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PhD Thesis ABSTRACT

Energy and Sustainable Development in the European Union. Case Study: Nuclear Energy Rol in the Energetic System of Germany, France and United Kingdom.

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Keywords

Energy, sustainable development, climate change, energetic resources, nuclear energy, energy policies, INPRO methodology

Introduction

Energy stands at the base of the evolution and development of our society. It protects us from the externalities of the environment and it has an essential role in the production of goods and services, thus contributing to welfare. Through the use of energy life standards can be improved and poverty reduced. Being an input to most production processes, the cost of energy plays an important role in the competitiveness level of products and services. However the access to energy sources is not easy and it involves financial and environmental costs. States and companies aim in attracting their energetic resources at the lowest cost possible. Energy can be analyzed from three dimensions: reliability through the availability of resources for an economy, sustainability regarding the impact upon environment and competitiveness in relation with the cost of energy. Thus states and companies will aim to have access at reliable, sustainable and competitive energetic resources.

Taking into account the importance of energy for society and economy the present thesis aims in highlighting the potential of a particular form of energy, nuclear energy to contribute to the reliability, sustainability and competitiveness of the European energetic sector.

The ***motivation*** in selecting this study theme is to be found in the fact that nuclear energy is a relative new and complex form of energy which generates controversies regarding its development potential, risks, economic, social and environmental costs. The paperwork analyzes nuclear energy's potential at the level of the European Union which represents the most important regional energy market with over 500 million consumers and the most important energy importer (European Commission, 2010). The European Units presents a low level of energetic reserves in contrast with its consumption level. It has a high level of energetic dependency especially for oil and gas, context in which we considered that useful to analyze the potential of nuclear energy in offering an alternative in contributing to the energetic security f its member states. We aimed at realizing the analysis at the individual level of Germany, France and Great Britain, countries which use nuclear energy but show different options regarding its future, but also at the general level of the Organization for Economic Co-operation and Development (OECD) area.

Within the European community we can find mixed array of energetic sectors with policies, resources, energetic mix and financial possibilities all in search of obtaining a reliable, competitive and sustainable source of energy. The UE aims in acting as single united entity in order to maximize its potential on the international energy markets. For this purpose it needs an energetic policy which takes into account the particularities and needs of each state in relation with three described dimensions. For the moment the main instruments of its policy are represented by the use of renewable energies, the internalization of Green House Gasses (GHG) emissions, energy efficiency and the internal market. We can observe that the theme of energy policy becomes a subject of competition for responsibility between member states and the European Commission. Also it is raised the question regarding who should have the responsibility of assuring one state energetic security: the states or the markets?

Taking into account EU's energetic situation the first hypothesis of the paperwork mentions that the need at the European level of the presence of a resource which offers the perspective of a high degree of physical control and favorable results regarding reliability, sustainability and competitiveness. The second hypothesis states that as important as the characteristics of ones energy source is the way in which these sources interact in the mix and they can be compared.

In order to achieve the fundamental objective of the thesis regarding nuclear energy's potential to the EU energy policy, we aimed at following a number of objectives:

- To define sustainable development in the area of energy: the concept of sustainable development, the relation between energy, sustainable development and environment, the characteristics of developing the energetic sector in a sustainable manner;

- To analyze the different sources of energy: to present the main energetic resources in the global energy mix having into consideration their main technical and economical characteristics.

- To analyze the energetic situation at European level: taking into consideration the international situation, current productions patterns, consumption structure and energy imports

- To analyze the EU’s energy policy: the objectives of the energy policy and the main instruments in order to achieve them

- To analyze from an economic perspective the different types of energy sources present on the EU markets: from the perspective of their production costs, investments, resource availability, economic attractiveness and their impact upon environment

In the area of methodology, methods and specific techniques of the research process we utilized ***the descriptive analysis*** in order to present a number of concepts such as natural resources, sustainable development, energy or energetic security. Through the ***comparative analysis*** we aimed in highlighting the main features of the energy sources that were approached within this paperwork. ***The historic method*** was used in order to highlight the development of the energy sources in the energetic mix or to describe the evolution of the sustainable development concept. A number of indicators such as the production level of energy or the level of CO_2 emissions per unit of energy were used in order to characterize the different sources of energy or to highlight the current energetic situation at the European level. With the help of the INPRO (International Project on Innovative Reactors and Fuel Cycles) methodology which facilitates the comparison of the levelized cost of energy and net present value the ***simulation method*** was put into practice in order to compare the economics of nuclear energy with the other alternatives found on the energy markets. Three states were taken analyzed, which are relevant for the EU due to their consumption levels and their nuclear energy sector.

In order to follow the research objectives, the present thesis was structured into four chapters. In the first part we aimed in highlighting the items that will be further used within the paperwork. In consequence in the first chapter we performed an analyze at the level of the sustainable development concept: what is its significance, how has the concept evolved, how can it be applied in practice, which are the main critics found in the literature, what is the link between sustainability and energy, how relevant in the concept for the EU policy. In the second chapter we approached the energy theme regarding its relevance for society, the main concepts associated with it such as energetic security and the evolution of these resources in the global mix. We have also performed a technical and economical overview of these sources and highlighted the way in which these sources interact. In the third chapter we approached in the part the European energetic sector: its energetic mix, how has it evolved, which resources are produced and which are imported. In the second part of the chapter we performed and review of the current European energetic policy: what does this policy represent, on what basis was it developed, what are its objectives, which instruments does it use. Having taken into consideration the main technical and economical features on the energy sources approached and also EU's strategy to redevelop its energetic sector towards the dimensions of reliability, competitiveness and sustainability, in fourth chapter of the thesis we aimed in analyzing the economic potential of nuclear energy through the use of the INPRO methodology which allows us to compare the levelized cost of electricity. The analysis was carried at the level for Germany, France and Great Britain but also for the OECD area to contrast the way in which nuclear energy can help develop the European energetic sector in a reliable, safe and sustainable manner

Regarding ***the limits of research*** these are associated mainly with the use of the INPRO methodology in the economic area and data availability. We aimed in using real data, reported by actual power plants operating in the three states. Where this data was not available, such as the case of Great Britain we used industry estimated data for the construction of power plants. The studies available in the literature for the calculation of levelized energy costs present a limited number of power plants from each country which have taken part at the questionnaire. In the case of nuclear energy due to the particularity of the economic tool, NEST (Nuclear Economic System Tool), specific input data such as the enrichment cost or the backend cost of the nuclear fuel cycle were used for all simulations from a common study performed by the Massachusetts Institute of Technology, MIT, in 2011. If we are to compare the input date from the two International Energy Agency/Nuclear Energy Agency (IEA/NEA) studies used as database from 2005 and 2010 we can observe significant differences at level of reported costs although the time frame in which these studies were performed in not large. For the wind energy analyzed within our case study we were not able to reflect the backup capacity needed to compensate for the intermittency of this source. In spite of the setbacks the results of our NEST simulations reflect a high degree of predictability in contrast with the results from the studies used as database. On the basis of these results we were able to perform a sensitivity analysis for nuclear energy's parameters but also for the other competing sources in order to highlight the main weak points of nuclear energy but also its opportunities for development.

Regarding the ***elements of originality*** of this thesis, we can state that were represented by link drawn between sustainable development, energy and the way in which sustainable development can be put into practice through the EU energy policy. Another element of originality is represented by the analysis performed in the case of nuclear energy which consists in a SWOT analysis for all the sources that can impact the performances of nuclear energy and through the use of the INPRO methodology developed by the IAEA at the level of the most important European countries in area of energy.

Summary of Chapter I: Sustainable Development

Our purpose within this chapter was to define the main items related with the concept of sustainable development, its practical application and its relation with the energy domain. For this we used the historic method in order to identify the time frames and the elements that influenced the concept, namely the relation between the human being and the environment. Thus, man develops himself within the environment which offers him the possibility to harness its resources. Through wisdom, knowledge man transforms matter into goods and services in order to improve its life standard and obtain progress. Also through understanding of what happens within the environment man can adapt to its changes. For the human being the environment represents a source of wealth but also danger. In consequence the idea of human development can be associated with the notion of predictability and evolution of the environment.

Due to this relation between man and environment, the theme of resource availability has attracted a great deal of attention in area of economics. We can find it at Thomas Malthus in the relation between population level and food availability or at Adam Smith who observes that resource use in spite of expectations increases their availability. More recently in the 20th century we can notice a great of attention within developed states for the protection of the environment in relation with the industrial activity. In the sixties at the level of these societies we can observe that the public opinion increases its awareness regarding that fact that man is part of the environment and the need to protect it. On the other hand at the level of poor and developing countries it is noticed the need of economic growth and improvement of life standards. These developing states regard with suspicion the orientation towards the environment of the wealthy as a reason to limit their developing objectives. However for these states experience has shown that mere replication of the development models based on industrialization and economic growth was not enough in order obtain the targeted results. Passing to the seventies we can remark the appearance of the *Limits of Growth* report which warns that current model of development will lead in a not very distant future to the limiting of economic growth due to the lack of resources. In order to avoid this outcome the authors of the report, favor an alternative model of development within the limits which contracts the level of population and capital growth. The report approaches the concept of natural resources from a static standpoint by considering the known level of mineral reserves and annual growth rates which with a help of a computerized model reflect the collapse of economic growth due to exponential growth. Pollution is treated as a consequence of economic development, thus its levels grow as society develops itself. By using this kind of logic the report highlights alarming conclusions such as the depletion of oil in the nineteen's, which did not occurred in reality. However, being released in the seventies a period marked by the oil crisis, the *Limits* enjoyed a lot of attention by the public opinion and the academics.

In this context it is observed on the international stage the need to develop an alternative concept regarding development. Through the work of World Commission on Environment and Development from the United Nations and its Brundtland Report it is shaped the concept of sustainable development with its most famous definition: *the development that meets the needs of the current generations without compromising the ability of future generations in meeting their needs*. Two elements are of interest from this definition: *needs* regarding the needs of the world's poor and *limits* in relation with the current level of technological development and social organization. In order to attain sustainability technology and social organization can be turned in a direction in order to achieve a new era of economic growth (WCED, 1987).

Regarding the critics attracted by this concept we can mention the difficulty in identifying the needs of the future generations and thus categorize and save resources according to their importance. A second aspect regards resource availability. Sustainable development implies the need to limit resource use in order for future generations to benefit them as well. Thus renewable resources are favored by sustainable development in contrast with non-renewable ones. However this kind of logic shows limits due to the fact that resources are not static, neither by volume or structure. They represent the product of human wisdom, knowledge to transform matter through the help of capital in order to achieve wealth. They are not discovered but developed. Most of what we know as natural resources can not be used in the absence of processing. Regarding their availability they best characterized be the price they have and by their physical inventory at a certain moment. As prices evolves the motivation to find new ores, alternatives or technologies. Thus resources are not physically depleted but replaced do to the presence of the price mechanism.

The link between energy and sustainable development is observed due to the presence of three factors: the importance of energy use within a society, resource availability and the impact upon environment. Energy represents an input to most production processes facilitating economic development. Due to the fact that our world energetic mix is dominated by fossil fuels which are considered to be non-renewable this raises the question of their availability in the future given the fact the world energy demand is expected to grow especially from the part of the developing economies. Regarding environment the relation is represented by fears of the effects in time of green house gasses emissions from the production and use of energy which sustain climate change. They involve negative effects such as floods or the occurrence of extreme meteorological events. Thus sustainability favors low green house gasses energy sources such as renewable energies.

Summary of Chapter II: Energy

The purpose of the second chapter is to present an overview of the structure and evolution of the world energetic mix, the main energetic resources from a technical and economical point and to realize an SWOT analysis between the main types. Energy represents a central element in society’s evolution and development due to the fact that it offers protection from the environment and helps in the production process. It allows to transform one material into another thus opening the way to progress (Bradely Jr., Fulmer, 2004).

From an economical perspective when we refer we consider it in terms of availability and costs. Attractive and stable energy prices help to stimulate the economy. Reduced energy process increase households available income and reduce enterprises production costs (WEF, 2012)

In consequence states are interested in having at hand reliable energy sources at costs that can be maintained over the long term. The concept of energy security involves an economical and physical dimension (WEC, 2008). But who should be responsible for assuring energetic security in a globalized world: the states or the markets? Their opinions that mention the fact that energetic independence is a difficult and costly objective, more important being the international trade of energetic resources (Pascual, Elkind, 2010). It is considered for a country to be vulnerable when its energetic decision are dictated by economic factors outside its control (WEC, 2008)

Energetic security as a concept involves a macroeconomic component regarding the price of energy and national security component due to the fact the vast majority of energetic reserves are geographically concentrated in a few instable political regions (Pascual, Elkind, 2010). This concentration is known as the strategic energetic ellipse where we can find about 70% of the known reserves of gas and oil covers the area between the Arabic Peninsula and the west of Siberia (Armaroli, Balzani, 2011)

Regarding the actors responsible for assuring energetic security we can say that free markets and price formation drives investments in new forms of energy and reduces consumption. However energy free markets are hampered in their development by the geographical concentration of energetic reserves. The main producing countries do not function after the principles of free market and they may use the trade with energetic resources for attaining political objectives. Known examples involve the oil crisis and OPEC and in the seventies and Russia actions towards Ukraine and Belarus nowadays.

Given that fact that energy use has environmental effects, sustainability becomes a topic related to energetic sector. Developed states which have lowered over time their demand are interested in using energetic resources with low environmental impact, while developing states are interested in abundant energy sources at attractive prices in order to meet their growing demand. These two orientations affect the relative competitiveness of their enterprises as some must bare the costs of reducing GHG emissions.

World’s gross energy consumption is leveled at over 13,000 Mtoe the main actors being China, the US and the EU. They evolution will influence the future of the world energetic mix. If we analyze the evolution of energy consumption at global level we can observe an ascending trend, being in 2011 with 30% as in 1995. There are divergent trends between developed and developing trends thus the US and the EU raise their energy consumption until the middle of the last decade which then shows a declining trend, while in the case of developing energy demand grows is spite of the economic downturn form 2005-2011. Due to these economies world energy demand is on the raise.

In 1995, the US was the main energetic actor with over 2000Mtoe, the UE coming in second position (1600Mtoe), China being the barely exceeding 1000Mtoe. However until 2005 China surpasses the EU and until 2010 becomes the world's main energy consumer. What we can also notice in the present is the fact that traditional exporting regions such as the Middle East are raising their energy needs. In this context we can say that the race for attracting energetic resources will intensify.

The current energetic mix is dominated by fossil fuels (80%), with oil representing over 30%. Renewable energies have known an important ascending evolution within the last decade with the help of sustaining measures such as the case of the EU. They represent 13% of the gross consumption but over 77% from this category is represented by biomass. The sources that involve a technological component such wind turbines or solar panels have a quite limited impact, namely 0.5%. From the perspective of growth consumption in the period 1995-2011 we can highlight the importance of gas (+53.81%) and coal (69.94%) (European Comission, 2014)

From a technical and economical standpoint of energetic resources we can say that oil is a flexible fuel, easy to handle and with a high energetic content. It dominates the transport sector (over 90%) in spite of efforts to raise to reduce its impact through biofuels or electric vehicles. As resources are on a growth (+60.58% in the period 1995-2012) we can not speak of a depletion of oil. The main disadvantage is represented by the geographic concentration. Being a strategic resource its availability on the market is not influenced by offer and demand but also by political events. Its volatility can represent a threat to economies such as the United States. Unconventional resources exploitation improve the perspectives of using this resources in the long run and widen the geographical distribution.

Coal highlights a varied geographical distribution that facilitates the prospects of assuring the energetic security of a country through this resource. There is varied number of producing countries and this resource can be shipped by sea to other continents in order to develop an international market. It presents attractive electricity generation costs which favor its use. The main problem is represented by the high GHG emissions and the fears of climate change. The use of coal can also represent a threat to human health being associated with respiratory diseases. In contrast to gas and oil it is a voluminous fuel which reduces its maneuverability. For some types of coal such as lignite it is economical to transport over large distances. Current efforts within developed states to reduce carbon emissions can be seen as a threat to coal use in the future.

Gas is a flexible resource which can be transported over long distances and has limited impact upon the environment. The world stock of reserves is on an ascending trend. Gas power plants can sustain the use of renewable energies being easy to start. Like oil it is geographically concentrated, and can be used in political purposes, Russia being an example. Due to the fact that it is transported by pipelines it increases the dependence between suppliers and consumers and the use of long term contacts that do not reflect market evolutions. The liquefaction of gas is an option only when it involves distances of over 3000km, but this can help to diversify the supplies. The development of the unconventional sector in the US showed how a technological development helped to increase the availability of this resource. This helped to lower the energetic dependency, to substitute coal, reduce emissions and spot prices. At global level it helps to diversify the availability of resources.

The main advantage of renewable energies is the fact that they do not need the presence of a fuel and can be locally produced thus improving the energetic security of a country. In the context of climate change they can help limit emissions. They are flexible and can be used by enterprises and households for their own energetic needs. For the moment as mentioned before wind and solar sources have a limited impact in the global energetic mix. They are also more expensive than the traditional energy sources and they require public support. They need backup capacities available and their results are driven mainly bye the presence of intermittent wind and solar sources. Due to the fact that they must be used when available the limit and influence the use of other base load energy sources such as coal.

Nuclear energy is an abundant and reliable source of energy. The capital component plays an important role in the use of this source which improves the level of control upon this source. Due to the fact the uranium is traded on the international market the perspectives of supplying nuclear power plants with uranium are improved. The fission reaction presents a high energetic content in contrast with the other available sources. Nuclear electricity price is influenced in a limited extent by the price of uranium, which offers stability to this resource.

Uranium resources are abundant and exploited by diversified number of countries. Once built, they present low operating and maintenance costs for long period of time (60 years). They are attractive for industries that require stable and reduced energy prices. Their impact upon environment from the perspective of GHG emissions is reduced, being a useful instrument in the battle against climate change. In contrast to other energy sources like gas or coal they are not so flexible. They are built in a long period of time (5-7 years) are complex technological projects and require considerable amounts of capital. They also require decommissioning at the end of their life time and management of radioactive wastes.

They main threat to the use of this source is represented by political orientation towards this source of electricity. This attitude can change as consequence of different events taking place at the global level. For example due to the Fukushima accident the German government decide to phase out nuclear energy although the tsunami that occurred in Japan can not be replicated on the German mainland. Also the price of fossil fuels can be a threat to nuclear power plants as it will affect its economic performance.

Summary of Chapter III: Energy Policy in the European Union

EU represents the most important regional energy market in the world with over 500 million consumer being also the most important energy importer (European Commission, 2010). Its energy products commercial deficit represented in 2012, 3.3% GDP or 421 billion Euros. This represents a significant evolution in contrast with 2004 when the deficit was at 150 billion Euros (European Commission, 2014a). EU imports mainly gas and oil.

Regarding the link between fuel prices and the evolution of economy we can notice that a IEA study from 2004 estimated that a rise of the price of the barrel of oil from 25$ to 35$ will incur over the period of two years a 0.4% GDP reduction in the United States and 0.3% in the Euro zone (WEC, 2008)

At global level EU represents 12.7% of the world’s gross energy consumption with a stable and declining consumption. Divergent evolutions in the area of consumption are to be seen between developed and developing states, China and India being the main representatives. Due to this evolution the position of EU at the international level has decreased from the perspective of consumption and emissions.

The EU stands out in the area of energy with a high level of consumption in contrast with its energetic reserves. Thus energy imports play an important role in the energetic security of the Union. The EU holds 0.4% of the known reserves of oil sufficient for 12 years of production and 1.7 trillion cubic meters of gas or 0.9% of the known reserves sufficient to meet demand for the same period (European Commission, 2014b, after BP, 2013). Regarding coal there are more optimistic estimations with 6.5% of the known reserves that can meet demand for 97 years of production (European Commission, 2014b).

In production terms, EU represents 6.1% of the global production, a reduced level in contrast with China (18,4%), Middle East or the United States (13.5%).Its production level is on a descending trend from the beginning of the century. The analysis of the European production structure highlights the substantial reduction of coal production from 270Mtoe at the beginning of the nineties to 170Mtoe in 2012. For gas there is observed a similar evolution: a growth in production until 2002 followed by continuous reduction to 2012. In contrast renewable energies have known an important evolution growing by 54& from the beginning of the century. Nuclear energy has not known important changes but it is on a declining trend due to the decision of Germany to phase out its nuclear reactors. However in spite of these evolutions, nuclear energy remains the most important source of energy produced within the EU (European C omission, 2014c). Due to low productions levels in contrast with consumption, EU shows a high degree of energetic dependency of 53.4% in 2012 and on an ascending trend in the period 1995-2012 (European Comission, 2014)

The main importer countries are the representatives economies of the EU such as Germany (196.8Mtoe), Italy (133.8Mtoe) or France (125.3Mtoe). Along with Great Britain and Spain they represent close to 70% of EU's energy imports (European Commission, 2014). If we are analyze energy imports by their origin we observe the importance of Russia: 34% oil, 32% gas and 21% coal (European Commission, 2014 after IEA, 2014). We can also observe the limited diversification of imports in the case of gas, as three countries namely Russia, Norway and Algeria represent 70% of the imports (European Commission, 2014). This aspect increases the vulnerability of the EU in the case of a supply disruption, which may come from Russia as a recent Commission reports suggests (European Commission, 2014c).

From the perspective of sector consumption we can observe the high share of transports (32%), followed by industry and households (26) and services (13%).By analyzing the period 1990-2012 we can observe a decrease in area of industry energy consumption (-23.79%)

along side an increase at the level of services (+36.42%) (European Commission, 2014c). This evolution reflects the orientation towards services with a lower energetic consumption.

Regarding GHG emissions and climate change EU represents 12% of the global emissions being behind China and the US in this area. The emissions are on the rise at global level with a growth with over 40% in the period 1995-2011. The EU decreased its emissions by 5% but it could not compensate for the evolutions that are taking place in developing countries. Until 2010 China has surpassed the US and EU in area of emissions being now the main source (800 Mt CO_2). China's growth represented 50% of the global growth within the time frame analyzed (European Commission, 2014). Due to these diverging trends and in the absence of a global agreement regarding emission cuts the efforts of developed economies will have a reduced impact at global level and will affect the competitiveness of their enterprises.

Having into consideration its energy position, the European Commission aims through its policy to direct its energetic sector towards the three dimensions of reliability, competitiveness and sustainability. Its policy it combines elements related to climate change, new sources of energy, energy efficiency, and the internal market. Due to these developments, energy has become a shared competence between the Union and its member states. The policy aims to transform the European energy's sector weaknesses into opportunities for growth. With the help of a series of objectives in aims to transform its energetic sector (European Council, 2007):

- a target to reduce GHG emissions with 20% in comparison with 1990 levels by 2020 and 30% if developed countries commit to similar measures;
- a target to obtain a 20% share of renewable energy in the primary consumption by 2020;
- a target to obtain a 10% share of renewable energy in the area of transport;
- a mandatory target to reduce primary energy consumption with 20% by 2020;
- the commitment of the Union to help the building of 12 power plants equipped with carbon capture and storage technologies (CCS).

On the international stage the EU favors the development of a global agreement regarding GHG reductions with compulsory targets by 2020 (European Commission, 2014). Given the fact that the EU supports the deployment and development of renewable in the case of the emergence of a global agreement we can see that there will be opportunities to export these technologies to states in need of low carbon technologies. Also by decreasing its consumption levels and the promotion of renewable energies the EU will reduce its energetic dependency.

In the area of instruments we can remark the European Transaction System (ETS) for GHG emissions through which they are limited and traded under the form of certificates. This system is used in order to limit GHG emissions at the lowest cost possible. Through this system EU aims to generate investments in low carbon sources. This kind of system modifies the relative competitiveness of the energy sources present on the market by favoring low carbon sources. The main problem in this system is to identify the *correct price* of carbon necessary to accelerate the rhythm emission reductions. Due to the fact that it is not a real problem perceived by society it is difficult to develop a functional market in order to reduce emissions. There are opinions that are in favor of using interventions mechanisms in order to accelerate the rhythm. In spite of the use of the ETS at the European level in countries such as Germany we can see the growth of coal use due to low resource and carbon prices.

A second point of interest in the area of policy instruments is represented by European directive to use renewable energies. The directive recognizes the need of public involvement in order to sustain these sources as the other present on the market do not reflect completely the social and environment costs (European Parliament, Council of European Union). In order to raise their renewable energies share, member states can use feed in tariffs, premiums or green certificates. Their role is to offer the green energy producer a higher price than that present on the market so as to compensate for the high capital costs of these alternative sources. The development of this sector is realized by translating the costs to the electricity consumers and the raise of the price of electricity. The presence of different schemes in the member states means that investors can orientate to the countries with most rewarding schemes. But this variety of schemes can prove problematic in the context of the EU's aim to complete the internal energy market. The main problem of these sources is not their public support but the fact that they limit the functioning of other energy sources thus affecting their economic performance.

Summary of Chapter IV: Nuclear Energy Role in the Energetic System of EU. Case Study: Germany, France and the United Kingdom.

The objective of this thesis is to highlight the potential of nuclear energy to help to the transformation of the European energetic sector towards reliability, competitiveness and sustainability. Within the technical and economical analysis of the energy sources we observed the fact that nuclear energy facilitates the assurance of energetic security but also the GHG emissions reductions due to its characteristics. Regarding competitiveness within the case study aimed to compare the costs and benefits of using nuclear energy with the ones of the other sources available on the electricity markets. For this research purpose we applied the INPRO methodology. In order to have an overview image of the nuclear energy's competitiveness we applied the methodology also at the level of the OECD area.

The analysis was carried out at the level of the most important countries from the EU from an energetic standpoint: Germany, France and Great Britain. These are the main European consumption countries, representing 46.34% of the gross energy consumption. These states also present a developed nuclear sector but have different strategies regarding its future.

In the first phase of the case study we performed an analysis at the level of the energetic sectors from these countries from the perspective of energy production, energetic mix, consumption, import dependency and sector consumption within the period 1990-2012.

Within the analysis we observed the role of fossil fuels in the energetic systems of the countries approached. In Germany oil (33.71%) represents the main component, followed by coal (25.01%) and gas (21.74%). In this country renewable energies contribution (10.30%) is superior to one of nuclear energy (7.99%). In the case of Great Britain we can see a balance between the shares of oil (34.16%) and gas (32.97%), while coal has a more limited contribution (19.30%). Nuclear energy represents 9.02% of the countries energetic mix while renewable energies have the lowest (share between the three states taken into consideration. There is an important difference in absolute terms between renewable energy contribution in Great Britain (8.39Mtoe) and the one in Germany (33.08Mtoe)but also in the area of oil consumption 68.75Mtoe versus 108.3Mtoe. For the case of France we can remark the role of nuclear energy, this being the main energy source in the mix (41.85%). Here oil comes in the second position (30.68%), followed by gas (14.58%). Renewable energies have a share of 8.09% and coal has limited contribution (4.37%). Thus in the case of France we can observe a different structure in the energetic mix in contrast with Germany and Great Britain (European Commission, 2014).

Regarding energy production we observed a descending trend in case of Great Britain and German. For the case of France there is constant level throughout the analyzed period. Due to this evolution France has surpassed the other two countries with a production of 134Mtoe in 2012. In the case of Great Britain an ascending trend was observed for the production for gas and oil was observed until the beginning of the century (277.6Mtoe) point from which the energy production decreased for the whole considered period. Finally in the case of Germany production followed a descending trend for the whole period. For all the three states taken into account it was observed the orientation towards reducing the contribution of coal and gas in the mix on the one hand and to raise the shares of sources with a lower environmental impact such as gas or renewable energies(European Commission, 2014).

In the area on energy policies we can say that all three states aim for the development of a reliable, competitive and sustainable energy sector. The German policy known as *Energiewende* supports the deployment of renewable energies as they should become the main source of energy in this country by 2050. GHG emissions should be reduced by this time with 85-90% in comparison with 1990. Also the government aims to reduce primary energy consumption with 20% by 2020 and 50% by 2050 in comparison with 2008 levels. Initially for nuclear energy the strategy mentioned the extension of the lifetime of the reactors in average with 12 years in order to facilitate the transition to low carbon energetic system but the Fukushima accident change the initial government decision to phase out nuclear energy by 2022 (OECD/IEA, 2013)

For Great Britain we can notice the importance given to the fight against climate change being assumed unilateral emission reduction targets with 50% until 2027 and 80% until 2050 in contrast with 1990 levels. The government wants to act in the power sector through the support of low carbon sources including nuclear energy and the development of CCS technologies. In order to achieve its purpose in this country it is taking place a market reform which includes measures such as a floor price of carbon over the medium and long term and a contract for difference (between market price and a certain level) in order to stimulate investment in low energies sources (OECD/IEA, 2012).

In France the energy policy mentions four principles: security of supply, competitiveness, sustainability and equal access and quality of service to all citizens. In order to combat climate change 75% cut in CO_2 emissions objective is assumed until 2050 in contrast with 1990. Regarding energetic security, French policy aims to support the deployment of renewable sources, energy efficiency, diversifying gas supplies, improving the interconnection with neighboring countries and the building of the new EPR reactors. The main challenge is represented by the coexistence of regulated tariffs and market prices which hamper the liberalization on the market and the drive for investments. (OECD/IEA, 2010).

The INPRO methodology is a useful tool in order to study the competitiveness of energy sources as it allows the comparison through the use of calculation instrument (NEST) of the levelized costs of electricity. Also it can help evaluate the financial benefits of using different sources by the calculation the net present value. The reason behind the use of the methodology at the level of Germany, France and Great Britain for nuclear energy was to compare it with the alternatives present, but also to highlight national differences between the cost of exploitation of a certain resource.

In the case of Germany, for a discount rate r =10%, we noticed that at first sight coal and gas power plants are attractive sources of electricity generation Nuclear energy comes behind them with a cost of 50$/MWh and at a considerable distance we can find the wind turbine with over 90$/MWh. For a 5% discount rate, we can observe a change in the hierarchy of the sources from the point of view of levelized costs. In this case nuclear energy presents the lowest levelized costs (34,10$/MWh), followed by coal (34,84$/MWh). The cost of gas electricity does not reduces in this case bellow 40$/MWh.

For France, nuclear represents the cheapest generation option slightly above 40$/MWh for a 10% discount rate in contrast with Germany's case where coal is the most attractive option (r=10%). At a 5% discount rate the difference between nuclear (25.83$/MWh), coal (33.91$/MWh) and gas (39.87$/MWh) costs increases. Regarding the net present value for nuclear it is closed to 8000$/kWe, while for gas it does not exceeds 5000$/kWe.

If we look at the NEST simulations that were performed in the case of Great Britain with data representing industry estimations for the construction of new power plants and fuel costs represented by the average import price in the OECD area we observed that nuclear energy presented the most reduced costs bellow 50$/MWh. Coal costs are close to those of nuclear, while gas costs range above 70$/MWh.

In the last part of the study the analysis was performed at the level of the OECD area, using average costs in order to have an overview of nuclear potential. At the level of electricity costs for 10% discount rate the most favorable result are obtained by coal (68.17$/MWh), followed by gas (84.83$/MWh) and nuclear (96.67$/MWh). In the conditions of a carbon tax the three sources of electricity level at about 95$/MWh, but nuclear remains the most expensive source. Wind energy is positioned at 120$/MWh far away from the base load sources. By using a 5% discount rate nuclear and coal position themselves bellow 60$/MWh, while gas remains at over 80$/MWh. For this rate also the economics of wind energy improve the cost being reduced bellow 100$/MWh. By considering also carbon costs in this NEST simulation we can observe a new hierarchy with nuclear being the cheapest option (59.13$/MWh), while coal is close to 80$/MWh and gas is over 90$/MWh. In this case the difference between gas and wind energy electricity costs is bellow 25$/MWh.

Regarding the effect of the discount rate upon the structure of generating costs we could observe in the case of nuclear energy that for a variation from 5% to 10% the capital costs grow from 57% to 73%. In the case of coal they reach 46% from 32% while for gas from they evolve from 12% to 18%. This simulation confirms the fact that nuclear and coal (at a lower level) power plants are vulnerable to the variation of capital costs. On the other side we can observe the reduced impact of fuel costs 15-22% for nuclear in contrast with coal 47%-59% and gas especially 79-85%. Regarding the sensitivity analysis we aimed in the case of nuclear energy to highlight the importance of the construction period. Thus by reducing the construction period from 7 to 4 years the levelized unitary electricity costs decreases from 96.67$/MWh to 87.35$/MWh, level comparable to that of gas 84.83$/MWh. A second aspect studied with the sensitivity analysis was the influence of fuel prices in the economics of gas power plants. Thus for a 15% growth of gas prices to 11.23$/GJ the electricity generation costs reach 94.95$/MWh from 84.83$/MWh.

Summary of Conclusions

In this section our aim is to draw a series of conclusions regarding the main items studied in within this thesis. Firstly the ***energy theme*** was selected as topic of research due to the fact that energy is fundamental aspect of our society. It facilitates economic development and the improvement of life standards. For developed countries the functioning of societies can not be imagined in the absence of energy while for developing countries the availability of energy represents the key to progress. Energy represents in the same time an element of competitiveness at level of states and enterprises. It is not facile to attract and it involves financial and environmental costs. At global level we can notice that the geographic concentration of gas and oil reserves hampers the development of a global market able to assure the security of supply.

Due to these considerations the present paperwork aimed to analyze the main factors that determine the availability and costs of energetic resources for a society. From the geographically standpoint the paperwork is placed at the level of the European Union because this entity distinguish itself through the variety of energetic sectors and policies within its member states, their aim to act as single entity in the area of energy and their reduced energetic reserves. Thus assuring energetic security represents a challenge to the EU.

From the perspective of resource analyzed the present paper is focused in ***the study of nuclear energy***. This represents a relative new source of energy within the global mix, which distinguishes itself through the complexity of nuclear power plants and the fission reaction, the destructive potential associated with the nuclear bomb and the risk associated the use of this source. It is unique source of energy in contrast with the traditional sources that focuses on the use of science and material capital in order to obtain abundant quantities of energy. These are reasons from which we considered that a research in the area of costs and benefits associated with the use of nuclear energy and also by comparing it with other sources of energy available would be useful.

In the first part of the paperwork we were interested in defining and analyzing the main elements associated with the energetic field. For this reason we focused on ***the concept of sustainable development*** which represents nowadays an omnipresent element at the level of decision factors and public opinion, which influences the development of sector policies. For the EU, sustainability represents a central objective present in every policy, fact for which we considered to useful to clarify its content and application within the energy field.

Regarding the link between sustainable development and energy we can say that there two elements of interest: resource availability and the environmental protection, the main theme currently being represented by climate change. Thus for a energy source to be considered sustainable it must present a high degree of resource availability and reduced GHG emissions. For this reason renewable energies are seen at the public level as a sustainable source of energy.

Traditionally the ***concept of energetic security*** was approached within two dimensions: security of supply regarding the energetic reserves of the states, their geographic concentration in instable regions and the cost of exploiting these sources. A third dimension has been added by the consideration of environmental aspects and GHG emissions. We can say that states will take into account these there dimensions in the development of their energetic sectors: security of supply through the development of local energetic resources or their access from the international markets; competitiveness in relation with the cost of attracting these resources – if it is reduced and stable it will sustain economic development; sustainability with the need of protecting the environment and reducing the emissions. Within this triangle we aimed to analyze the potential of nuclear energy to contribute to the energetic security of the EU.

A second field of interest in the analysis of concepts necessary to elaborate this paperwork was represented by ***energy sources***: what to they represent, what is their position in energetic mix, how have they evolved, what are their main technical and economical characteristics. We considered that it was useful to approach this topic of resources in order to understand their strengths, weaknesses, opportunities for development, threats and also the way they interact.

Having considered the main concepts and elements associated with field of energy, in the third part of the paperwork we orientated in ***analyzing the European Union from the perspective of its energy situation and its energetic policy***. What we noticed is the fact that the Union aims to develop an energy source which will allow it to reduce its dependency on fossil fuels and reduce GHG emissions all at a competitive cost. Within this context we wanted to study the way in which nuclear energy can represent a solution to the European energetic sector.

Through the analysis performed at the level of energy sources we observed that nuclear energy has the potential of assuring ones entity energetic security due to the abundance and diversity of uranium supplies while in the same time reducing the level of GHG emissions in the context of climate change.

For the third dimension namely ***competitiveness*** we study it with the help of the INPRO methodology which allowed us to compare different energy sources through the use of the levelized cost of electricity. The analysis was carried on at the level of France, Germany and Great Britain due to the fact that these are most representative states in the EU area from the point of view of energy consumption, production or energetic imports volumes. Also these states present developed nuclear energy sectors but have different orientations regarding their future. For an overview image we also performed the analysis at level of the OECD area.

Following the analysis performed with the help the economic tool NEST of the INPRO methodology we noticed that nuclear energy is a competitive and reliable source of energy. At first sight after performing the NEST simulations in countries such as Germany we observed that nuclear energy can prove more expansive than fossil fuels but the sensitivity analysis showed us by reducing the construction period, internalizing CO_2 costs or raising the price of fossil fuels, nuclear becomes an attractive source of energy. For France the long experience in building and operating nuclear power plants proves to be valuable as this source presents the most attractive costs of generating electricity. The different cost structure between fossil fuels sources and nuclear energy is the main cause of the differences between these energy sources. By attracting the capital at a reduced cost, nuclear becomes the most attractive energy source on the market as our NEST simulations have shown. Nuclear energy is vulnerable up until the point of recovering its capital costs, from which it will generate electricity at stable costs for a long period of time. This fact offers stability while fossil fuels such gas or coal offer volatility to the energetic to the energetic system. In the context of developing an efficient electric vehicle, nuclear energy might represent an opportunity to offer an alternative to oil in the transport area. Regarding renewable energies our analysis showed that they are positioned at a considerable distance from the other sources present on the market from the perspective of costs, confirming the need for subsidies. The deployment of these sources at large scale will require a tremendous effort from the EU in order to limit energy dependency and GHG emissions. For these reasons nuclear energy represents with certitude a part of the answer the energetic dilemmas of the European Union, which has the potential of offer reliability, sustainability and competitiveness to the European Energetic sector.

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