as extensive utilization of useful heat, or adoption of new innovative energy policies.

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