A Delphi Analysis for the Electricity Supply Security in Greece

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***Abstract*—During the last twenty years the electricity generation sector in Greece, in line with the EU policy, faces significant changes in almost every sector of the production, transmission, distribution and pricing of electrical energy. At the same time, reliance of the Greek electricity generation sector mainly on the local lignite deposits as well as on imported fossil fuels (i.e. oil and natural gas (NG)), implies electrical energy dependence at the levels of 35-40%. In the meantime, contribution of the renewable energy sources (RES) is still relatively limited. The present work investigates the expected electricity supply security in Greece taking into consideration the most important technological solutions used in the electrical power sector. The work is based on a well documented three rounds Delphi method in which the experts' opinion and their high knowledge on the local economy and the energy system is deducted with a suitably designed and elaborated questionnaire. The results obtained are quite interesting, while useful conclusions have been achieved concerning the electricity supply security in Greece for the next few years.**

***Index Terms*—energy imports, lignite, natural gas, wind energy, RES, carbon dioxide emissions**

I. Introduction

Electrical energy is assumed as one of the main benefits of contemporary societies, since electricity is not only one of the main production resources but also one of the major parameters that govern everyday life. During the last twenty years the electricity generation in Greece, in line with the EU policy, faces significant changes in almost every sector of the production, transmission, distribution and pricing of electrical energy. Actually, the liberalization (or deregulation) of the local electricity market modifies significantly the status of the national electricity generation and encourages the introduction of private players in this sensitive segment of the economy. In brief the major changes encountered during the last ten years is the remarkable creation of new RES-based power stations (mainly wind and solar based ones due to the significant financial encouragement by the State [1]) and the gradual replacement of indigenous but environmental risky lignite with the imported and expensive natural gas (being the results of political decision), see also Fig. 1.

At the same time, during the last twenty years national gross electricity consumption of Greece may be determined by a long-term annual increase rate in the order of 3.3%, although according to the latest official data a remarkable decrease has recently been noted (2008-2012), mainly owed to the impacts of the economic recession. In this context, reliance of the Greek electricity generation sector (see also Figs. 1, 2) mainly on the local lignite deposits [2] as well as on imported fossil fuels (i.e. oil and natural gas (NG)), implies electrical energy dependence at the levels of 35-40% along with production of considerable greenhouse gas (GHG) emissions [3].

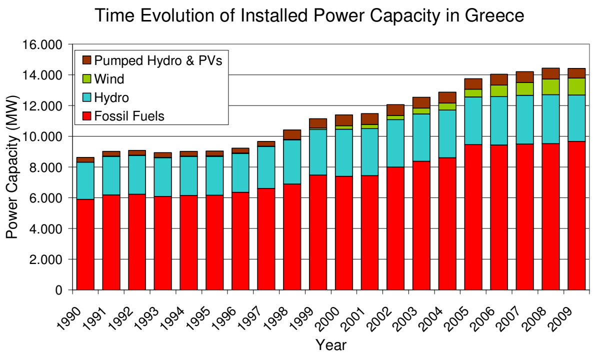

Fig. 1. Time evolution of electrical power capacity mix in Greece.

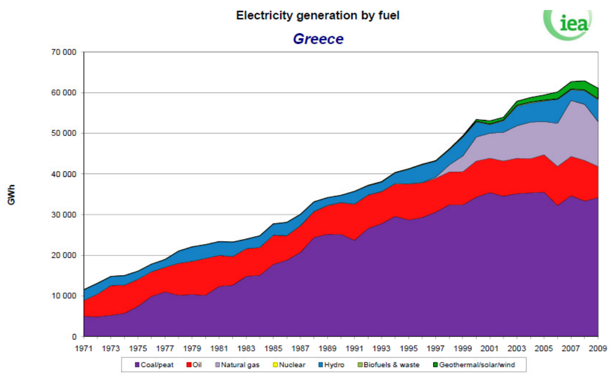

Fig. 2. Time evolution of electricity generation by fuel in Greece.

More precisely, the electricity demand throughout this long period of study has been satisfied mainly on the basis of thermal power plants, while contribution of large hydropower units should also be taken into account [4] (serving however mainly as peak power plants). In the meantime, contribution of the rest of renewable energy sources (RES) is relatively limited [1] (given that the RES potential of the entire Greek region is of medium-high quality), with the wind and PV power shares only recently exceeding the capacity of 1.7GW and 1.3GW respectively. In the meantime two of the existing thermal power stations are going to be decommissioned due to their age (almost 50 years of operation), Table I.

TABLE I
MAIN CHARACTERISTICS OF GREEK LIGNITE-BASED THERMAL POWER STATIONS

Power Station	Power Unit	Start Up	Rated Power (MW)
Ptolemaida	I-IV	1959-1973	850
Kardia	I-IV	1975-1981	1200
Agios Dimitrios	I-V	1984-1997	1586.5
Aminteo	I-II	1987	600
Megalopolis-A	I-III	1970-1975	550
Megalopolis-B	IV	1991	300
Florina (Meliti)	I	2002	330

Taking into consideration the above mentioned indicative information and the expected continuous economic recession that limits the role of State in controlling the local energy market it is almost certain that the electricity supply security in Greece may be questioned in the next few years. For this purpose, the present work investigates the expected electricity supply security in Greece taking into consideration the most important technological solutions [5] used in the electrical power sector. The work is based on a well documented [6,7] three rounds Delphi method in which the experts' opinion and their high knowledge on the local economy and the energy system are deducted with a suitably designed and elaborated questionnaire.

II. GREEK ELECTRICITY GENERATION SYSTEM

The Greek Electricity Generation System (EGS) consists of two discrete sub-sectors, i.e. the interconnected mainland electricity production network and the corresponding non-interconnected Aegean Archipelago islands. This classification demonstrates not only a geographical demarcation to account for, but also the parallel operation of two entirely different electrical systems to be considered. More specifically, the first sector includes the Archipelago region where the approximately 250 thermal power units [8] comprise 13 Autonomous and 19 Local Power Stations on top of the Crete island autonomous power network [9], all operating on the basis of imported amounts of diesel and heavy oil.

On the other hand, the mainland's electrical grid is mainly supported by 15 major thermal power stations rated at 8300 MW, with 13 of them owned by the Greek PPC (Public Power Corporation), see also Fig. 3. The existing electricity generation units are mainly based on the local lignite reserves -seven (7) power stations (Table I) with approximately 5400 MW of installed capacity- while the corresponding capacity share for the natural gas along with the operating combined cycle stations reaches 2900 MW. In the interconnected electrical system one may also find fifteen (15) large hydropower stations of 3000 MW total capacity [3] in conjunction with several (~200) other small ones with an estimated rated power of 250MW. Apart from the hydro power units, additional RES contribution ascribed to the mainland's grid derives either from the more mature wind power generation or from photovoltaic generators, supported by approximately 1700 MW and 1300 MW of installed power respectively [10,11].

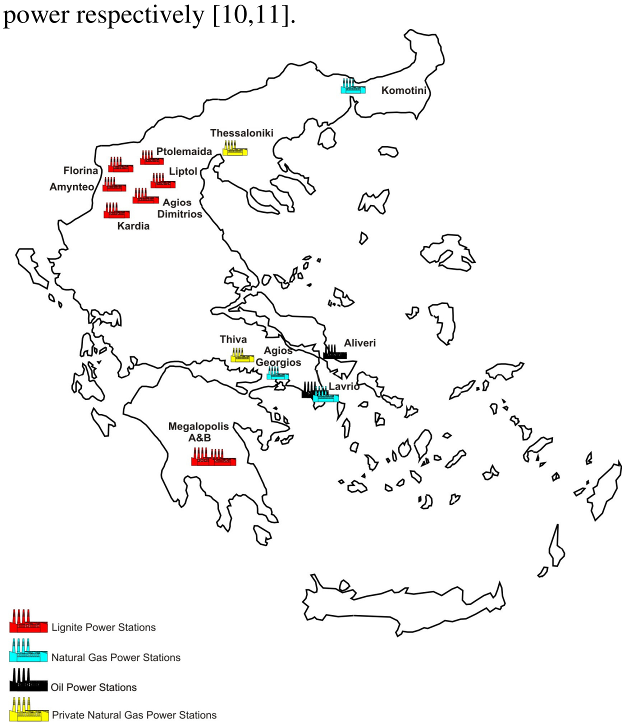

Fig. 3. Major thermal power stations operating in Greek mainland.

In Fig. 2 one may configure the increasing rate of national electricity consumption demand during a 40 years' time period, also involving the first stage of domestic electrification. During the same period of time (1970-2005), the local lignite's electricity generation contribution identifies its leading role in the national electricity system development. More specifically, for the overall period examined, a mean contribution share of 55% is to be considered, while, when accounting for the years since 1980, the corresponding value is estimated at 66%. However, during the last decade the contribution of lignite is gradually limited, being replaced by the new natural gas-based electricity generation units in Komotini, Lavrion, etc. This natural gas introduction, in the name of improving the natural environment, leads to considerable increase of the electricity generation cost and questions the electricity supply security of the country.

On the other hand, the total proven lignite reserves in Greece amount to approximately 5.8 billion ton distributed widely across Greece [2]. Today 3.1 billion ton of them are exploitable reserves suitable for electricity generation. Due to the non renewable character of lignite and the fact that almost 50% of the electricity generation is still based on lignite, Greece should take measures in order to achieve decarbonization of electricity production and improve the electricity security level in long term.

Finally, during the last twenty years and especially after the 2244/94 law implementation a remarkable activity on creating new wind parks and lately photovoltaic parks has been encountered. This distributed generation (DG) starts to question the functionality of a centralized electricity system, based almost exclusively on the lignite power stations in west Macedonia and central Peloponnesus along with the natural gas units of Komotini and Lavrion. However, in the course of time several hundreds of small and medium sized wind parks along with thousands of very small and small photovoltaic generators and almost 200 small hydro power stations may add more than 3000 MW of renewable electricity at various points of the electrical system on the basis of meteorological conditions. This is a quite new element for the operational status of the national electrical system, reducing the environmental impacts of the fossil fuel based power stations and at the same time increasing the diversification and the independence of the local fuel mix [12].

III. THE PROBLEM OF ELECTRICITY SUPPLY SECURITY

Energy security and more specifically electricity supply security is an important but controversial topic among policy and energy experts and in most cases depends on the relative angle that the topic is analyzed. For example, if the main problem for energy security is relevant to market failure then improving market functionality is the appropriate solution. In a similar way, if terrorist attacks are a threat to energy facilities then the solution is to enforce policies against terrorism [13].

Several definitions can be found in the existing literature concerning electricity (energy) supply security. Actually, researchers, authors and energy experts usually define the term according to their area of interest [14,15]. Hence they use the term of energy security to describe a situation in which energy supply remains uninterrupted, meeting the needs of the global economy in a reliable and adequate way. Frederic [16] stated that the general concept of security of supply was at first concerned only with oil supply and its physical availability. Nevertheless, now it is extended to natural gas and electricity along the supply chain and the concept of energy security includes price as well. He actually focuses mainly on affordability and availability.

Historically, energy supply security has focused on the finite stock of fossil fuels and their use within a centralized energy model. Use of indigenous energy resources was given priority in national energy policy. Recently, Nuttall [17] suggested that energy security is about diversified supplies and trade routes rather than energy independence.

Following the oil crises in the 1970’s, energy security focused primarily on concerns about oil disruption in the oil-producing world, with particular focus on the Middle East. Among the changes that could drive a shift in the energy security paradigm are the emergence of global terrorism focused on energy supply systems and climate change regulations (World Economic Forum, [18]). Moreover, in the 1990s, the contribution of natural gas for electricity generation starts to put pressure in gas transport routes towards Europe. In the meantime the climate change agenda challenges coal’s popularity as a power generation fuel, due to its high carbon dioxide emissions. Simultaneously, the depletion of fossil fuel resources has made EU indigenous coal and natural gas less available than before. Finally competition policy and the development of international trade have allowed increasing cross-border transfer of energy products. Thus supply security in the electricity sector is nowadays achieved also by technological and resource diversification, whereas using a wide range of options is considered to be an optimal strategy [19,20].

The World Bank [21] refers to energy security as an approach that must focus on three different pillars, namely energy efficiency, diversification of energy supplies and energy price volatility. Further to that, they consider that a country’s energy security means sustainable production and use of energy at affordable prices. The International Energy Agency [22] described energy security through its opposite term, insecurity "stems from the welfare impact of either the physical unavailability of energy or prices that are not competitive or overly volatile"; and that is why in most of definitions, physical energy availability and energy prices and their volatility are being mentioned.

Within the European context, energy supply was integral to the foundation of EU’s predecessor, the European Coal and Steel Community (ECSC). Energy supply security remained at the centre of the European project that was transformed into the European Economic Community (EEC) in 1957. The European Commission continued to highlight the issue of energy security especially after the publication of Green Papers in 2000 and 2006 (European Commission, [23,24]). According to these documents "security of supply in the energy field must be geared to ensuring, for the good of the general public and the smooth functioning of the economy, the uninterrupted physical availability on the market of energy products at prices for all consumers (both private and industrial)".

This issue is of vital importance for EU’s policy because EU produces less than 50% of its energy needs during the last decade. More precisely, import dependence has risen throughout the two decades between 1990 and 2012 for all primary fossil fuels used in the EU. Almost all EU members depend on oil and gas imports for nearly 100% of their needs. Approximately one third of oil and gas imported in the EU comes from

Russia (remember the recent natural gas conflicts between Russia and Ukraine), while Norway supplies approximately one third of gas and one sixth of oil imports (European Commission, [25]). To face these significant problems, currently the EU's 20-20-20 policy provides the operational framework for climate and energy policy in the EU.

In this context, the EU energy security action plan includes measures relevant to balancing power demand and supply and expansion of infrastructure, encouraging investment in gas and electricity interconnections throughout the EU. On top of these, the action plan lays out strategies for better use of indigenous European energy resources including coal, natural gas, oil, renewables and nuclear energy. Finally, energy is made central to intergovernmental EU's relations with other countries not belonging to the EU.

Finally, in the US the importance of energy security is demonstrated by what is known as the Carter Doctrine, the pursuit of energy security even by military force [26]. In this context all the US presidents have relied on the threat of military force to secure uninterrupted oil supply [27].

IV. THE IMPLEMENTATION OF DELPHI METHOD USED

The Delphi is a well-known method for technology forecasting, particularly for long-range and large-scale forecasting [28]. Historically the Delphi method is one of the oldest processes, developed first by the Rand Corporation in 1964, and recently a revival of this method has been observed in technology forecasting attempts all around the world [29]. In its fundamental principle, the Delphi method consists in collecting the "raw" opinion of experts on a series of relative questions and to confront these opinions with those collected through a second investigation where each expert can review his/her judgment knowing the average opinion of the first phase. This two-stage procedure is then able to exhibit deviant behaviours of the first round and more consensual futures of the second round. In this context Delphi is a consensus method, hence this normally means that a globally acceptable output should be produced for most of the issues investigated. For this purpose at least three rounds of answers to the questionnaire should be expected, although additional rounds may be needed sometimes [7].

During the first round, the questionnaire is circulated to the panel of carefully selected experts. When answers are collected, the median value and the inter-quartile range are calculated for each answer. Then, results of the first round (median and inter-quartile range) are circulated again to those experts, whose answers during the first round fell outside the inter-quartile range. This time they are asked to give reasons for their answers and to revise their former given values in case that they wish to do so. After receiving the second round forms, the median value and the inter-quartile range are recalculated, while a list is also formed with the reasons that the experts gave, explaining their answers. All this data is again circulated to the experts for round three, asking them to proceed with their final evaluation. More precisely:

- ✓ As the initial step in order to conduct this Delphi forecasting survey, an administrator of the project has been selected by the members of the team in order to organize the whole project in terms of its contents and results elaboration.
- ✓ The proposed questionnaire has been prepared by the team members with great care, taking into account the different opinions of some team members. The final edition of this questionnaire is given in Table II, presenting the outcome of the team's work after reaching agreement in all of its specific aspects.
- ✓ The questionnaire developed is at first circulated at a trial mode between a small number of properly qualified colleagues, in order to check its validity. For this purpose group meetings are realized, in order to check and -if possibly- improve the questionnaire's accuracy in terms of the targeted outcome.
- ✓ Right after this stage, the selection of the experts has been the very hard and really essential part of the project. Great efforts have been made in order to maximize not only the number but mainly the "quality/relativeness" of the participating experts. The major different knowledge groups of the national "reservoir" have been included, almost equally divided in academics, electricity sector senior managers/white collars and individual consultants or executives of relevant private companies.
- ✓ After the circulation of the questionnaire, appropriate time has been offered to the experts (about 2-3 weeks) in order to carefully check and return their answers. A kind reminder has been sent at the mid of the time period given.
- ✓ After having received the first round's results (27 answers out of 30 questionnaires), elaboration of them took place, in order to locate the areas that the experts had not reached an agreement or an opinion consensus. After this analysis, respective supporting questions have been prepared for every "peculiar" expert's answer. Subsequently, the modified second round's questionnaires have been circulated.
- ✓ After the end of the time period given to the experts to reconsider part (or whole) of their opinions with regards to the first round results, the analysis of the second round results has taken place. Fortunately, the new

answers/explanations facilitate the research team to prepare the final forecast, at least for the questions included here. The most interesting results are synopsized in the next section.

TABLE II
THE QUESTIONNAIRE

I. Do you think that the exploitation of lignite deposits in Greece compared with the available resources will affect the security of electricity supply, and if so in what time frame?	
A.	It will affect it, before 2015
B.	It will affect it, between 2015 and 2020
C.	It will affect it, between 2020 and 2030
D.	It will affect it, after 2030
E.	It will not affect it
II. Do you think that a possible turn to distributed electricity generation in Greece will help in the long-term to achieve security of electricity supply?	
A.	It will definitely help
B.	It will not change anything, neither positive nor negative
C.	It will not help, while instabilities will be introduced in the network
III. In view of the high dependency on imported fuels for electricity generation in Greece, how directly do you consider that the security of electricity supply will be affected from the continuing economic crisis?	
A.	It will be affected in 2012-2013
B.	It will be affected before the end of 2015
C.	It will be affected , between 2015 and 2020
D.	It will be affected after 2020
IV. In view of the current economic crisis, do you consider that reduction in investments on infrastructure and power plants' maintenance will affect the security of electricity supply and if so in what time frame?	
A.	It will affect it, before 2015
B.	It will affect it, between 2015 and 2020
C.	It will affect it, between 2020 and 2030
D.	It will affect it, after 2030
E.	It will not affect it
V. Do you consider that a possible introduction of nuclear energy in Greece (in the form of power plant construction) is an appropriate choice, in the context of security of electricity supply?	
A.	It is appropriate, it will provide an alternative choice
B.	It is not appropriate, the imported fuel will create additional problems
VI. The target for renewable energy contribution in Greek electricity production is 40% by 2020. Since the current contribution is approximately 12%, in what percentage do you think that this target will be achieved, without affecting the security of electricity supply?	
A.	Whole percentage, 40%
B.	25% to 35%
C.	20% to 25%
D.	It will reach maximum 20%
VII. Which of the following measures / methodological aspects of managing electricity demand do you think that can contribute to ensuring security of electricity supply in Greece and why?	
A.	Subsidies to industry to reduce electricity consumption
B.	Financial incentives to reduce consumption in the residential sector
C.	Information-education to create awareness on proper management of electricity
D.	Other-please identify

V. DISCUSSION OF THE RESULTS

The first issue to be analyzed (see also Table II) concerns the impact of the depletion of local lignite deposits on the electricity supply security and the corresponding time frame. According to the first round Delphi results, 55% of the experts believe that there is no serious danger before 2030, while only 15% of them expresses worries believing that related problems will arise between 2015 and 2020, Fig. 4. It is also important to note that this minority's opinion did not practically change in the second round, although the respective experts have received the first round's results. Finally, a quite remarkable percentage of 30% states that possible problems will appear between 2020 and 2030.

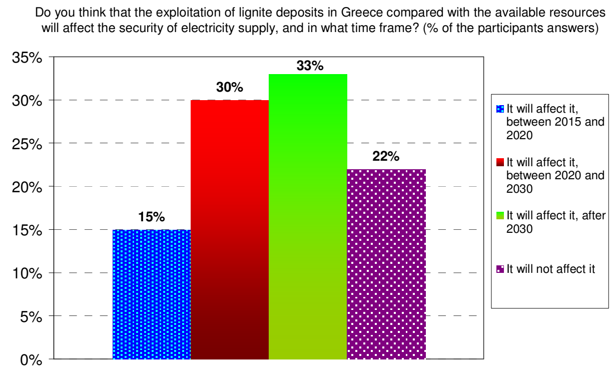

Fig. 4. Lignite deposits' exploitation potential impact on electrical energy security supply of Greece.

The second subject investigated is the impact of encouraging the distributed generation may have to the long-term electricity supply security in Greece. During the first round 83% of the participants express the opinion that DG will definitely help on improving the ESS, Fig. 5. The rest 17% of the experts state that no major changes are expected, while most of them are convinced about the positive impact of DG on achieving long-term ESS during the second round of Delphi survey. The only problem that some of them still mention is the relative high initial cost of the respective RES-based installations.

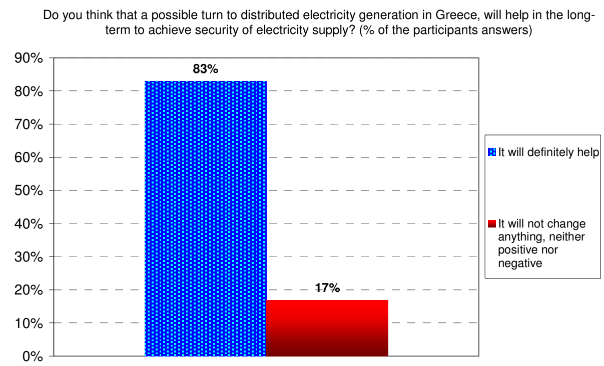

Fig. 5. Turn to distributed generation potential affection to electrical energy security of supply in Greece.

Assuming that the international and national economic crisis will continue to press the local economy and taking into consideration that the mainland and island electricity generation is strongly dependent on imported fuels, about 73% of the experts believe that problems in ESS will possibly arise until 2015, Fig. 6. Another 9% of the experts seem to be much more concerned, believing that problems in ESS will take place within the 2012-2013 periods. Only two experts believe that any problem may appear after 2020. However even this small minority expresses second thoughts in the second round of the Delphi survey underlining the aspect of the expected consensus for the Delphi method.

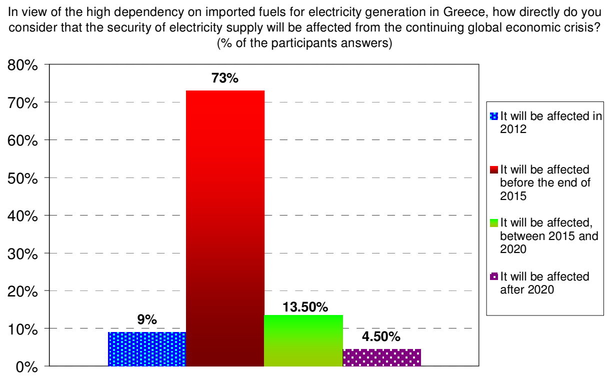

Fig. 6. Continuation of global economic crisis potential affection to electrical energy security of supply in Greece.

Furthermore, regarding the results of investments reduction for improving the infrastructure and for power plants' maintenance due to the current economic crisis, two opposing views have been mentioned. The vast majority (71%) believes that problems will take place before the end of 2020 since the poor maintenance and the infrastructure deterioration will definitely affect the operation of the existing power plants. On the other hand, a small minority states that no serious problems are expected, since the electricity demand is continuously dropping, thus "helping" the delay of problems in the ESS, Fig. 7.

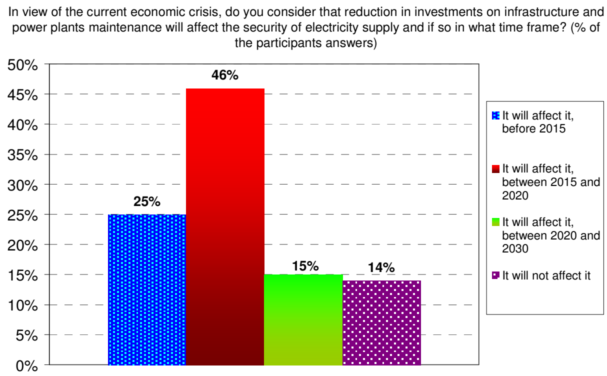

Fig. 7. Infrastructure investments reduction potential affection to electrical energy security of supply in Greece.

In view of a possible introduction of nuclear power stations in Greece most of the experts' opinions are negative. More precisely, about 83% of the experts do not believe that such an evolution is going to support the long-term security ESS in Greece, Fig. 8. The rest 17% believes that it would be another option for improving the ESS. At this point it is important to mention that in the second round of Delphi survey, most of the experts that include the nuclear power as one alternative for improving the ESS of the country, confessed that their opinion has mainly be driven by the assuming low cost of the nuclear energy. Subsequently, most of them recognized that nuclear power is not a realistic solution for Greece.

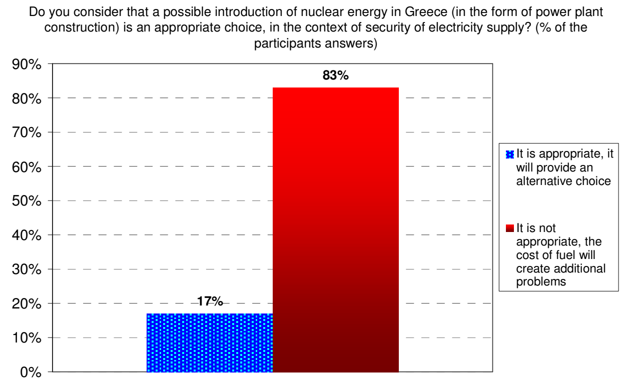

Fig. 8. The impact of nuclear power stations introduction in Greece on the local electrical energy security of supply.

One of the most interesting findings of the current analysis is the opinion of the experts about the impact of increased RES participation in the ESS by 2020. Actually the question set is to what extend the RES penetration may be implemented without affecting the ESS in Greece.

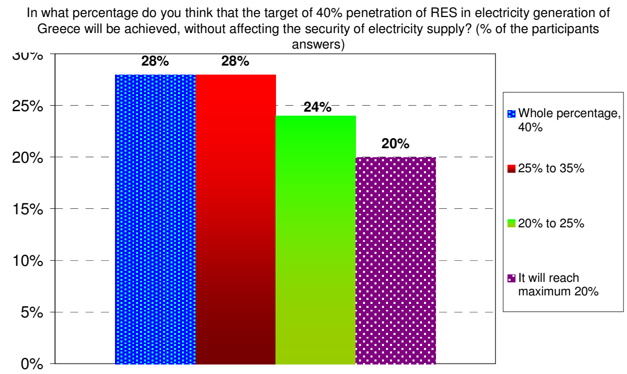

Fig. 9. 40% RES penetration target achievement in relation with electrical energy security of supply in Greece.

As it is demonstrated in Fig. 9, the experts' opinions are almost equally divided in all four possible answers. Thus 28% of the experts believe that the EU target (40% of the local electricity consumption) can be achieved without affecting the long term security of electricity supply in Greece. Another 28% believes that the rational percentage would vary between 25 and 35% in order to avoid problems on maintaining the ESS. Subsequently, 24% of the experts believe that the RES participation should not exceed 25% in order to avoid ESS problem, while the rest 20% of the experts believe that the maximum percentage is 20%. Even after the second round results polarization has been encountered, thus 2 out of 3 of experts state that the significant participation of RES in the electricity generation sector does not affect the ESS of the country, while the rest 1/3 insists on limiting the RES participation less than 25% of the national electricity consumption.

Finally, consensus has been reached on the ways of encouraging the management of electricity demand in order to ensure the ESS. More precisely, the vast majority of the experts mentioned that the most essential way is the information-education to create awareness on rational management of electricity consumption, followed by the financial incentives in order to reduce electricity consumption in the residential sector.

VI. CONCLUSIONS

The expected electricity supply security in Greece for the next twenty years has been investigated in the current work taking into consideration the most important technological solutions used in the electricity generation. The work is based on a well documented three rounds Delphi method in which the experts' opinion and their high knowledge on the local economy and the energy system are deducted with a suitably designed and elaborated questionnaire. The results obtained are quite interesting and enlightening, revealing the most popular technologies and reflecting the role of the various decision makers and shareholders in the energy supply security.

On the basis of the Delphi analysis adopted the following conclusions have been obtained:

- As far as the exploitation of the lignite reserves in Greece is concerned, no serious problems are expected before 2030.
- In terms of the maintenance of the electricity system infrastructure serious problems have been forecasted most possibly before 2020.
- Besides, negative impact of the economic crisis is possible before 2015 regarding the electrical energy security of supply.
- On the other hand the distributed generation (mainly RES-based) would possibly affect in a positive way the long term achievement of electrical energy security of supply in Greece.
- This is also the case for the significant contribution of RES-based electricity, although the one third of the experts states that the corresponding share should not exceed the 25% in order to avoid any problems related with the electrical network stability.
- Subsequently, the nuclear power is not qualified as an acceptable solution in order to support the ESS of the country.
- Finally, the effort to provide information-education in order to create awareness on rational use and management of electricity has been characterized as a critical tool in the context of achievement long-term security of electrical energy supply in Greece.

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