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Energy security vs. climate change: Theoretical framework development and experience in selected EU electricity markets

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ABSTRACT

Electricity generation in different countries is based on a variety of fuel mixes compromising solid fossil fuels, oil, natural gas, nuclear and renewable energy sources. While in the past, national energy agendas have directed the optimal utilisation of domestic resources as a means to achieve supply security, today's environmental debates are influencing the electricity fuel mix in new directions. In this paper we examine the electricity sectors of Germany, Greece, Poland and the UK in an attempt to identify the policy and technology choices implemented in each country. The country selection is deliberately made to facilitate an extended overview of national agendas, varying domestic energy resources and industrialisation levels but still within the common EU framework. The focus is placed on policies related to two objectives, climate change mitigation and improving electricity supply security. The theoretical framework developed provides the possibility to assess the electricity sector independence at a national level using a multi-parametric analysis of the fuel mix data. Through a comparative assessment of the knowledge gained in different countries the authors provide insights and suggestions that allow for an improved understanding of the trade-offs and synergies that various policy options may introduce.

Contents

1. Introduction

The availability of energy is one of the key factors affecting the well being and smooth functioning of modern societies [1]. Indeed it is plausible to argue that the requirement to secure energy resources has become dominant to the extent that it drives the foreign affairs agenda of countries at all stages of development [2]. As dependence on energy grows, energy carriers with higher flexibility and user-friendly characteristics become more popular. Electricity, being the best example of such an energy carrier, is facing increased demand from all sectors of the economy [3].

The electricity generation mix is based on a variety of fuels; solid fossil fuels, oil, natural gas, nuclear and renewable energy sources. In the past electricity policy in nearly all countries was

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based on the optimal utilisation of domestic resources and technology for generating electricity. The result can be observed in the radical variety of fuel mixes existing in different countries; Norway [4,5] relies mostly on hydro, France [6] on its vast nuclear programme and Poland [7] places almost absolute reliance on coal. Apart from these countries that have achieved a considerable degree of energy independence, most others need to import fuel, technology, or often directly electricity, which compromises their supply security.

While in the past, national energy agendas have focussed on supply security which has been achieved using domestic resources, today environmental and market liberalization debates increasingly dominate policy and influence the fuel mix in new directions [8,9]. The threats posed by climate change and local air pollution raise public and political concerns regarding the legitimacy of the continued use of coal and other solid fossil fuels in electricity generation, despite the fact that for most European countries solid fuels are the major indigenous energy resource. Imported natural gas (via pipeline from ex-USSR countries or liquefied from the Middle East and Northern Africa), nuclear energy and renewable sources are increasingly promoted as environmentally friendlier solutions; however, each has an impact on supply dependency. Simultaneously within the context of electricity market liberalization, multinational firms emerge as producers and cross-border trade is providing financial benefits [10] and enjoying legal support [11,12].

These observations are valid for most developed countries but are of crucial importance for the EU not only because of the active promotion of the internal market for electricity among its mix of developed and transitional economies, but also due to its ambition to be recognised as a world leader in climate change abatement initiatives and air pollution measures [13]. The countries examined in the present paper are Germany, Greece, UK and Poland. All but the latter are mature members of the EU with accessions dating back to 1957, 1981, 1973, respectively while Poland joined the EU in 2004. This shared membership background might suggest significant similarities in the energy and climate policies (and performances) of the countries, particularly as the role of pan-EU policy has become stronger. However, reality shows rather the contrary. After this brief introduction this study continues with a description of the methodology adopted. The individual examination of the four countries in Sections 3.1–3.4 while in the fourth section we discuss the results. The fifth and last section contains our conclusions.

2. Methodology

As already mentioned this paper includes a brief analysis of each country studied with primary focus placed on the regulations that serve for the mitigation of climate change. However, not all regulations related to climate change are introduced, but specifically those that are of relevance to the energy supply security of each country. We consider all policies that have a specific impact, regardless if that impact is positive or negative. In order to clarify if the impact of a policy is negative or positive one needs to define supply security.

In the previous decades supply security in the energy sector has been nation centred and based on three major components. First has been the dominant use of indigenous resources which directed the electricity sectors of most European countries to rely to a significant degree on coal. Second has been to acquire technology "know how" in advanced generation methods such as nuclear power. The third pillar has been to gain access to foreign energy resources through investments in their energy sector or even engagement in long-term diplomatic or armed conflicts for disputed resources. More recently, a few parameters have contributed to the evolution of a new reality. In particular the climate change agenda has challenged the continued popularity of coal as a generation fuel, due to its high carbon dioxide emissions. Simultaneously, depletion of indigenous fossil fuel resources has made coal or natural gas in Europe 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 by technological and resource diversification, where using a wide range of options is considered to be an optimal strategy. At the same time, it can be argued that exploitation of renewable energy sources makes a positive contribution to the supply security since they are national and may last forever. Finally, energy exchanges either in the form of fuels or in the form electricity are facilitated by grid expansion, increasing interconnector capacity and harmonizing trading and other transmission related rules such as capacity allocation.

Having considered the definition of electricity supply security, this study uses recent data from the Eurostat database to calculate the extent to which each of the examined countries relies on imported resources for its electricity generation. In this context direct electricity imports and are taken into account as well as imports of fuels. The former is calculated as the net result of exports subtracted from imports, yielding net imported electricity. Introducing fuels into the calculation is far more complicated since some fuels used in the electricity sector are partly imported and partly indigenous. Another complication is derived from the fact that some fuels used for electricity generation are used in other sectors of the economy.

The general parameters used in that respect are as follows:
Fuel Fi,j,k where
i refers to the fuel type and takes values shown in Table 1;
j refers to the year studied and takes values shown in Table 2;
k refers to the country studied and takes values shown in Table 3.

If Fi,j,k is imported by $A\%$ then the indigenous contribution of the fuel is $B\% = 100\% - A\%$. For fuels Fi,j,k being exclusively imported, $A\% = 100\%$, $B\% = 0\%$ and their full share in the electricity fuel mix is added in the imported total. For fuels Fi,j,k being exclusively indigenous, $A\% = 0\%$, $B\% = 100\%$ and their full share in the electricity fuel mix is added in the indigenous total.

However, when fuel Fi,j,k is imported by $A\%$ being $0\% > A\% > 100\%$, then $B\% = 100\% - A\%$ and $0\% > B\% > 100\%$ as well. If this fuel Fi,j,k is used outside the electricity sector in other sectors of the economy, then it is very difficult to identify if the imported $A\%$ or the indigenous $B\%$ or which mix of them has been used in the electricity sector. Since no specific data are available with regards to this issue the current study considers that the electricity sector consumes proportionately from imported and indigenous amounts. Hence for these fuels $A\%$ of their share in the electricity

Table 1
Types of fuels taken into account.

Fi	$i=1$	$i=2$	$i=3$	$i=4$	$i=5$	$i=6$	$i=7$	$i=8$	$i=9$	$i=10$
	Hard coal	Brown coal	Natural gas	Oil	Derived gas	Industrial waste	Hydro	Wind	Biomass	Nuclear

Table 2
Years studied.

Fj	j = 1	j = 2	j = 3	j = 4	j = 5	j = 6
	2000	2001	2002	2003	2004	2005

Table 3
Countries studied.

Fk	k = 1	k = 2	k = 3	k = 4
	Germany	Greece	United Kingdom	Poland

fuel mix is added in the import amount and *B*% of their share electricity fuel mix is added in the indigenous amount such as *A*% + *B*% = 100%.

This study provides snapshot of the fuel mix used in the examined countries for years 2000 and 2005. The results are compared and improve understanding with respect to the trends that climate policy regulations are imposing in the electricity markets.

3. Individual examination of countries

3.1. Focus on Germany

In 2005 the generation mix in Germany comprised 46% hard coal/lignite/peat, 28% nuclear, 11% natural gas with just over 4.5% each for hydro and wind [14]. The Nuclear Exit Law (2000) mandates the phasing out of nuclear generation by 2020, and though the time frame is now up for renegotiation, the phase-out remains and the effect of the policy will be to pose significant challenges for the generation sector if Germany is to avoid a supply gap. Clearly one option would be to expand the proportion of electricity generated from renewable energy sources (RES-E). At the time of writing, there is approximately 30 GW offshore wind planned for the North Sea [15] though how much of that will be built is not clear. Neither is it obvious whether the required grid infrastructure would be in place to facilitate the serving of high load pockets located in distant parts of the country. But given Germany's endowment of coal and lignite, supply security might suggest the building of new fossil fuel capacity.

Germany has one of the highest penetrations of renewable generating technologies in the EU, due in part to the stability and high level of political support and range of supporting policies, which has provided the long-term certainty required by investors and generous subsidies to generators [16]. The main RES-E supporting policy is the feed-in tariff, which was first implemented in 2000 and revised in 2004. Additional policies include investment subsidies, income and environmental tax regulations and exemptions and subsidised loans. Taken together, these policies have supported the development of a dynamic and mature market for renewables in Germany, with capacity of onshore wind, PV and solar thermal enjoying particularly strong growth. Germany's 2010 RES-E target is 12.5% of gross electricity consumption.

3.2. Focus on Greece

The Kyoto protocol was ratified in Greece with Law 3017/2002 and under the EU burden-sharing agreement Greece is obliged to limit the growth of GHG to 25% and has a 2010 RES-E target of 20%. The National Greenhouse Gas Emission Registry was set up in 2006 following the acceptance of the National Allocation Plan for Greece by the EU in 2005. The Greek legislature adopted the 2003/87 Directive for the establishment of emissions trading earlier in 2004 with law 54409/2632. However, at the time of writing, media announcements [17,18] state that Greece has been suspended from the EU emissions trade scheme for a period of 3 months due to unreliable methods of measuring and observing greenhouse gas emissions. According to the same media sources, the decision followed the inadequate explanations that the Greek ministry of Environment, Planning and Public Works has provided to the UN during the Bonn meeting earlier in March.

Electricity generation in Greece has been traditionally based on fossil fuels, mainly low quality domestic lignite and imported oil. RES-E makes only a small contribution: hydro-power plants exhibit low load factors due to lack of rain and the applied water management plan [19,20]. And despite the excellent wind (particularly onshore) and solar potential, non-hydro-renewable energy sources currently provide only a small fraction of the total electricity generated in the country [21]. During the last years the penetration of natural gas in the electricity sector has been the dominant change. It is noteworthy that over the last 5 years only one lignite fired power plant has been commissioned in Greece while the number of combined-cycle gas turbine (CCGT) installations has reached three units and one 150 MW gas-fired peak demand station.

Greece has operated a feed-in tariff since 1994, and followed this with investment subsidies of between 30% and 50%, but capacity building in RES-E has remained disappointing. New laws promoting simpler licensing and implementation procedures for RES installations have recently (2006) been approved by the Greek parliament, and it is hoped, may support the expansion of RES-E capacity. Additionally the new legal framework introduces updated prices for RES-produced electricity; the tariff for photovoltaic systems is particularly generous. While Greece has excellent wind potential there are concerns that the subsidies to wind power installations might be overgenerous. Finally, the issues for the production and market introduction of biofuels in Greece have been solved with the law 3423 of year 2005.

3.3. Focus on the UK

The UK generation mix is dominated by conventional thermal generation, which in 2005 accounted for 77% (308 GWh) of generation of 400 GWh, with nuclear contributing 20% (82 GWh), hydro 2% and wind 0.8% [14]. The UK is strongly committed to supporting renewables as part of their climate change strategy.

UK policy concerning support for renewable generating technologies comprises several components, dominated by variants on a quota based system, in which typically the quota, say a minimum share of generation, or of renewable capacity, is set by policy makers, and actors choose how to meet the quota (or avoid the penalty imposed if is not reached). A dominant argument in support of a quota based system is that it results in the least-cost path to diffusion of renewable technologies since it encourages investment in those technologies which are closer to commercialisation.

Policy falls into two distinct periods. In the first phase, 1990–1998, it was based on the Non-Fossil Fuel Obligation (NFFO). The NFFO was based on contracts with renewable generators allocated through auctions. The Department of Trade and Industry (DTI) set target capacities for specific technology bands, renewables project developers offered bids to generate power, and the DTI awarded contracts at given prices, such that their declared capacity targets would be met. In addition, a must-take obligation was imposed on distributors. Support to renewable generators was in the form of a rebate equal to the contracted price minus the pool selling price. The rebate was funded from the Fossil Fuel Levy.

In the subsequent period (1999 onwards), policy has been dominated by the Renewables Obligation (RO), a variant of tradable certificate scheme. Renewables Obligation Certificates (ROCs) are awarded to eligible facilities (1 ROC for each MWh generated) and suppliers obliged to buy ROCs to cover some fraction of total energy sales [22]. The penalty for non-compliance is the requirement for suppliers to pay the buy-out price (set by policy makers) on the proportion of sales not covered by ROCs, the revenue from which is re-cycled as subsidies to renewable generation.

Additional UK policy instruments are the Climate Change Levy on electricity not produced from renewable sources, and a system of grants under the New Opportunities Fund which covers investments in energy crops/biomass generation, small-scale biomass/CHP heating and planting energy crops.

Growth in UK RES-E got off to a slow start relative to the steady increase in installed capacity in Germany, which supports the argument that the policy mix in Germany has provided favourable conditions for renewable generation. While we do not have the scope to fully evaluate the evidence here, we note that such an assessment must consider a number of factors.

For the case of onshore wind energy, Butler and Neuhoff [22] find that the German system of a feed-in tariff, the EEG and its predecessor the Stromeinspeisungsgesetz, was more successful than either the NFFO or the RO in terms of increasing installed capacity of onshore wind. They suggest that the long-term commitment inherent in the feed-in tariff reduces regulatory and market risk to which project developers are exposed. Butler and Neuhoff further show that while the NFFO and RO were expected to deliver a least-cost solution, when averaged over the lifetime of the project, the resource-adjusted cost to society of the German feed-in tariff is lower than that of the RO.

Mitchell et al. [23] focus on the risk to which generators of RSE-E are exposed, and their findings support the Butler and Neuhoff results. They argue that the EEG has been more successful than the RO in bringing renewable generation capacity online because the EEG more effectively reduces the risk to which developers of renewables project are exposed.

While as Sawin [24] argues, the adoption of a portfolio of policy instruments is vital, it appears that the design and type of direct support for the diffusion of RES-E technologies is important; those that are successful in mitigating risk for investors are likely to be more successful in achieving their goal.

3.4. Focus on Poland

Poland is the EU's largest producer of hard coal, and therefore it is one of the most secure countries from the perspective of energy independence, with an import dependency very significantly below the EU27 average of 50.1%. The generation mix is completely dominated by domestic coal, and though the share of natural gas has risen sharply in recent years, it remains very low. The share of renewables in electricity generation is very low.

Interestingly, despite the strong position of Poland with respect to import dependency, there are public concerns regarding security of supply, since gas is imported primarily from Russia. The structure of domestic demand for energy gives rise to an energy intensity of 444 (toe/MEUR), almost 2.5 times the EU 27 average. While CO_2 emissions per capita are high, in 2004 they were slightly below the EU27 average of 8180 (kg/cap).

There are three principal support instruments for RES-E in Poland; Tradeable Certificates of Origin introduced by the 2005 amendment of the Law on Energy (1997), an Obligation for Power Purchase from Renewable Sources which dates from 2000 (amended in 2003), and an excise tax exemption on RES-E, introduced in 2002. In addition, there is a variety of financing options, including soft loans, grants and low interest loans available to support investment in RES-E projects and the modernisation of thermal power plants. Each instrument plays a part in the modest but consistent contribution of RES-E in Poland, but despite significant potential, particularly in biofuels, hydro and landfill gas, attainment of the primary energy and RES-E target of 7.5% by 2010 remains challenging. In particular, the lack of enforcement of penalties for the failure of electricity suppliers to meet the minimum share of RES-E renders this policy instrument ineffective. The slow rate of growth of RES-E in Poland is in part a function of the availability of domestic hard coal, but the failure to enforce legislation to support the acceleration of the growth of this sector suggests a lack of political will is also a factor.

4. Discussion of the results

After the brief presentation of the electricity policies and status of Germany, Greece, UK and Poland in this section we compare snapshots of the changes in fuel mixing the electricity sectors of the four countries. The careful observer will notice that when adding up the values of the following figures, the sum is not equal to 100%. This is a result of cross-border electricity trade. In particular when the sum exceeds 100% by *y*% then the country in question has been a net exporter and that *y*% has been the generation surplus that was transferred abroad. Respectively when the sum of a pie is less than 100% by *z*% then the country in question was a net importer and that *z*% has been the energy imported. In the following paragraphs the authors give specific explanations for every figure presented. At this point is essential to clarify that international trade of electricity exceeds by far the amounts *y*% and *z*% that appear in the following figures. However, the figures present the net electricity trade or more specifically *y*% represents how much higher exports were from imports while *z*% represents how much higher imports from exports were.

More specifically Figs. 1 and 2 show the electricity fuel mix used in Germany for years 2000 and 2005, respectively. While solid fuels accounted for 51.1% of the sector in 2000, by 2005 coal and lignite had reduced their share to 43.6%; an obvious consequence of German energy policy to promote cleaner fuels. Similarly in the 2000–2005 period the shares of wind power, biomass and waste have increased significantly together with natural gas. It is noteworthy that output from hydro-power fell from 4.5% to 4.3% during the examined period. The exploitation of hydro-resources for power generation in Germany was exhausted several years ago; therefore, there is no option to further increase hydro's share in the fuel mix. However, total electricity production in Germany has risen in the period, resulting in the hydro-share falling. At the same time nuclear energy has reduced its share in the fuel mix by 3.4 units from 29.7% to 26.3% reflecting the first stage of the phase-out process taking place in the German nuclear industry.

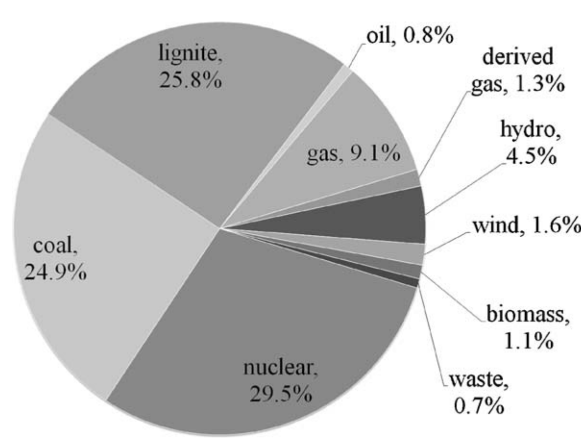

Fig. 1. Fuel mix in German electricity sector for year 2000 (source: Eurostat 2007).

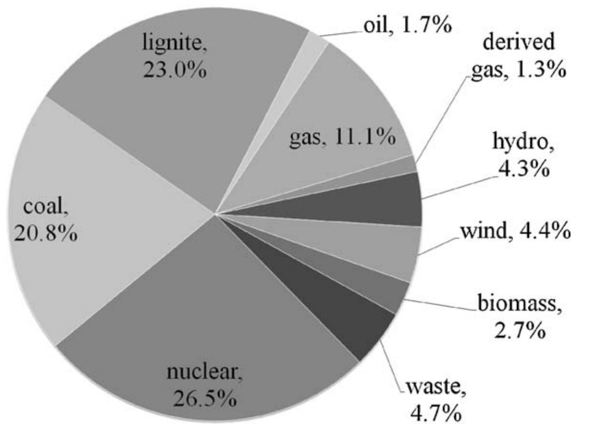

Fig. 2. Fuel mix in Germany electricity sector for year 2005 (source: Eurostat 2007).

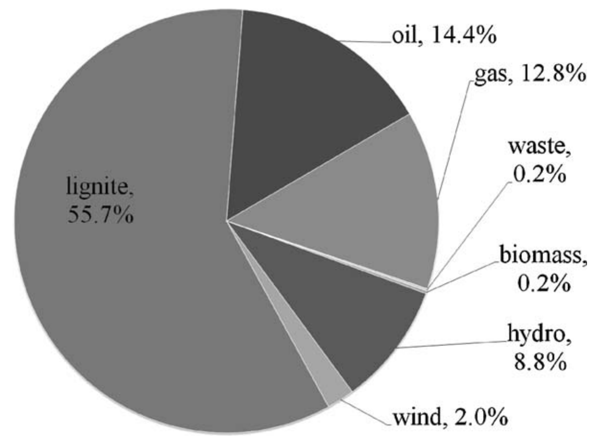

Fig. 4. Fuel mix in Greek electricity sector for year 2005 (source: Eurostat 2007).

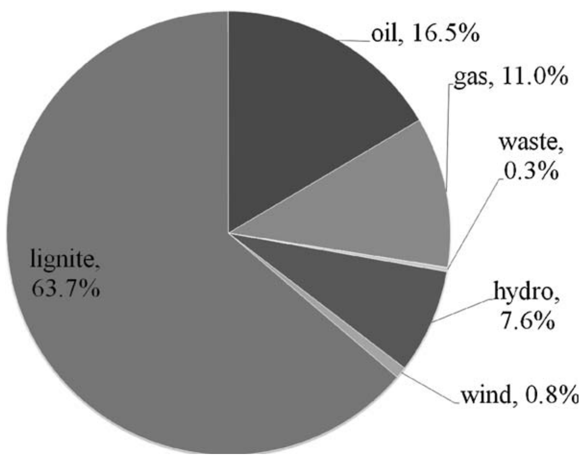

Fig. 3. Fuel mix in Greek electricity sector for year 2000 (source: Eurostat 2007).

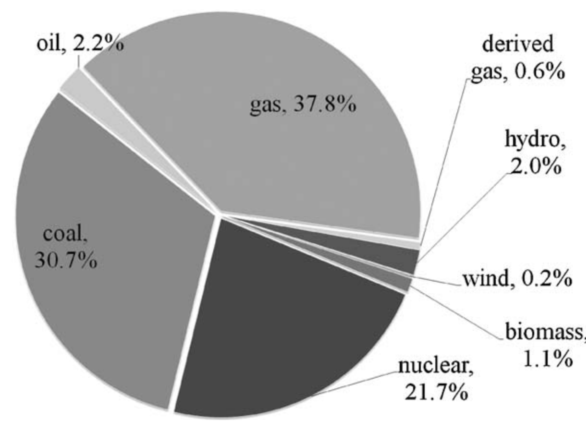

Fig. 5. Fuel mix in UK's electricity sector for year 2000 (source: Eurostat 2007).

In 2000 Germany was a net importer of electricity and covered 0.7% of its needs by imports. In 2005 we observe the reverse situation, with Germany being a net exporter of 0.5% of the electricity generated.

During the same period the Greek electricity sector reduced its reliance on domestic lignite from 63.9% to 59.4% (Figs. 3 and 4). That was to be expected given that the only company having access to the lignite reserves of the country is PPC, which was excluded from tendering for new capacity during that period. Simultaneously oil's share decreased from 16.6% to 15.4%. This decreasing trend is bound to continue while all the inland oil-fired utilities are switched to natural gas. However, the Greek islands currently rely on oil in order to generate electricity at their autonomous power stations and that may maintain the relatively high share of oil in the Greek generation mix, despite the fact that future investment for gas networks for the big islands (e.g. Crete) and electricity connections to the mainland have been announced. Hydro-power has contributed increasingly to Greek electricity generation, starting from 7.7% in 2000 ending up at 9.4% by year 2005. While that reflects the commissioning of several small-scale hydro-power stations, this trend is not expected to continue due to a lack of available potential locations [25]. The increased role of wind energy in electricity generation of Greece is shown by the 250% increase in wind power installations, albeit from a very low base. Additionally natural gas use increased from 11% to 13.7% during the period examined, as a result of the current energy policy framework in Greece that requires new fossil fuel power stations to be gas fired. Finally, in 2000 Greece was a (marginal) net importer (0.1%), while by 2005 that situation had reversed, as Greece relied on electricity imports to the tune of 5.9%.

Turning now to the snapshots of the UK fuel mix in 2000 (Fig. 5) and 2005 (Fig. 6), one may initially notice that natural gas, coal and nuclear are the dominant fuels for the British electricity sector for both years. Hence, despite the fact that the proportions of these fuels change in the examined period, their sum changes only slightly from 90.2% to 90.5%. In particular, the share of coal rose by 2.3% between 2000 and 2005, while that of nuclear energy fell by 1.7%. The sum of carbon neutral energy sources in year 2000 was 25%; hydro, wind, biomass and nuclear energy all contributed. In 2005 the comparative figure was 25.8% due to the reduced use of nuclear energy offsetting the increased participation of all renewable energy sources (except hydro which fell by 0.1%). At the same time the use of oil for electricity generation fell from 2.2% to only 1.3%. Finally in 2000 the UK was required to import 3.7% of its electricity generation, while the respective figure for 2005 was 2%.

Figs. 7 and 8 present the fuel mix used in the electricity sector of Poland for the years 2000 and 2005, respectively. The Polish electricity sector has been traditionally based on solid fossil fuels and we note that in both years, lignite and coal are hugely dominant in the Polish electricity fuel mix, accounting for 96.1% and 98.7%, respectively. Naturally, despite the fact that several other fuels are used in Poland, their presence is minor. More specifically in the examined period the use of oil fell by 1.8% from 3.4% to 1.6% while the use of natural gas increased by 1.7% from 0.7% to 2.4%. At the same time wind energy was introduced to the

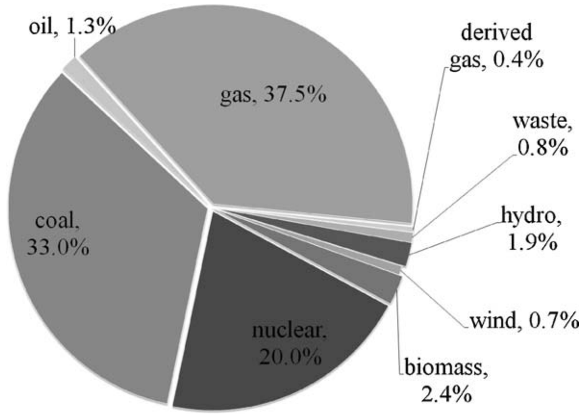

Fig. 6. Fuel mix in UK's electricity sector for year 2005 (source: Eurostat 2007).

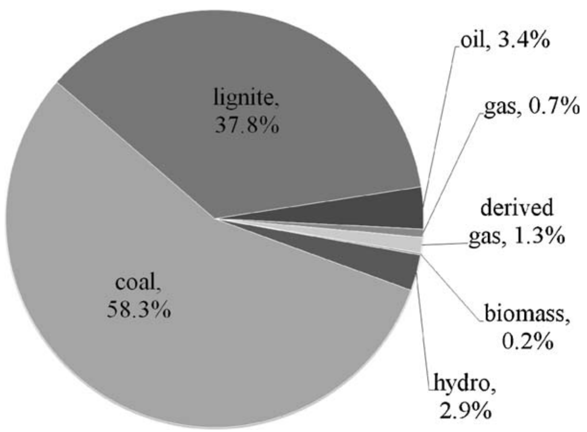

Fig. 7. Fuel mix in Polish electricity sector for year 2000 (source: Eurostat 2007).

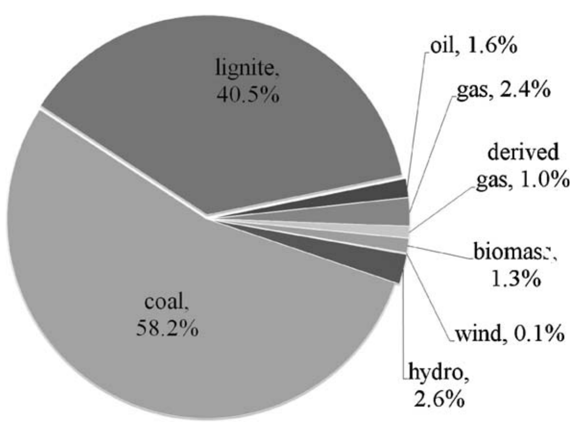

Fig. 8. Fuel mix in Polish electricity sector for year 2005 (source: Eurostat 2007).

Polish market and reached 0.1% while biomass use rose from only 0.2% to 1.3%. It is noteworthy that biomass presents the highest potential for further development among the renewable energy sources that are used in Poland, due to significant amounts of both agricultural and forest waste [26]. Derived gas use fell by 0.3% and so did hydro generation, which fell from 2.9% to 2.6%. Finally, Poland was a net exporter of electricity for both of the years studied, with surpluses of 4.6% in 2000 and 7.7% in 2005.

Having analysed the evolution of the fuel mix, we now address the critical question of the impact of these developments on the energy independence of the countries in question. Renewable energy sources and lignite are the Greek indigenous electricity related fuels. Hence the electricity dependence of the country has increased from 27.5% in 2000 to 33.2% in 2005 and the increased imports of electricity have made a significant contribution to this result. With regards to Germany the situation is more complicated as some of the fuels used in the electricity sector of the country are both extracted locally and imported. More specifically, apart from renewable energy sources, lignite is the single fully local fuel for Germany. While uranium[1] and oil are imported fuels, hard coal and gas are both domestic and imported at different rates. At the same time surplus generation that was exported offset the majority of other factors increasing Germany's electricity dependence which increased during the examined period by only 0.3% from 48.6% to 48.9%.

The UK experienced depletion of its indigenous fossil fuels, specifically natural gas and coal. In particular, the share of indigenous natural gas fell from 98% in 2000 to 85% in 2005. The situation with coal was similar, since in 2000 55% of coal used in the British fuel mix was indigenous, a figure that had fallen to 30% by 2005. Slight increases in the use of renewable energy sources did not offset the increased gas and coal dependency of the UK and therefore the electricity dependency of the country rose from 40.7% to 51.4% during the period. Turning lastly to Poland, we see that throughout the examined period Poland has kept dominant control over its electricity generation resources while slightly improving its exporting ability. More specifically in 2000 99.6% of the Polish electricity was generated from indigenous resources and in 2005 the respective figure was 102.2%; the country has remained a net exporter of electricity. Solid fuels, lignite and coal, are the dominant fossil fuels used in the Polish electricity sector and during the examined period the former was always produced by 100% in Poland while the latter was imported by 2% in 2000 and by 4% in 2005. Oil and natural gas play only a very minor role in Polish electricity generation, so the fact that 97% of oil was imported in both 2000 and 2005, and 67% and 69%, respectively of natural gas was imported, has very little impact on the positive energy dependency of Poland.

5. Conclusions

Electricity supply security is a central tenet of energy policy at both national and EU levels, and this is reflected in the Directive 2005/89/EC "concerning measures to safeguard security of electricity supply and infrastructure investment" [27]. However, increasing the (environmental) sustainability of EU energy systems has become an increasingly dominant objective of EU energy policy. Roller and Delgardo [28] argue that this implies a series of trade-offs between the differing policy objectives. But care must be taken in interpreting this argument. Let us consider the case of intermittent generation. It is sometimes argued that a high penetration of renewables, particularly intermittent technologies, undermines security of supply and that the potential contribution of renewables in satisfying energy demand is small. However, Neuhoff [29] points out that renewable technologies are characterised by differing intermittencies, and therefore a diversified portfolio exhibits an increased probability of the renewables portfolio as a whole making a positive contribution to supply security. On this basis, Neuhoff argues for large-scale deployment of renewables, in a diversified portfolio reflecting local resource endowment (of, for example, very windy sites).

At the national level, countries are to some extent free to develop policies and instruments enabling them to meet their agreed targets such as RES-E and emissions reductions. Despite Greece and Germany adopting the feed-in tariff as the basic support scheme for investment in RES-E, it is clear from this brief

[1] There is a very small amount of uranium mining in Germany.

analysis that the achieved results are not similar. Reasons should be sought within a range of factors, among others the variability of potential, interconnection availability and implementation process which reflects the degree of political support. At the same time Poland and the UK present different examples with the UK using the scheme of the Renewable Obligation in order to improve the penetration of renewable energy sources in the electricity market and Poland following up with a similar scheme of renewable energy certificates imposed on the supply sector. However, especially for Poland the share of RES-E is lamentable and judged by this standard, the policy cannot be considered to be successful. However, we should not disregard the background of countries, which in the case of Poland shows a dominant fossil fuels sector that influences the local politics. We note that with regards to coal and natural gas, the indigenous contribution fell slightly during the examined period but at the same time the increased use of lignite has kept the independence of the Polish electricity sector remarkably high. However, this might be an early indicator that high quality fuels of Poland such as coal and natural gas are gradually depleting and giving place to lignite which may eventually lead to more carbon intensive electricity generation.

However, it is remarkable that although both Greece and Germany are increasing natural gas imports to substitute for domestic solid fuels, at the same time they increase the share of the renewable energy sources in the electricity fuel mix. Overall Poland was the only one of the studied countries to improve its energy independence factor while Germany has kept it almost unchanged. In contrast both the UK and Greece have witnessed a sharp increase in electricity dependence by 10.6% and 5.7%, respectively.

The present study provides a comprehensive theoretical base for the assessment of supply security at a national level and the impact of climate change related regulations coming from the national or EU law. Further research is needed in order to address questions regarding the reasons of success or failure of electricity policies (e.g. feed-in tariff, renewable obligation, and renewable energy certificates). The outcome of this research should be a framework for the development of policy-response functions concerning the climate change related regulations for the electricity sector. Finally, additional research should provide an extended evaluation of the relations of electricity independence and climate change indicators performance with regard to the current and forthcoming policies.

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