Energy security in the European power system towards 2030

Technology and regulatory frame for the integration of the German, French and Spanish power systems

MEMORIA

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Abstract

The electrical system in the European Union as a whole, has suffered during the last years from several threats, both from international causes as the recent crisis in Ukraine, but also from the lack of natural resources in the continent. A common energy policy in the Union is necessary to counteract these threats and to guarantee the continental energy security.

This paper has the aim of offering a perspective of how three particular countries could act in the upcoming years in order to assure access to electricity in Europe, taking into account their current electric power situation and their actual policies in a frame towards year 2030.

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1. Introduction

During the last decade, the energy policy of every country within the European Union is marked by a tendency to promote the use of renewable sources as energy supply to assure national energy security. This multinational energetic regime, observed also in common policies within the Union, responds to the necessity of the State members to reduce their dependence on fuels imported from non-EU countries, besides reducing the greenhouse emissions derived from the use of fossil fuels and decoupling energy costs from oil prices (European Commission, 2009).

"A country that can't control its energy sources can't control its future" (Obama, 2006).

1.1. Objectives

The main aim of this document is to determine the structure of the European power system towards 2030 in three particular cases, those of Germany, France and Spain, in a frame in accordance to the current European Union directives and the respective national strategies in the matter.

The necessary technologies to be implemented as well as the integration of the countries' systems will be analyzed and their effectiveness to guarantee energy security and sustainability will be assessed, focusing in the integration of renewable energies.

Finally, based on the strengths and weakness of the determined scenarios, a set of recommendations for the improvement of the actual regulatory framework of the studied countries will be put forward, so the energy security in a long-term in the region can be enhanced.

1.2. Justification

Energy security constitutes a matter of first importance for any country, since on this source depend all the industry, infrastructure and transport of a nation, and by these means, the ability of the state to provide basic services to the people, such as health care or sanitary services. Nevertheless, many factors may hazard the stability of an energy system, for instance geopolitical issues, armed conflicts, natural disasters or malfunctions of the power sources or of the energy transport systems. The recent crisis in Ukraine has highlighted energy security as a truly strategic issue for national security of the implied countries.

Historically the term of energy security had been associated to oil supply of a country, but nowadays, gas and electricity constitute also priorities for the governments in order to assure the quality of life of the population and keep the economic activities going on. And, unlikely in the past, the price of energy is established as a central factor in the definition of energy security.

Europe, as a union, is one of the largest energy importers in the world and, as recent events in the east of the continent have shown, the energy security of the European Union is quite fragile. Moreover, the lack of conventional sources in the region results in the immediate necessity of changing the energy panorama of Europe in order to assure energy for the 500 million inhabitants of the continent.

Nowadays electricity is one of the most used forms of energy and it has clearly a tendency of growing up in the next decades and to cover the territory today dominated by conventional energy sources.

Germany and France are the countries with the largest total gross electricity generation in the European Union and together with Spain, they constitute 45.7 percent of the total electricity production in the Union. In absolute terms, these nations are also in the top five of the largest primary production of renewable energies in Europe. Even though, their dependence on primary energy imports from third countries is relatively high, 70.5 for Spain, 62.7 for Germany and 47.9 for France.

In order to help to revert this tendency, the European Union has set targets that may relief the situation in a mid- and in a long-term scenario. The measures adopted by the Union on that respect are focused on two main pillars, which are the integration of renewable energies and energy efficiency improvement. In spite of that, the countries have adopted drastically different plants to reach their respective objectives, exemplified by the total shut down of nuclear energy plants in Germany by 2022 while France will still rely on this form of power generation for a long time in the future.

The European Commission, after demonstrating that a 20% target of renewable sources of the total share of energy supply and a 10% target for energy from renewable energies in transport were feasible and reachable objectives and those were compatible with the already existing plan for improving a 20 % the energy efficiency by year 2020, decided to implement a directive so it could be implemented in every member state of the Union (European Parliament and Council, 2009). In order to ensure that the mandatory national overall targets are reached, the European Commission established some specific aspects to be followed. The main ones are the establishment of national renewable energy action plan including information on sectorial targets as well as setting out measures to achieve the proposed targets. Assessing the contribution of energy saving measures and energy savings measures to the reach of the objectives was also established as a task for the countries. The optimal combination of energy efficiency technologies with energy from renewable sources should have been taken into account at the time of establishing the national plans.

Because of the complexity of the future scenarios related to power generation, determining their structure and comparing them in order to find opportunity areas would result in a useful set of policy recommendation for energy security enhancement in the region.

1.3. Research methodology

The research will be related to the territory of the European Union, considering the 28 countries that form part of it until the end of 2014. In this document, The European Union will also be referred as the European continent or as Europe, unless otherwise stated.

In the case of France, the power system to be analyzed will be the one on the continental land, neglecting the overseas departments and territories of the French Republic. By its part, the Spanish land to be considered on the study will be the one located in the continent, without considering the non-peninsular territories. The federal territory of Germany will be included in the study and in the case of each country, the exclusive economic zones to the mentioned lands are also to be considered.

The gathering of information is an essential part of the present study, so the following classification has been established in order to guarantee the quality of the quoted sources.

The information regarding national data is controlled by each state and in a further stage, different organizations, either national or international, gather and interpret these data in order to make reports or statistical studies. Is for this reason, that, in numeric terms, the data that here is treated is not supposed to present larger differences from one source of information to another one.

In contrast, the data that deals with policies and the interpretation of the national information and trends may drastically differ among sources.

According to the nature of the source, the classification shown in table 1 will be followed:

	By type of source	**By publisher**
1	Peer-reviewed literature	Research centers
2	Non-peer-reviewed literature	Universities
3	Unpublished data	Government agencies
4		International organizations
5		Companies
6		Non-governmental organizations

Table 1 Classification of sources according to type of source and publisher

In case of an opposed or non-concordant information derived from using two or more different sources, the classification of table 1 would guide the selection of data by considering the source in an upper position on the table as a more trustful as one in a lower position, so conflict of interpreting information is avoided.

The data that will be handled will be as up-to-date as possible, and the reference year from each source will be mentioned at every time. In order to try to gather the most up-to-date information, all of it comes from online references, always focusing in the meaningful data that these may contain.

Since the sources managed by each country differ about the naming of the technology, the following classification will be followed:

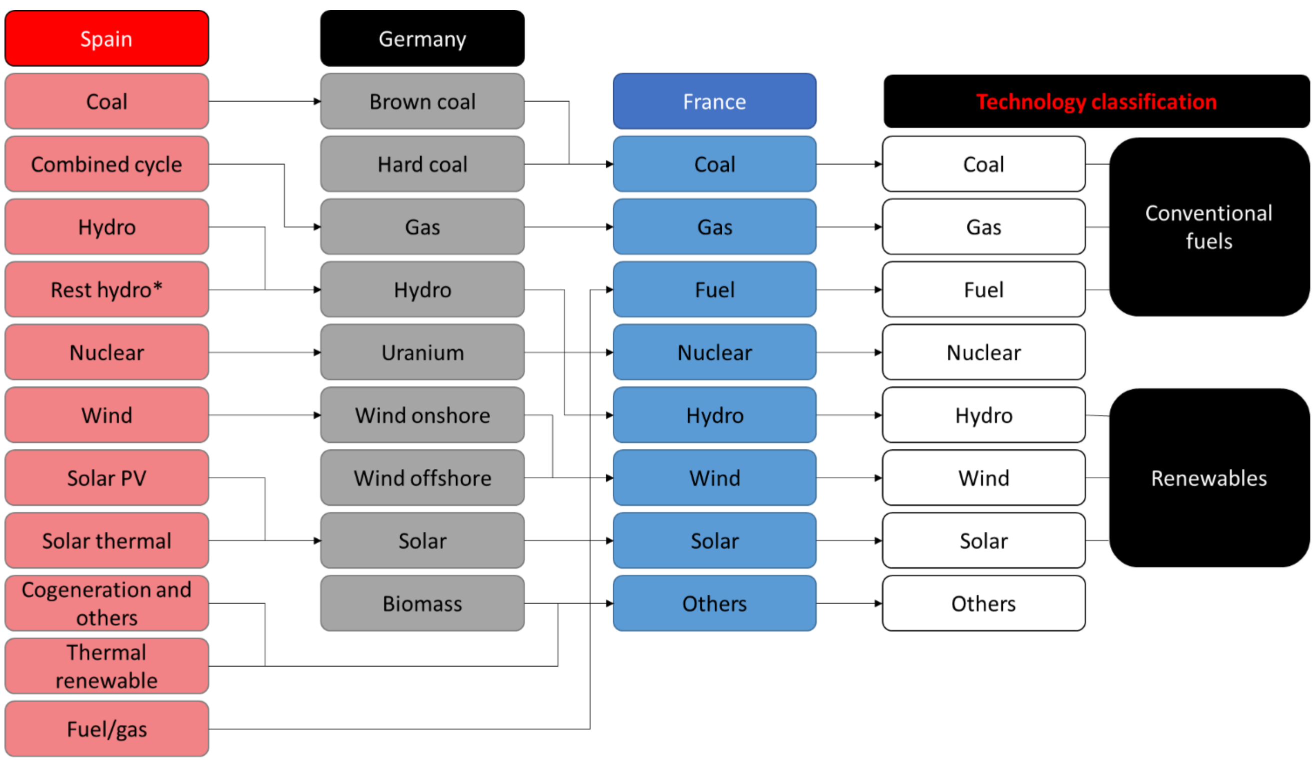

*Figure 1 Technology classification for the studied countries (*According to the Spanish classification of different generation regimes)*

These are the general considerations for the technologies classification:

- Coal: the German brown-coal and hard-coal power plants have been grouped into a single type.
- Gas: the Spanish combined cycle has been grouped into this technology.

- Fuel: French oil and Spanish fuel/oil power plants have been included into this section.
- Nuclear: since the Fraunhofer Institute of Germany considers the fuel of the power plants to name them, uranium power plants have been included in the category of nuclear power.
- Hydro: Spain has a special classification of hydropower depending on the capacity of the plant, but all of the plants have been included in this category.
- Wind: both wind onshore and offshore are considered in the category of wind power.
- Solar: this category includes both solar photovoltaic and solar thermal for all the countries.
- Others: All the other electrical energy sources, either conventional or renewable, that are not included in the enlisted categories have been considered under this category.
- Conventional fuels: the coal, gas and fuel technologies are considered conventional forms of energy.
- Renewables: Hydro, wind and solar technologies will be treated as renewable technologies in the study.

All this information is valid through all the document unless otherwise stated.

2. Energy security

While it is true that energy has always been a matter of importance for practically all the countries in Europe, recent political crises in the European continent have put the topic of energy on the table as a first-order priority.

Despite the fact that there does not exist a globally accepted definition of energy security, one of the most accepted ones is the one that defines it as the uninterrupted availability of energy sources at an affordable price (International Energy Agency, 2014). By these means, not only the availability of a source in a region is sufficient to say that energy security is ensured, but also the price that is paid for that source plays a central role for making energy security certain.

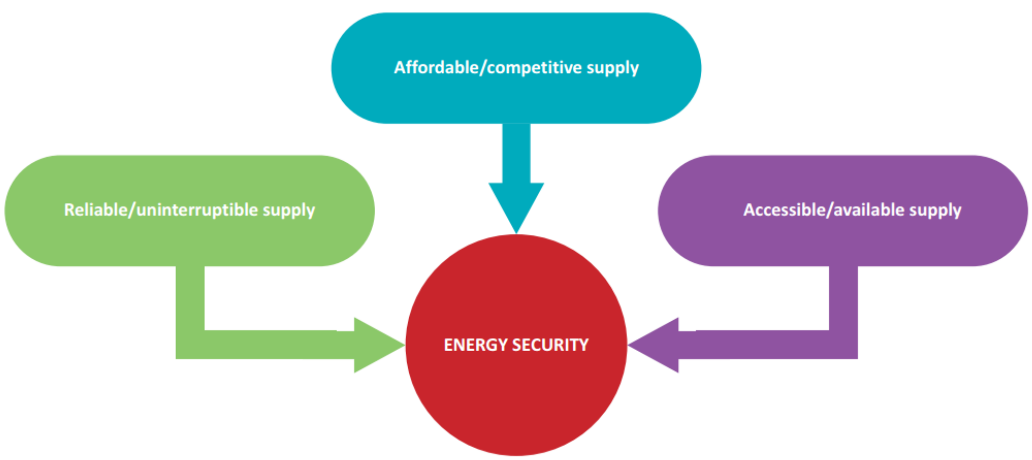

Figure 2 Defining energy security (International Energy Agency, 2014)

In terms of time framing, energy security can be understood from two perspectives, a long-term scenario, which is intended to focus on timely energy supply investments taking into account the economic development and protection to the environment, while the other one, a short-term scenario, consists on planning reactions to sudden changes in the energy supply chain.

Energy security concept covers, unlike in the past, not only conventional sources of energy, such as gas or oil, but also electricity. And, as well as in the case of conventional energy sources, diversification plays a central role in the preservation of energy security. In figure 2 the main sources in an energy system are displayed. A complete energy system of a country, or group of countries, covers from supply to transformation, distribution and end-use energy services.

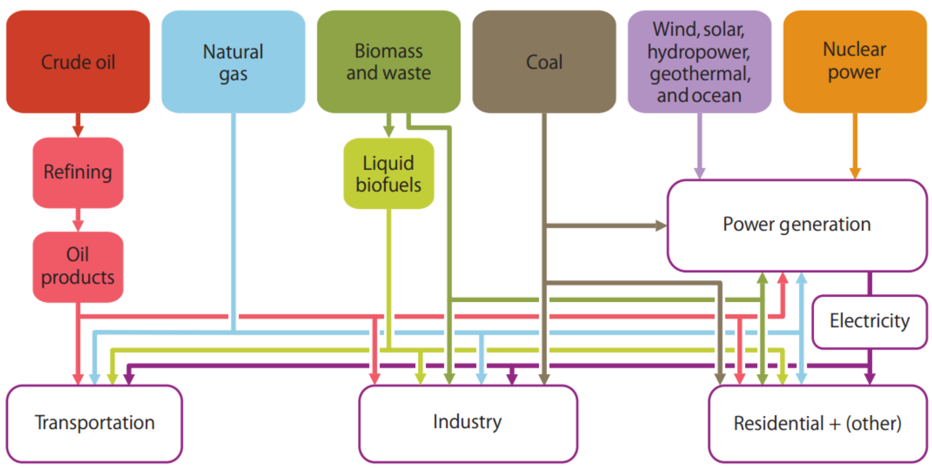

Figure 3 Energy systems approach (International Energy Agency, 2011)

The concept of energy security encompasses much more than just the supply of energy to a country, since it also closely related to strategic security of a nation (North Atlantic Treaty Organization, 2014); these strategic fields comprise economy and politics, concepts on which the sovereignty of a nation relies on.

2.1. Electrical energy security

From all the used forms of energy, electricity represents the most widely energy source in the European continent (European Commission, 2014). Due to electricity's variety in production throw power generation as it can be observed in figure2, it constitutes a very flexible form of energy, characteristic that explains its increasing use over the time compared to other forms of energy, particularly to the conventional ones.

Several countries around the world have put their trust and efforts to improve the production and use of electricity as an alternative to conventional forms of energy, because the use of renewable technologies, in the absence of indigenous fuels, is the only possible way to achieve energy independence from other countries as it is shown in figure 3, thereby guaranteeing energy security in the long-term.

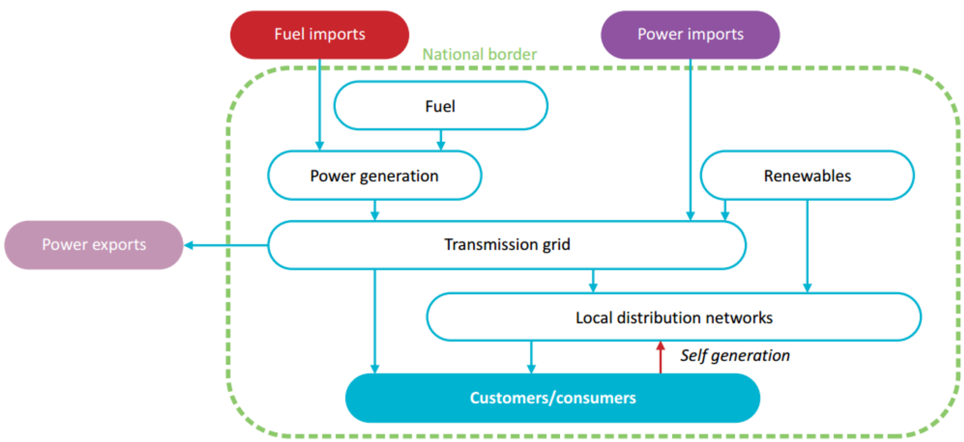

Figure 4 Breakdown of the electricity supply chain (International Energy Agency, 2014)

According to the International Energy Agency, a power system shall enclose the whole value chain. That means laws, rules, regulations and institutional and market arrangements related to the electricity sector operation and development as well as end-use are included in a power system definition.

For the purpose of maintaining energy security in the electricity sector, the countries must possess well-functioning markets and issue policies that allow efficient, timely and innovative operations on those markets.

Distributed generation is a way to enhance energy security, since it replaces the conventional vertical model of electricity producer to consumer to make a more dynamic one, where the consumer can also produce its own energy and moreover become an active member of the grid, also supplying energy when it is possible and necessary which involves also new challenges for the transmission system operators.

An adequate regulatory frame that allows the integration of all the small players in a fare way when competing against the big generation companies is necessary is fundamental for the adequacy on generation and consumption in the electricity sector.

The integration of energy markets within a region is a basic measure to allow electricity flows from excess generation entities to other ones with excess electricity demand, phenomena that also implies economical exchanges for the traded electrical energy. This integration represents a major change for the national transmission system operators, since they need to exchange energy with other operators from many other countries.

Efficiency and the integration of renewable energies play a very important role in the new international electricity regime, because renewable energy, being unforeseeable, pushes the operators to react almost immediately to sudden changes in the supply of energy from these sources.

All these factors must be taken into account when establishing new policies regarding electricity security.

2.2. Energy security in Europe

The European Union is highly dependent on energy sources from foreign countries. In terms of primary sources, the EU imports 53% of the energy it consumes (European Commission, 2014). Since Europe lacks enough reservoirs of conventional sources and the renewable energy technologies are nowadays not enough to meet its energy needs, it has to import most of its energy from different countries and this rely on imports puts the European Union in a risky situation in terms of energy security. Figure 4 shows the actual situation of energy dependency for member countries of the EU in total primary energy supply (TPES).

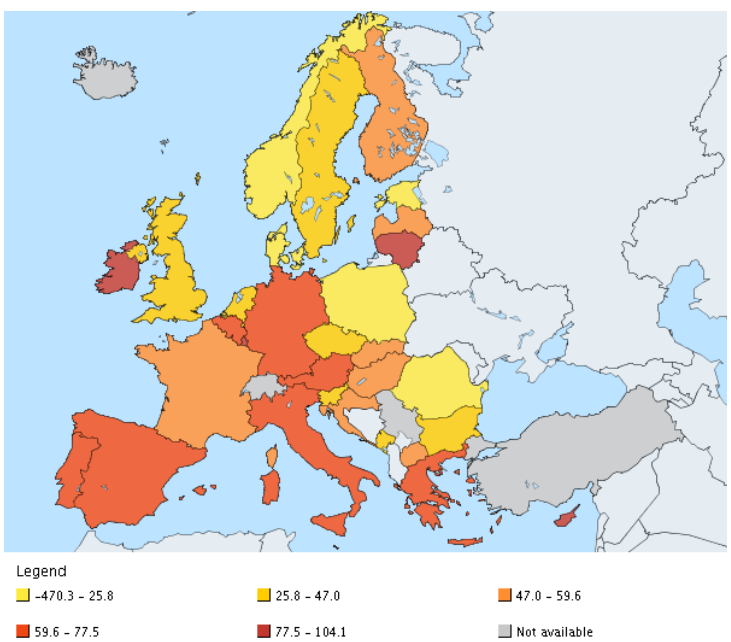

Figure 5 Energy dependence in Europe 2013 (%) (Eurostat, 2013)

Most of the electricity that is produced in Europe is derived from the use of conventional fuels. Solid fuels constitute 27.4% of the power mix in Europe, while gas is 18.7% of the total; from these quantities, 25.6% of the solid fuels and 65.8% of gas are imported from outside the European Union (European Commission, 2014). These numbers differ significantly among member states, but the tendency on dependence is generalized.

Many strategies, depending on the nation that applies them, can be and have been implemented to enhance energy security, such as diversification of sources and supplies, integration of markets, interconnections, storage facilities, etc. But, in spite of the current measures taken by the European Union, the tendency of depending on other countries in terms of energy will continue in the long-term and, in fact, the importations will be increased in the upcoming years in absolute numbers.

The only way for the European Union to reduce its energy dependency on foreign countries is by maximizing its use of local energy sources. In order to achieve that objective and considering that there are not enough conventional sources of energy in the continent, only the promotion of renewable energy as well as an integrated grid in the union can lead Europe to achieve energy independence and by doing so, assuring energy security.

From the 28 countries in the European Union to-date, the electricity production is concentrated mostly, 65.55%, in five countries; Germany, France, the United Kingdom, Italy and Spain, as it can be seen in figure 5. These countries represent also the largest economies within the member states of the Union.

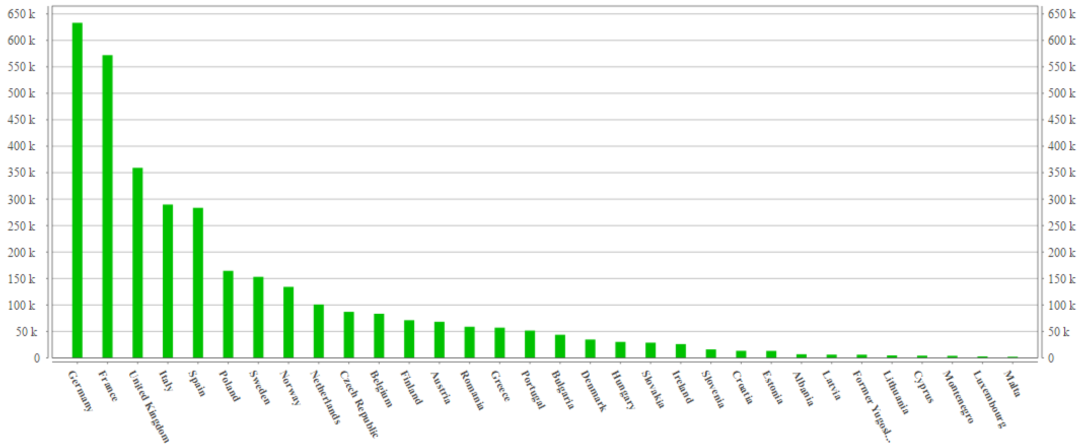

Figure 6 Total gross electricity generation (GWh) (Eurostat, 2013)

For the present study, the countries to be analyzed will be Spain, Germany and France. By these means, a total of 45.65% of the European electricity generation will be covered. It happens to be that these three countries differ drastically one from each other in terms of energy dependence and their electricity generation mix.

2.3 Spain

Being the fifth largest energy consumer in Europe, Spain has a dependence on imports to meet its energy needs in terms of primary sources of 70.5 % (Eurostat, 2013), due to its virtually lack of production of liquid fuels and natural gas. That means that this state relies highly on other countries' supplies to assure its energy requirements, situation which, independently of the price of those supplies, represents a risk for the national energy security. Several measures have been taken by the Spanish government to ensure diversity of supply, such as limiting the total percentage amount of oil and gas from a single country, but the dependence, in general terms, is still there.

Fossil fuels, nuclear and renewable sources represent the primary energy forms required to generate electricity in Spain. The mix of energy relying on imports is composed by combined cycle, coal, nuclear and fuel-and-gas power plants. They together represent 43.72 % of the total installed capacity of the country (Red Eléctrica de España, 2014) and, with the exception of the coal power plants, all the other fuels come represent importations from foreign countries.

Nevertheless, Spain has an important presence of installed capacity of renewable energies, one of the largest in Europe and in the world. For instance, in 2014, renewable energies covered 42.8 % of the total production (Red Eléctrica de España, 2014). But, despite the fact that the country has enviable conditions compared to other states in the region, Spain has not increased considerably its renewable energy capacity during the last years, and actually, it has implemented retroactive measures that have stopped the development of new renewable energy technologies.

The nuclear power in Spain is fundamental to meet the energy needs of the country - almost 23% for the national demand during 2014, so a policy to pull-out this technology is not considered in the Spanish agenda.

2.4 Germany

On the other hand, Germany, the largest economy and also the largest energy producer and consumer in Europe, has made drastic changes to its energy laws, increasing the presence of renewables and improving energy efficiency. These two aspects are the pillars of the "Energiewende", a philosophy that Germany is following in order to become an energyindependent country, free of nuclear power plants and relying instead mostly in renewable energy. By year 2022, the German government will shut down the last nuclear power plant so, considering that for year 2014 this technology provided 16.49 of the total energy generation of this nation, that goal can be considered as very ambitious. In order to do so, the country has established a path that has been followed with engagement, such as the renewable energy act (EEG), a law pretended to enhance the power energy market allowing investments in renewable energies without asking the power companies either if they wanted to accept it or not; it was in fact a historical measure, imposed actually against the power companies (Scheer, 2011).

But today, coal is still Germany’s most abundant indigenous energy resource (U.S. Energy Information Administration, 2012). For the year 2014, coal, both brown and hard, accounted 43.17% of the total electricity generation of the country (Fraunhofer Institut, 2015). Even though, the country possess the largest installed power of solar and wind energies in the country, and the potential is still growing each year.

2.5 France

For its part, France has a very particular power mix in the continent and in the world. The most important source of electricity in the country is nuclear power; for year 2014 it provided 77% of the total energy production in the country (Réseau de transport d’électricité, 2015). These numbers place France as the second largest producer of nuclear power in the world. But, in spite of these figures, the nation experiments a dependency on other countries to supply the fuel needed for the operation of the nuclear power plants it possesses.

France, as well as the other two countries, has a very low production of oil and gas compared to its needs, so they need to import the rest they require. Because of this reason, the country has established a policy of diversification to avoid a dependency on a reduced number of suppliers. The production of electricity from fossil fuels has decreased during the recent years, while, thanks to recently established long-term policies, the support to renewables has resulted in an increase of the installed power of these technologies. For its part, energy production from nuclear power will be reduced from 75% to 50% of the total electricity production by year 2025 (Assemblée nationale, 2014).

3. The European power system

Nowadays, most of the electricity produced in Europe comes from fossil fuels. There is exactly where the problem of energy security lies in. The second source of energy in the continent is nuclear power and renewables come in the third place, with hydropower being the most important technology of this kind.

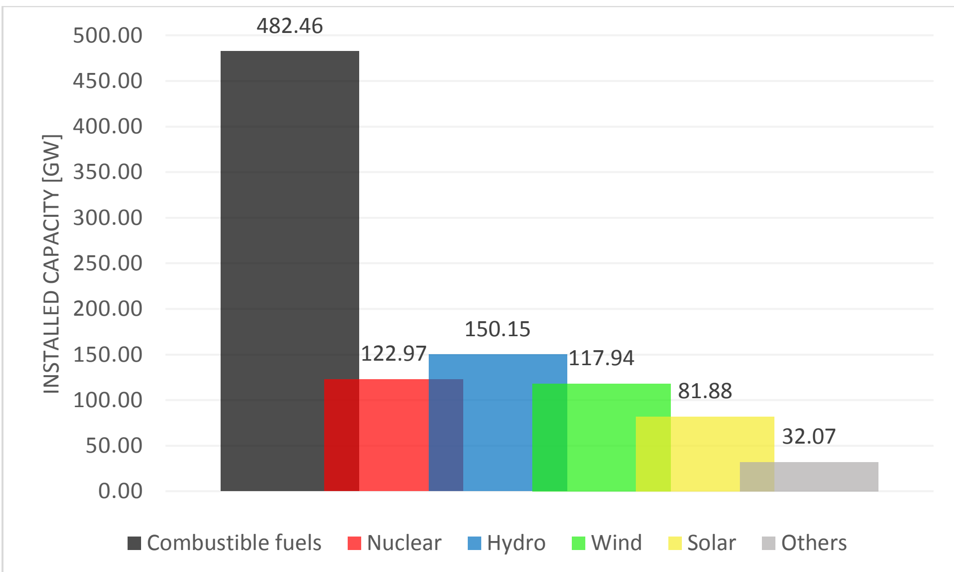

Figure 7 Installed capacity in Europe 2013

For the end of year 2013, as it is shown in figure 6, most of the installed power in the continent depend on fossil fuels. That is understandable considering that the largest economies rely on either gas or coal to fulfill their energy needs. The total capacity of the European Union was 987,461 MW, which is 3.5% more compared to year 2012 (Eurostat, 2015).

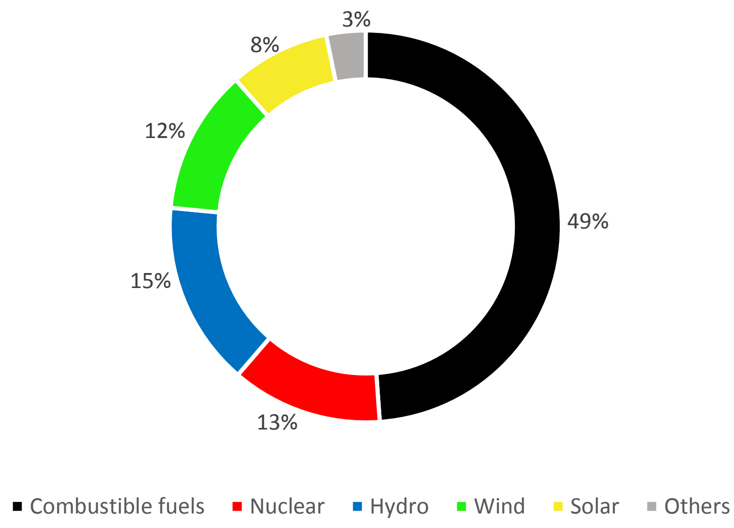

Figure 8 Installed electrical capacity in Europe 2013 (Eurostat, 2015)

About energy production, since the crisis of 2008 with the exception of 2011, the European Union has suffered a decrease in electricity generation every year (Eurostat, 2015). In year 2013, the net electricity production was 3.1 million of GWh, which represents a decrease of about 1% compared to the previous year. Figure 8 shows the percentages of production of electricity for this year. In the figure, the dominance of combustible fuels and nuclear power in the total mix in net terms is remarkable.

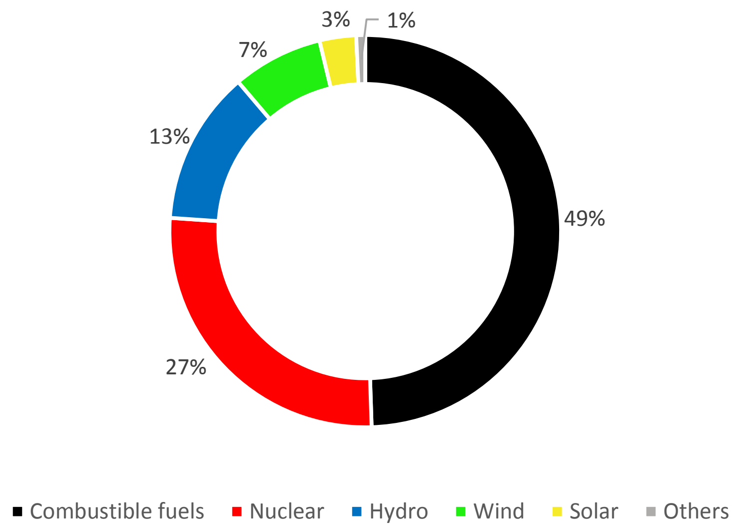

Figure 9 Net electricity generation for year 2013, EU-28 (Eurostat, 2015)

An increase in installed power at the same time that the production is decreasing constantly is understandable considering the expansion of the renewables. Since the capacity factors of the renewable technologies is lower than conventional fuels, a larger installed capacity is required for fulfilling the same needs.

Comparing percentages of installed power and electricity production in the European Union, it can be seen how important has been nuclear power for supplying energy, since with only 13% of the installed power, it contributed with 27% of the electricity for year 2013. The reliability of this technology is the characteristic that will allow it to continue being an important part of the European power mix for many years.

3.2. Spain

Spain has a total installed power of 102.26 GW, which are composed as follows:

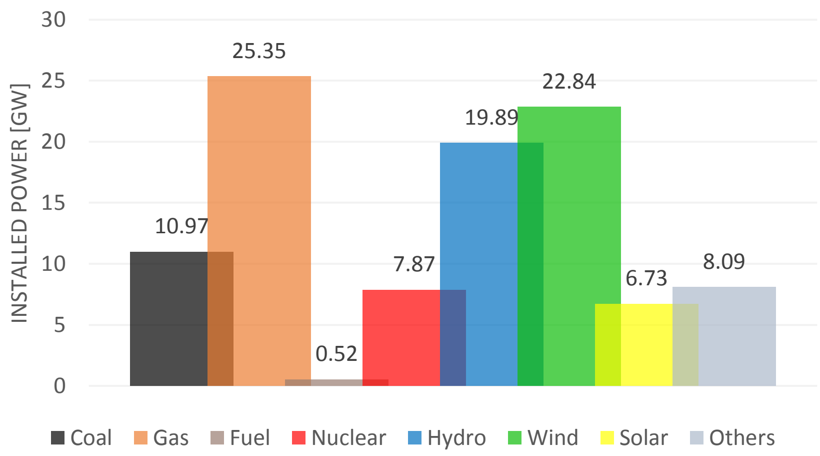

Figure 10 Installed power in Spain 2014 (Red Eléctrica de España, 2014)

In the percentages shown in figure 10, it can be observed that the country relies mostly in gas and wind for fulfilling its energy needs, but hydropower is also important for the country.

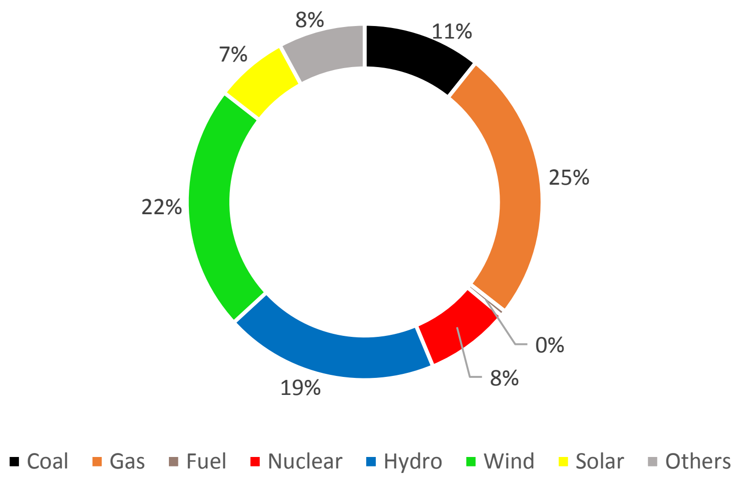

Figure 11 Percentages of the Spanish power system mix

The electricity production in Spain was led by nuclear energy followed by wind production as it can be observed in the next figure:

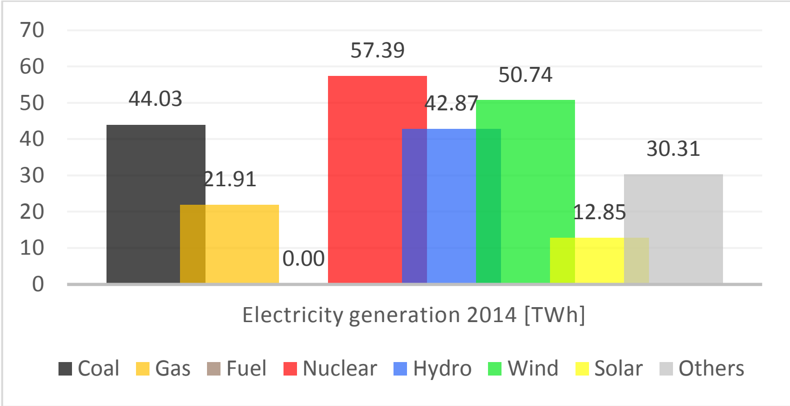

Figure 12 Electricity production in Spain in 2014 (Red Eléctrica de España, 2014)

The country has had the most important presence of electricity coming from wind in the continent, partially due to the favorable conditions for the development and operation of this technology compared to its neighbors; by itself, wind represented the largest renewable energy contribution for the studied countries, despite the fact that Spain has not the largest installations among them. The presence of nuclear energy is still a fundamental piece of the Spanish power mix and in the future it will continue to represent one of the main sources of energy for the country. Hydro-electricity plays also a central role for fulfilling the country's energy needs.

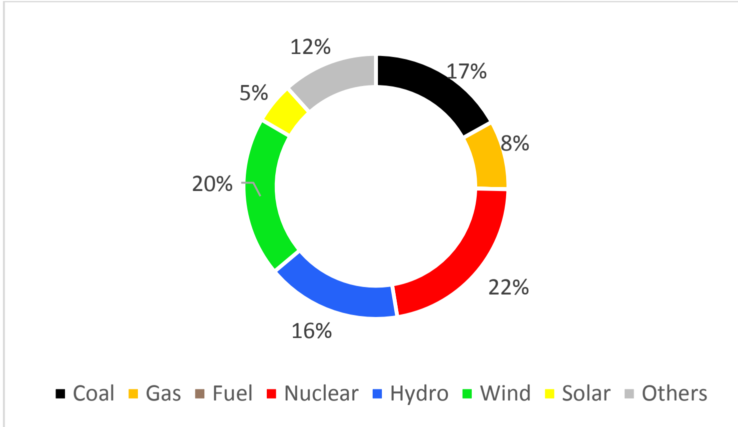

Figure 13 Percentages of the electricity production in Spain 2014

One of the particularities of the Spanish power system is that, despite the fact that the country has one of the most favorable locations in the continent for the development and installation of solar technologies, either thermal or photovoltaic, during the last years there has not been an improvement in the installations of any of these kinds in the country. This phenomena will be studied more deeply in the following chapters.

3.3. France

France has, after the USA, the largest amount of installed nuclear power in the world. The country relies mostly on this technology to fulfill its needs, but hydropower plays also a central role in the country's electrical energy mix and is, by itself, approximately the same quantity as all the installed capacity of conventional fuels in this country. This installed capacity can be observed in the next chart:

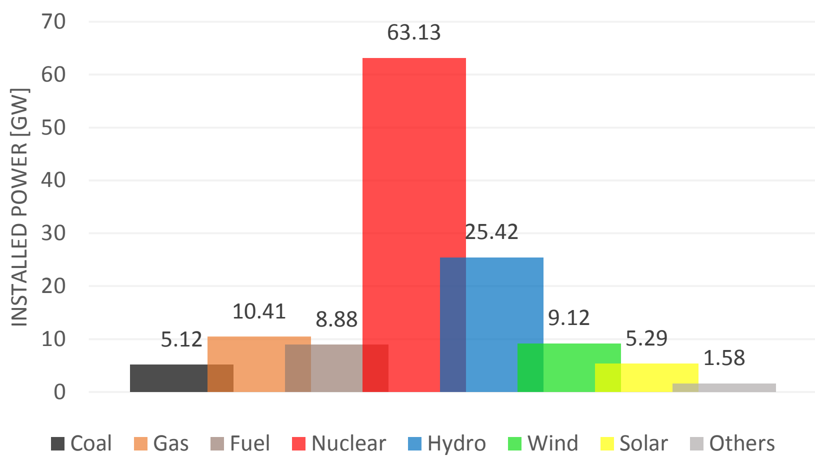

Figure 14 Installed power in France 2014 (Réseau de transport d'électricité, 2015)

The installed capacity in France is led, as already stated, by nuclear energy followed by hydroelectric plants. Hydro power in France is the most important source of this kind of technology in Europe. For this country, the hydraulic sources represent the most important renewable source of energy, since the development of this technology was chosen by the government in the last century to adapt the national power mix to the consumption needs of the country, since this technology, besides being renewable, is able to start almost immediately compared to other technologies and, when there exists the possibility of pumping, it can also be used as a way to storage energy during low-cost periods of time during the day.

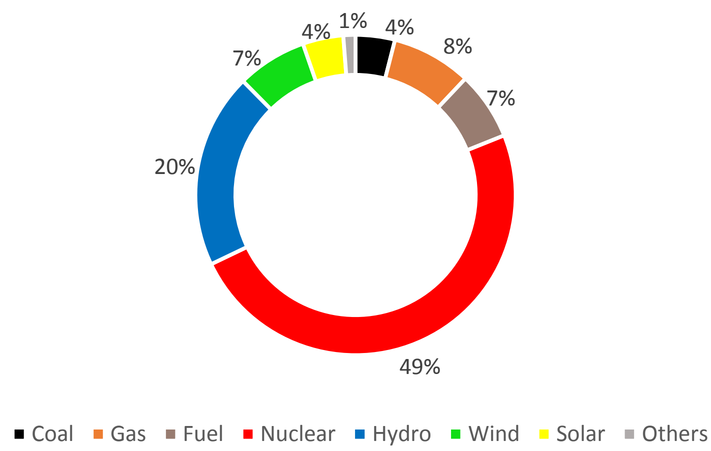

Figure 15 Percentages of the installed power in France 2014

The electricity production in France was coming mostly from nuclear power, 77%, one of the highest ratios in the world. Since the nuclear technology is highly reliable, it can be running for long periods of time and, when neighbor countries require energy, France is able to deliver as much energy as those countries need, since the country has almost always enough energy to fulfill its own energy needs. This has been a good business model for the French companies, both producers and transmission system operators, but as, it will be studied in the following chapters, the situation in the upcoming years will change drastically to the hitherto model, representing a need of adaptation for the French power mix and system operators.

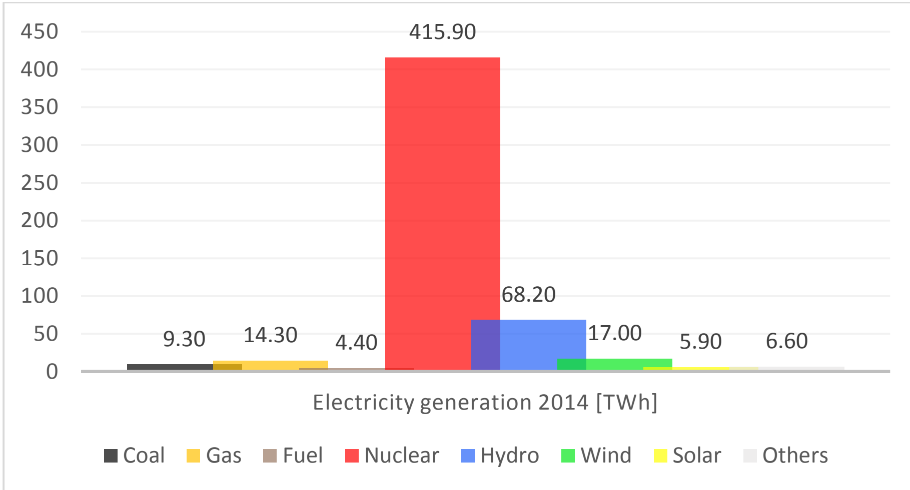

Figure 16 Electricity production in France in 2014 (Réseau de transport d'électricité, 2015)

The production of electricity from renewable sources has not been so relevant for the country in the last years with the only exception of hydroelectric power, which has been for the country the way to adapt the consumption to the constant production of electricity coming from nuclear power plants. The curve of daily demand of the country is, as it can be deduced from the next chart, constant during large periods of time due to the nuclear energy produced in the country, being adapted, when needed, by hydro plants and gas plans. In the recent years, is when more renewable energies have been integrated to the power system, but still much lower than the neighbor countries, specifically the cases of Spain and Germany.

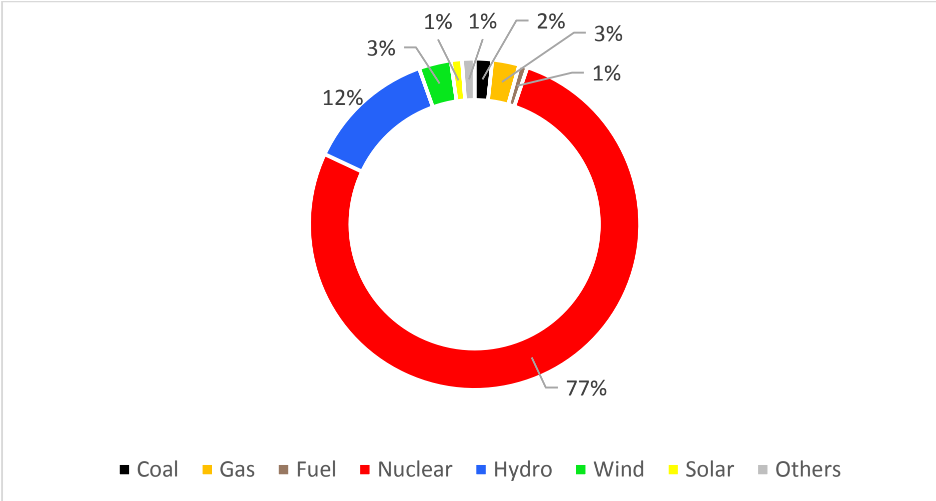

Figure 17 Percentages of the electricity production in France 2014

With the actual model of the power system of France, the policies of the government following a new model integrating new renewable energy technologies to the system will be harder than the cases of Spain or Germany, for example, since the country is the second largest consumer of energy in the continent and shutting out the number of power plants that the country possesses would represent a major challenge for the country, both in terms of regulation and technologically, but, as it will be studied in the following chapters, the government has been committed to change the actual scenario to a new one according to the European objectives and in a relatively short period of time.

3.4. Germany

Germany has one of the most diversified power systems in the continent, integrating not only important fossil fuel plants, but also the most important renewable energy installed capacity in Europe in absolute terms. The hitherto installed capacity in the country is shown in the following figure:

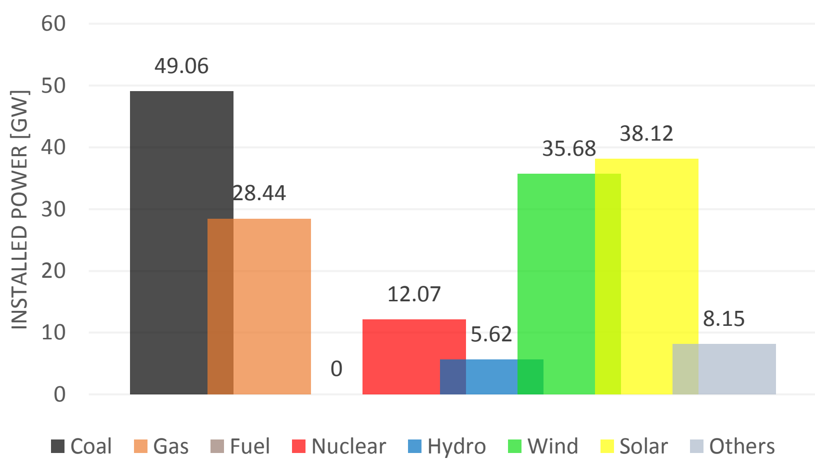

Figure 18 Installed power in Germany 2014 (Fraunhofer-Institut für Solare Energiesysteme, 2015)

Until now, the largest installed capacity of the country is of fossil fuel plants, specifically of coal, both lignite and hard coal. The other type of fossil power plants that the country possesses is of gas, which are more important than the nuclear power installed in the country. But, it is quite interesting the amount of renewable energies installed capacity in the country. Germany relies highly on solar power, practically all photovoltaic. This fact is even more interesting when the weather conditions are compared to the other studied countries, since Germany has the worst weather conditions among them in terms of solar radiation.

Nevertheless, this nation has committed itself to achieve high goals of integration of renewable energies since several years ago and it can be seen in the today energy production.

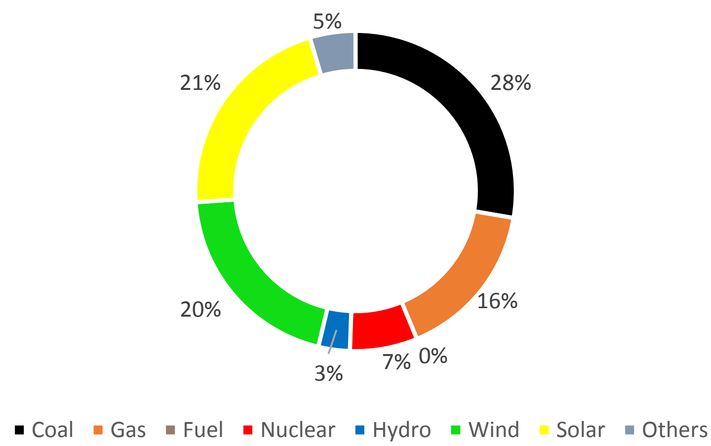

Figure 19 Percentages of the installed power in Germany 2014

Despite the fact that this country has a huge installed power depending on renewable sources, the country has not the best conditions neither for wind nor solar energy, which means that the production of these technologies is not so high in a year compared to other forms of energy, such as coal or nuclear energy. For year 2014, the energy production of the country was composed in the following way:

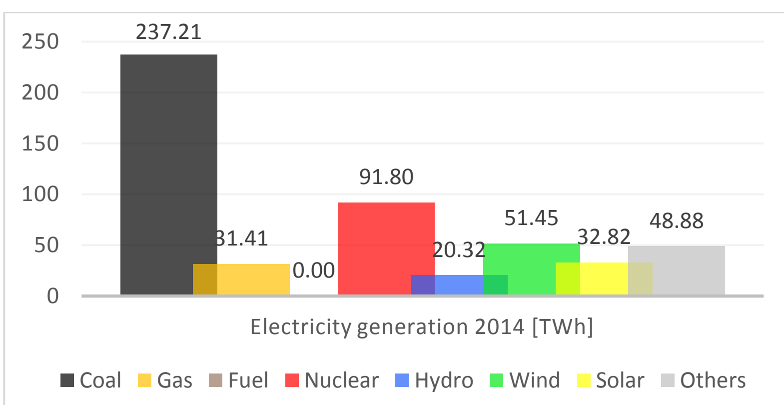

Figure 20 Electricity production in Germany in 2014 (Fraunhofer-Institut für Solare Energiesysteme, 2015)

If these figures are put in a percentage base, it can be seen both the reliance of the country on fossil fuels, which accounted by almost the half of the country for year 2014 and also the importance of nuclear power, 18%. This figure is particularly important since, as it will be studied in the following chapter, the country pretends to get rid of it by year 2022, which mean than a new challenge is emerging for the country and it is to adapt the system to be able to keep reliability and continuity of supply lacking this form of technology.

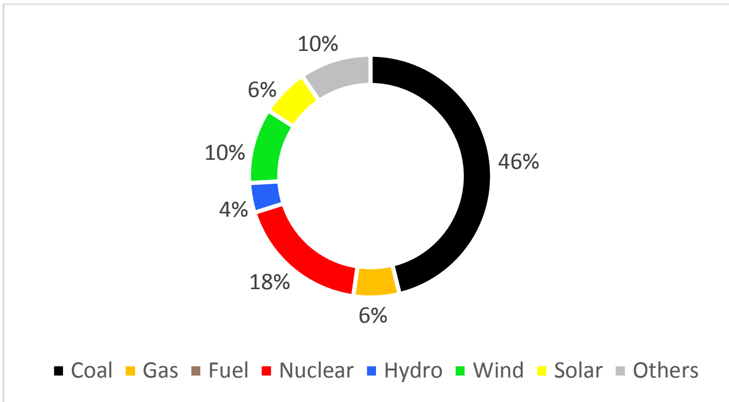

Figure 21 Percentage of the electricity produced in Germany in 2014

But is not only the phase out of the nuclear power plants of the country that will be a major concern for Germany in the upcoming years, since, in order to achieve GHG emissions targets according to the EU objectives, the country will also decrease the amount of energy coming from coal power plants, which mean that even more base electricity production of the country will be cut in the following years, so a proper integration of renewable energies to the system will be fundamental fort ensuring energy supply for the country in the future.

4. The European power system towards 2030

The European strategy in a horizon towards 2030 in what concerns to renewable energies, sets a target of at least 27% of renewable energy consumed in the EU. (European Commission, 2014). But, unlike the 2020 strategy, the objectives are not binding to the member states, which mean that the 27% share of renewables will be accounted for all the European Union as a whole and not individually for every nation in the union.

The member countries have independence to determine which are the best fitting options for determining the structure of the corresponding national energy systems as well as the percentage of renewable energies forming part of it. The current strategy will be reviewed in year 2020.

The European Union is expected to decrease its final energy consumption by year 2030 in a rate of 3%, but the electricity demand is expected to rise 12% between 2010 and 2030 due to the economic growth, increasing use of heat pumps and electro mobility (European Commission, 2014).

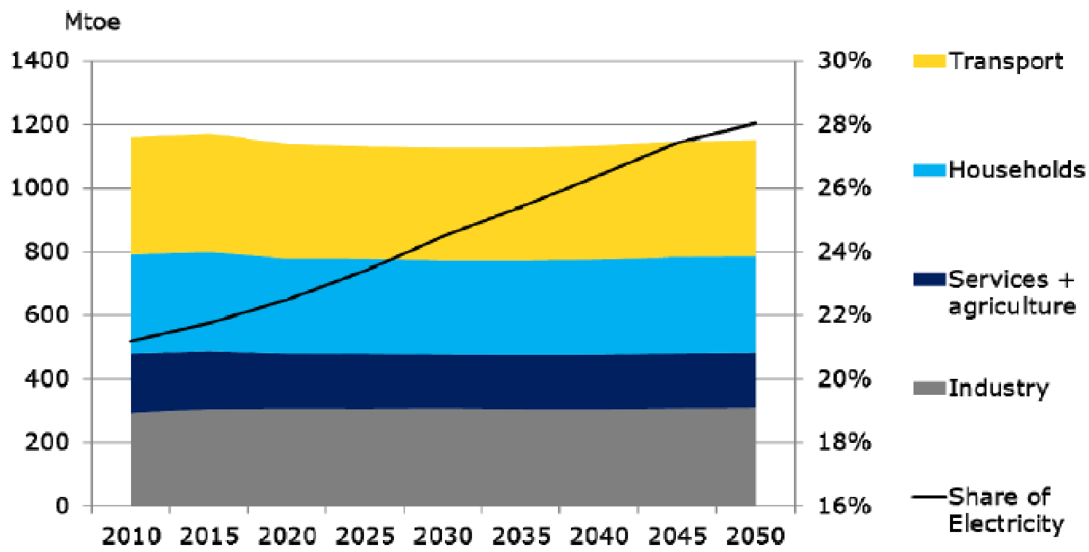

Figure 22 EU-28 Final energy consumption by sector and share of electricity (European Commission, 2014)

Another priority of the European Union is the interconnection of the electrical network in order to achieve larger quantities of transferred power. The objective of the EU is to achieve a 15% of power interconnections by 2030.

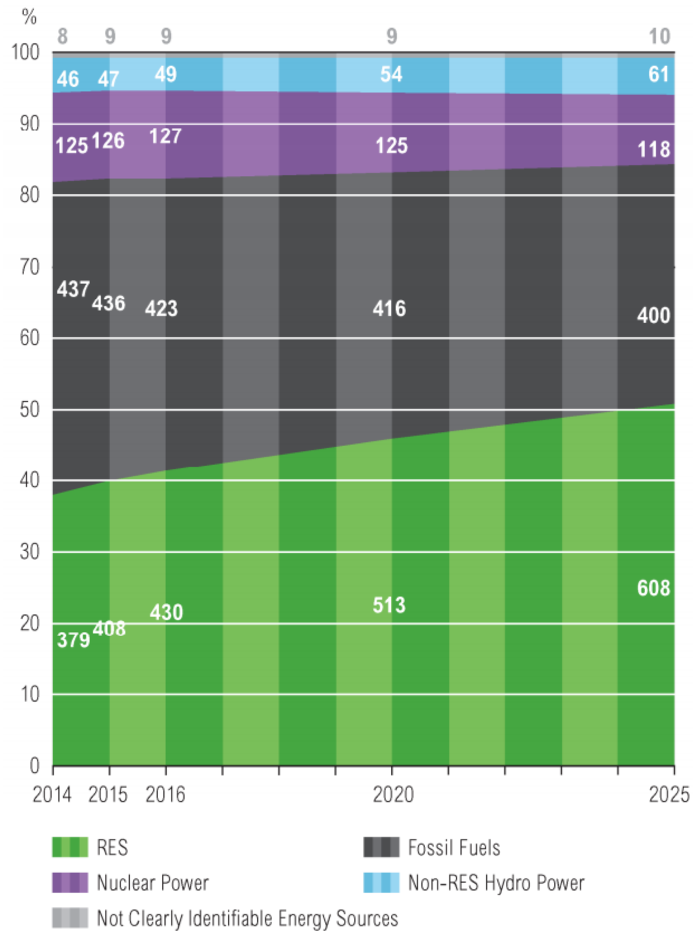

Figure 23 Total net generation capacity breakdown per fuel type (all years; January 7p.m.) (ENTSO-E, 2014)

3.1. Germany

Germany has been working in long term energy policies since several years in order to achieve energy independence. All these efforts have led to the creation of the *Energiewende* or Energy Transition, a philosophy that is related to a responsible way of creating energy policies and apply them. The *Energiewende* has two pillars on which all the policies rely on: renewable energies and efficiency (Bundesministerium für Wirtschaft und Energie, 2014).

The future of the German power system will have a major change compared to the one of today, and that is that by year 2022, all the nuclear power plants in the country will be phased out. Considering that today, the energy coming from nuclear sources is about 28% of the total, this strategy is a major concern for the country energy strategies. The plans of the government consist on pushing through renewable technologies in energy production and still relying on conventional fuels for several years, but decreasing the presence of them in the total power mix year after year.

Different reasons have taken the country to take drastic measures in order to achieve energy independence as soon as possible, and they include, among others, not only environmental matters but also economic and political causes.

The policies on energy have been gathered in the Germany’s Renewable Energy Act (EEG), a law that specify that renewable technologies have priority over the conventional ones on the grid and also guarantees that the investors on renewables receive sufficient compensation independently of electricity prices on the power exchange (Heinrich Böll Stiftung, 2014).

The EEG 2014 has the purpose of enabling the energy supply to develop in a sustainable manner, reduce the economic costs, conserve fossil energy resources and promote the further development of technologies to generate electricity from renewable sources (Gesetz für den Ausbau erneuerbarer Energien, 2014).

The ultimate objective of the act, is to increase the presence of renewable energies in the electricity consumption to 80% by year 2050. The intermediate objectives are 40 to 45% by year 2025 and 55 to 60% by year 2035, which would mean about 50% for year 2030. By year 2030, the green-house-gas emissions are intended to be reduced by 55% compared to year

1990, the share of renewables in the final energy consumption is intended to be 30% and the reduction of primary energy consumption objective is 50%.

The following specific set of measures are contemplated in the EEG 2014 towards year 2030:

- Increase of the wind onshore capacity by 2500 MW a year
- Increase of the wind offshore capacity to 15000 MW by year 2030
- Increase of the solar photovoltaic capacity by 2500 MW a year
- Increase of the installed capacity of biomass by 100 MW a year

Specific objectives of the country related to conventional energy technologies, such as gas and coal, are not as clearly established as the renewable ones, but in the upcoming years and according to the government's political speech, the country will increase its gas power plants while reducing the power coming from coal. Historically, Germany's government has had a strong relation with coal producers, since this source has been essential for the development of the steel industry in the country. Since the coal produced within the country is nowadays unable to compete against the imported one, the local coal mining is subsidized. Despite the fact that the subsides are supposed to eventually come to an end in the future, they are secured until year 2019 by the Federal Government and the government of North-Rhine-Westphalia, one of the most important producer states in the country.

For its part, gas will play a key role in the energy mix of the German's power mix in the upcoming decades. This technology will be fundamental in the country to compensate the variation on renewable energies. Additionally, the CO2 emissions derived from the combustion of gas are much lower than those coming from coal, the reason why gas is considered as a green fossil fuel (Scheer, 2011). But Germany has a particularity related to its very widespread use of gas, and it is that the country lacks gas reservoirs necessary to fulfill its energy needs, being able to cover only about 10% of the national consumption. This means that the country will rely in the future on imports to cover its gas needs. The main measures that the federal government is taking in order to assure the energy security on gas supply are the diversification of supply sources and trade routes, the establishment of stable relationships with supply countries, long-term supply contracts and a highly reliable supply infrastructure which includes underground storage facilities (Bundesministerium für Wirtschaft und Energie, 2014). In the future, it is intended that natural gas, biogas as well as hydrogen and synthetic methane produced from renewable energies integrate a composite system forming a huge energy source.

Cogeneration is another conventional technology that will be boosted by Germany in the upcoming years, because of its higher efficiency compared to separate power and heat generation.

Other renewable technologies, like geothermal energy, will not play a considerable role in the German power mix in the upcoming years. Geothermal energy for example, is expected only to account about 1 GW by year 2030 (Deutsches Zentrum für Luft- und Raumfahrt e.V., 2012)

According to the previously described strategies, in year 2030 and according to the current power mix, the power system would be approximately structured as follows:

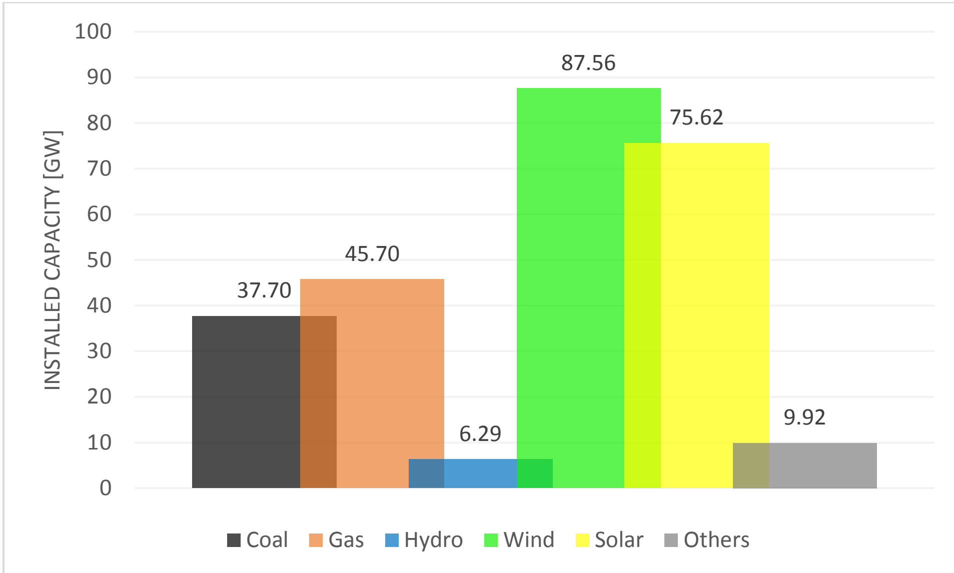

Figure 24 Installed power in Germany projection 2030

The country will depend by that time mostly on renewable energies to fulfill its electricity needs and it will be follow the line of renewables until achieving the goal of 80% by year 2050.

4.2. France

The French government is still working on a national plan according to the European objectives for 2030. Until now, the ministry of ecology, sustainable development and energy has presented a project of law to the national assembly of France in order to establish the path to be followed by the nation in energy terms. The term that the French government has adopted for the set of policies and measures in the energy field is “energy transition”.

The main aim of the country with the energy transition policies is to reinforce the energy independence of France and to fight against climate change. The general objectives of the project of law are the following:

- Reduction of greenhouse gases in 40% compared to year 1990
- Reduction of the final energy consumption in 20% compared to year 2012
- Reduction of 30% of fossil fuels in primary energy consumption compared to year 2012
- Increase the presence of renewable energies to a 32% of the final energy consumption and 40% of the electricity production
- Decrease the nuclear power share to 50% of the electricity production towards 2025

(Ministère de l'Écologie, du Développement durable et de l’Énergie, 2015)

In order to achieve the main goals related to the French power system and the promotion of renewable energies, these concrete targets have been proposed:

- To at least double the share of renewable energies of the French energy model in 15 years
- To improve financial support
- To modernize the hydroelectricity framework
- To create jobs
- To bring to 32% the share of renewable energy in final consumption in 2030

(Ministère de l'Écologie, du Développement durable et de l’Énergie, 2015)

Whit these purposes in mind, according to the actual structure of the French power system, and considering that the proposed objectives are fulfilled, the power mix of the country would be composed as follows:

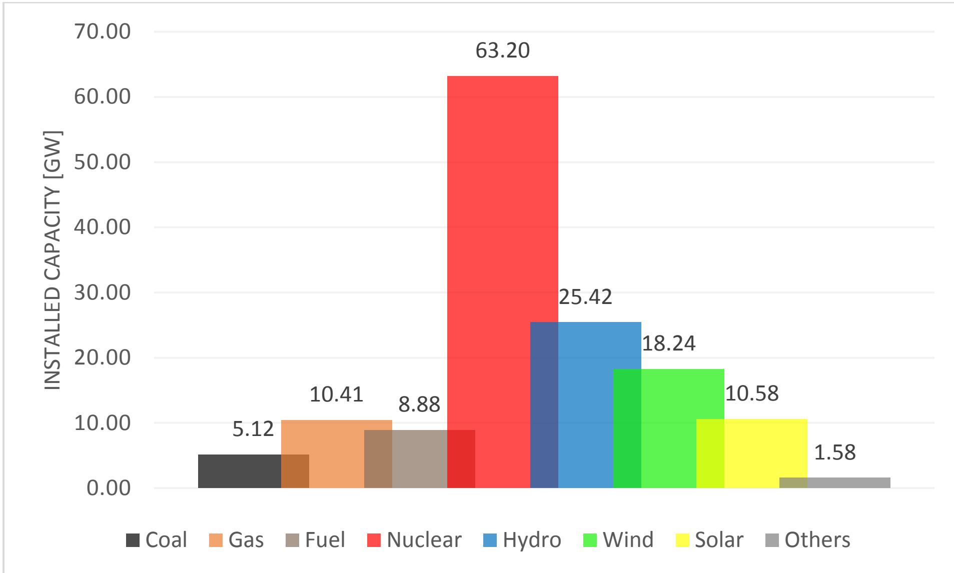

Figure 25 Installed power in France projection 2030

One of the central milestones of the French policies on energy is the one related to nuclear energy. Since most of the country relies nowadays on that technology, it seems logical to think that the government could not get rid of it as fast as the German case. Instead, the government has established a limitation for the nuclear power in the country and a transition to electricity from conventional forms of energy, as the time as solar and wind are boosted at a national level. Hydro will still play a central role in the France's power mix in the upcoming decades, being actually, as nowadays, the most important renewable source of energy in the country by year 2030.

4.3. Spain

By date, the Spanish government has not established yet a strategy further than year 2030. This country has been particularly hit by the global financial and financial crisis. The demand in 2013 is at 2005 level and in the upcoming years, there are not significant increases in the projections. In the best estimated scenario, the peak demand is expected to reach 55GW in January 2025 under severe conditions, and annually a growth of energy of 2% is forecasted (ENTSO-E, 2014).

Since the current power system in Spain has already one of the major shares of renewables within the European Union and the objectives towards 2030 are not binding at a national lever, a major effort from the government promoting the use of renewable technologies is not expected in the upcoming decade. The electrical companies are the entities that could contribute to the expansion of the installed capacity in the country with the purpose of obtaining profits from the energy production.

Since the scenarios in the Spanish power system future are uncertain, a moderate growth ratio with adequacy to fulfill the European objectives will be chosen based on the current national renewable energy action plan that contemplates the period from 2011 to 2020. During the upcoming years, the new installed power in the country is expected to be lead mostly by renewable energy technologies, particularly solar and onshore wind; additionally some hydro units are expected to be installed and, in order to achieve adequacy standards, thermal units would also be installed, all this leading to a national installed capacity 16% higher than today (ENTSO-E, 2014). Taking these parameters into account, the Spanish power system would have a structure as follows:

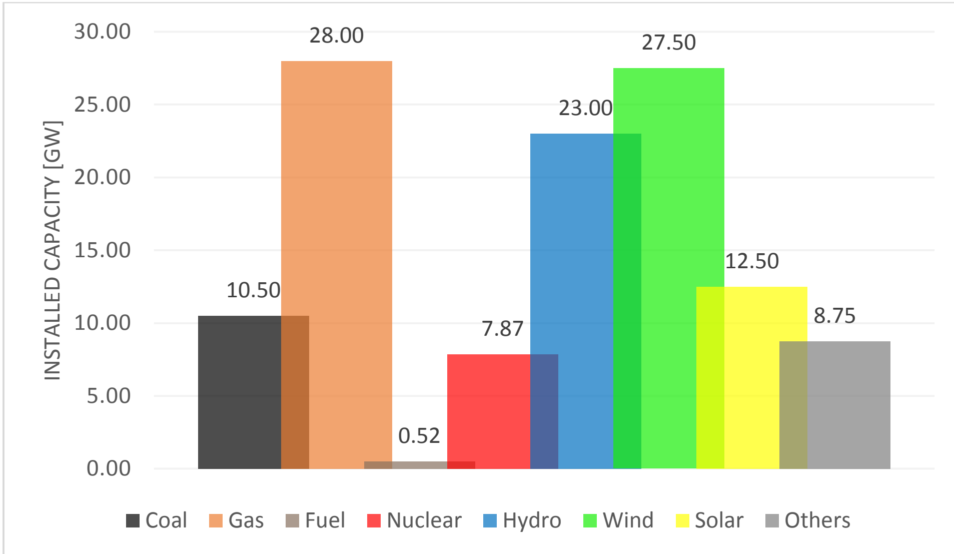

Figure 26 Installed power in Spain projection 2030

Since the government has not expressed any intention to reduce the nuclear power in the country and it also considers coal as an instrument to guarantee the supply of electricity in the country, so an important reduction in this form of energy is no expected either.

Contrasting with France and Germany, Spain has implemented a retroactive policy concerning a boost on the installed solar power in the country. Originally, the idea was to push through investments on solar panels, but in the first years, the boom in the technology reduced drastically the panels' prices and after the crisis of 2008, the demand of energy went down, increasing the amount of the economic deficit in the country. The original rates of support for the installed panels had to be reduced by the government, which took the investors to the uncertainty. Even though and since the production of electricity from renewable sources has a much higher ratio on its capacity factor in Spain than in the other studied countries, nowadays the electrical companies that want to invest in the country are doing it without any support of the government and paying taxes that exist only in Spain, like a tax on the use of the grid and support in case of failure of the system.

5. Electricity production from renewable energies

The production of electricity from renewable sources in the studied countries shows important differences among them. As it has been mentioned in the last chapters, the installed capacities differ drastically in the selected nations, but the electricity coming from those installation per installed unit does not follow the same pattern.

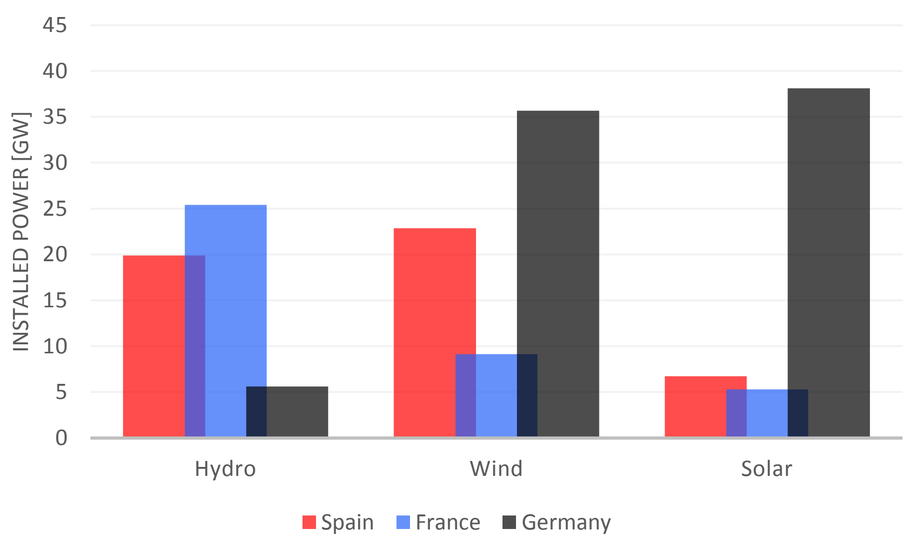

Figure 27 Installed power from renewable sources

Germany is the country that has the largest installed capacity among the studied countries in total, particularly in solar and wind technologies. Spain has the second largest installed capacities in wind and solar while France has the most important hydro energy resources. But, the production of electricity does not follow the same pattern as the installed capacity in these countries, as it can be seen in the next chart:

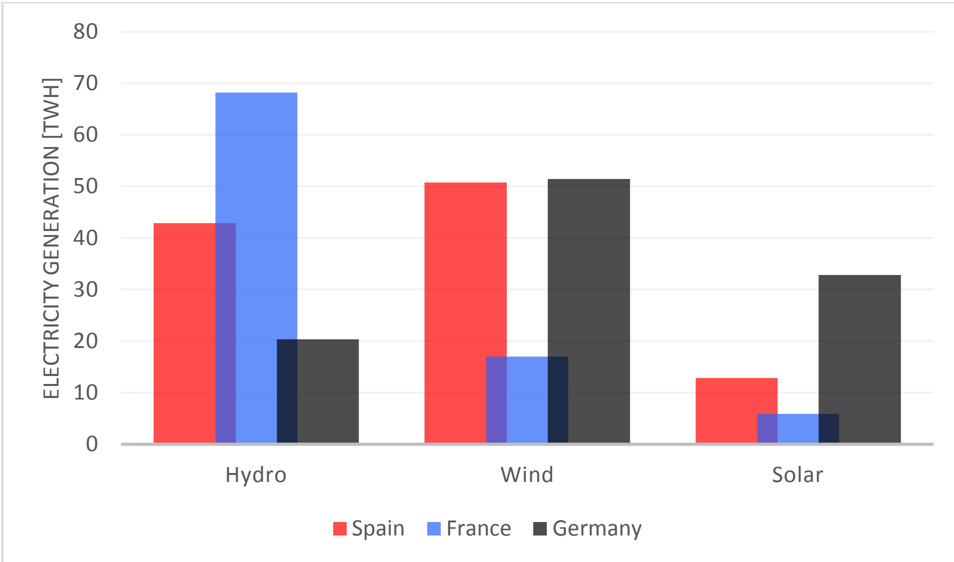

Figure 28 Electricity generation in 2014

It can be observed that, for example, the electricity production from wind in Spain is almost the same as the one in Germany, despite the fact that the installed capacity in Germany is higher. The production of electricity coming from solar sources in Germany is also lower proportionally than the installed power in the country.

5.1. Monthly production

The energy produced in the three countries for year 2014 monthly is presented in the following graphs:

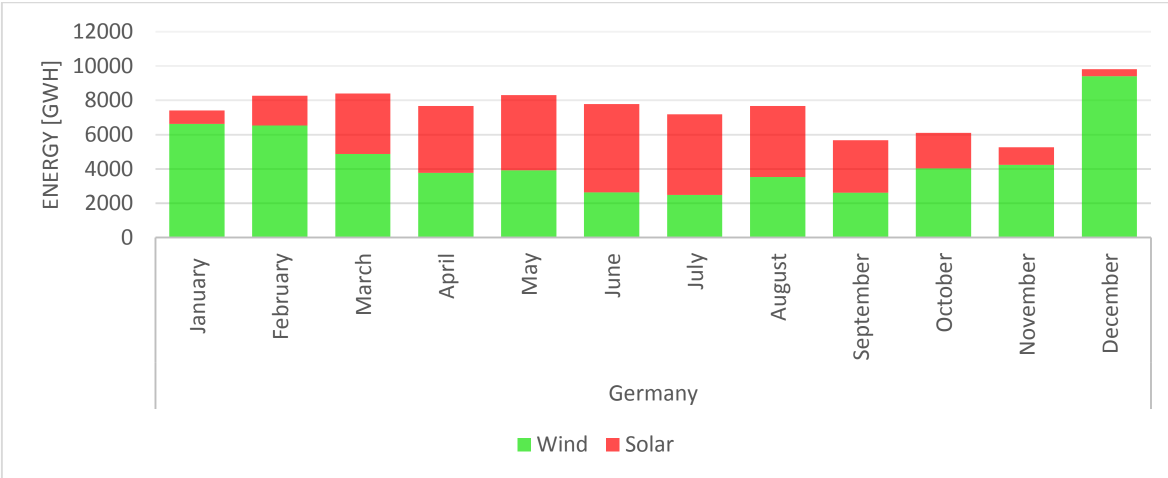

Figure 29 Monthly energy produced in Germany per month in 2014

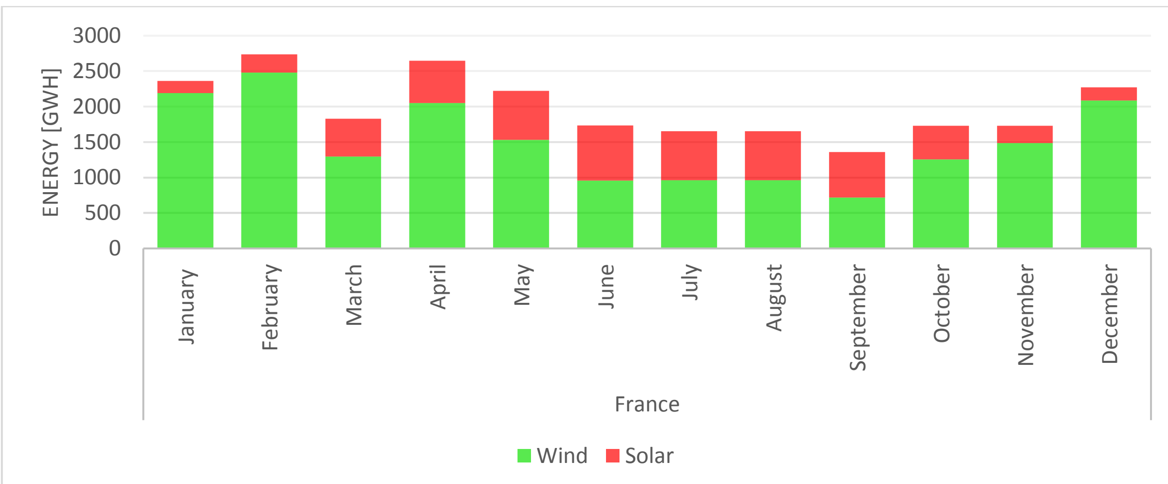

Figure 30 Monthly energy produced in France per month in 2014

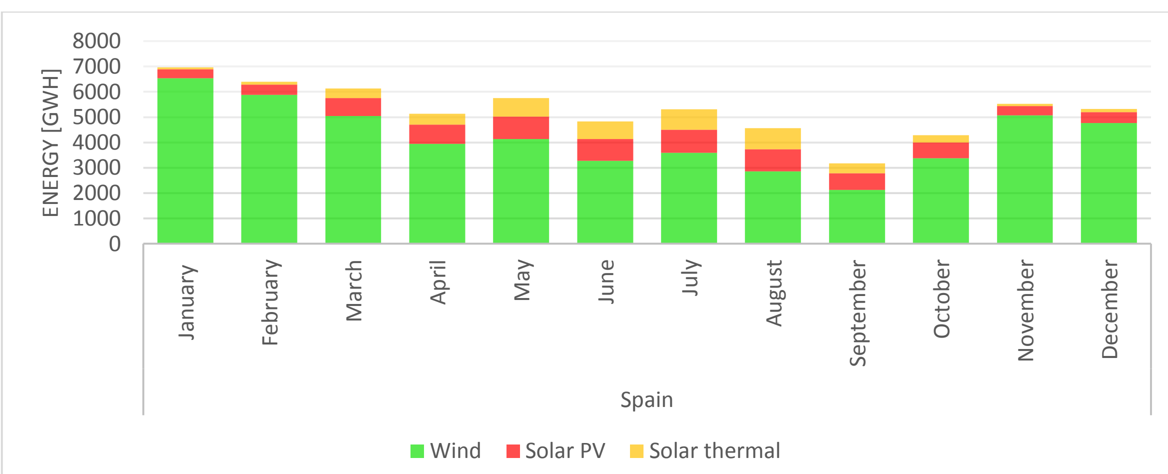

Figure 31 Monthly energy produced in Spain per month in 2014

From these charts it is observable that there exists a trend relating wind and solar electricity production and it is that they are approximately inversely proportional for the three countries but it is clearer to observe in the case of Germany. In general, in the winter months the energy produced from wind is higher than in summer, while, logically, the solar production is higher in summer than in winter.

For the particular case of Spain, where solar photovoltaic and solar thermal energies are shown in a separate way, it can be seen that the production from thermal solar is much less important in winter than the solar photovoltaic technology. That phenomena is understandable because of the necessary temperatures and the radiation amount for the technology to operate properly.

5.2. Capacity factors

The capacity factors are a measure to indicate the availability of a source in energy technologies, a fundamental measure when investing in a power plant because it affects directly the electricity production that a facility is available to produce.

If the capacity factors resulting from dividing the produced electricity by the installed power in the three studied countries are compared, the following charts come out for year 2014:

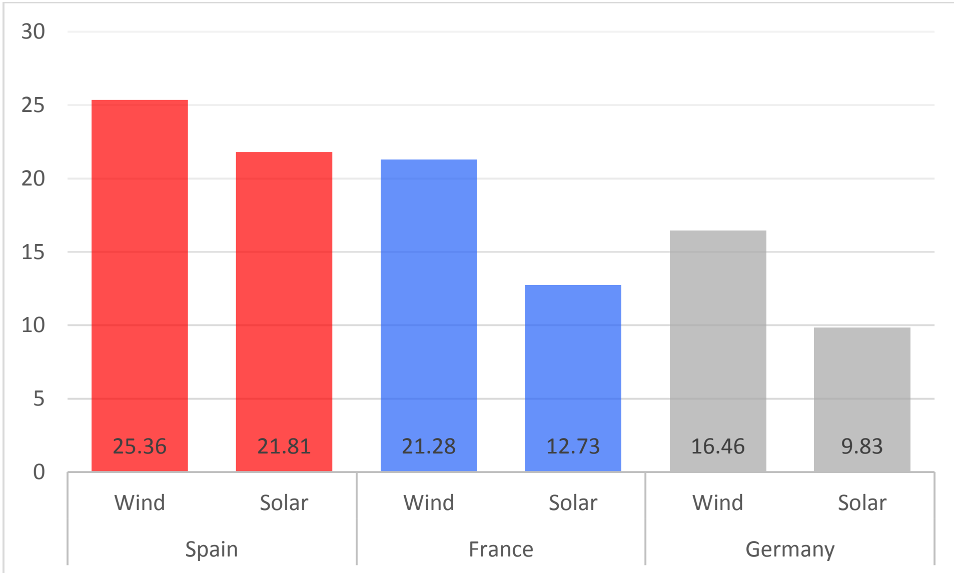

Figure 32 Capacity factors of the three countries in solar and wind power for year 2014

In the cases of both technologies, solar and wind, the capacity factors are higher in Spain and lower in the case of Germany. These figures are understandable considering the higher radiation that is received in the Iberian Peninsula compared to central Europe. The conditions of wind are also better in Spain and, because of this reason, is that the country has been the largest producer of electricity from wind technology in the last years in the European Union.

There is one particularity in the case of Spain, because this country counts with both photovoltaic and thermal solar installations. In order to analyze these technologies by separate, the capacity factors are the following:

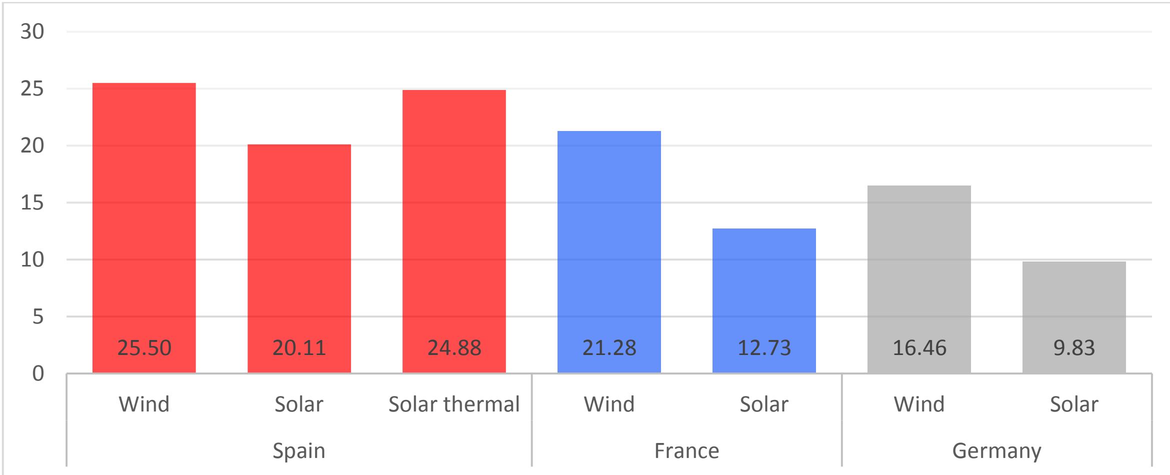

Figure 33 Capacity factors for year 2014

The solar thermal technology is then the second one with the highest capacity factor among the technologies studied. The main reason of this difference, is that solar thermal power is the only technology that allows energy storage, which means that is has a huge advantage since the lack of this characteristic is exactly the crucial weakness of most renewable technologies.

These figures mean, that, even when the investments are not compensated by the government in the production of electricity, a power plant installed in Spain would produce, depending in the technology, approximately the double amount of energy than if the plant was installed in Germany. Compared to other technologies, solar thermal energy in Spain presents a very unique characteristic, and it is that it is the only one capable of storing energy. It is particularly this property, the energy storage, which has been fundamental for the increase on the capacity factor in the technology. The next figure shows the historical evolution of the capacity factors for solar technologies in the three countries:

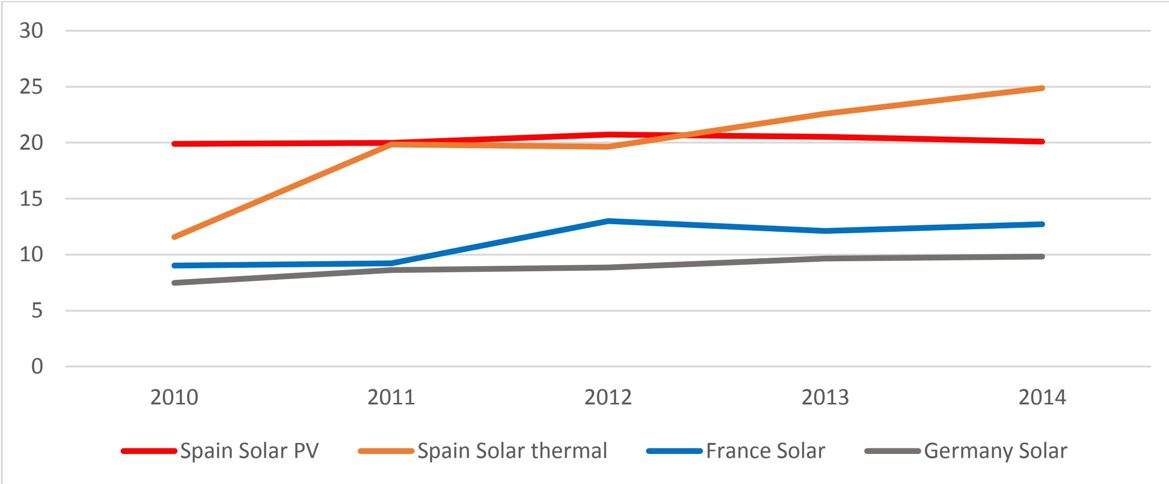

Figure 34 Evolution of capacity factors in solar energy

Solar thermal energy, together with increased solar field sizes and storage capacities, is expected to achieve a capacity factor of 45% in average by year 2030 (International Energy Agency, 2014).

Solar photovoltaic energy capacity factor evolution has different scenarios which are not so certain towards 2030, but an increase of about 5% is a moderate figure for this number (International Energy Agency, 2014).

By its part, wind energy is expected to present an increase in capacity factors between 26% and 31% on land and from 36% to 42% offshore towards 2050 (International Energy Agency, 2013).

With these figures, the capacity factors in the studied countries would seem as follows:

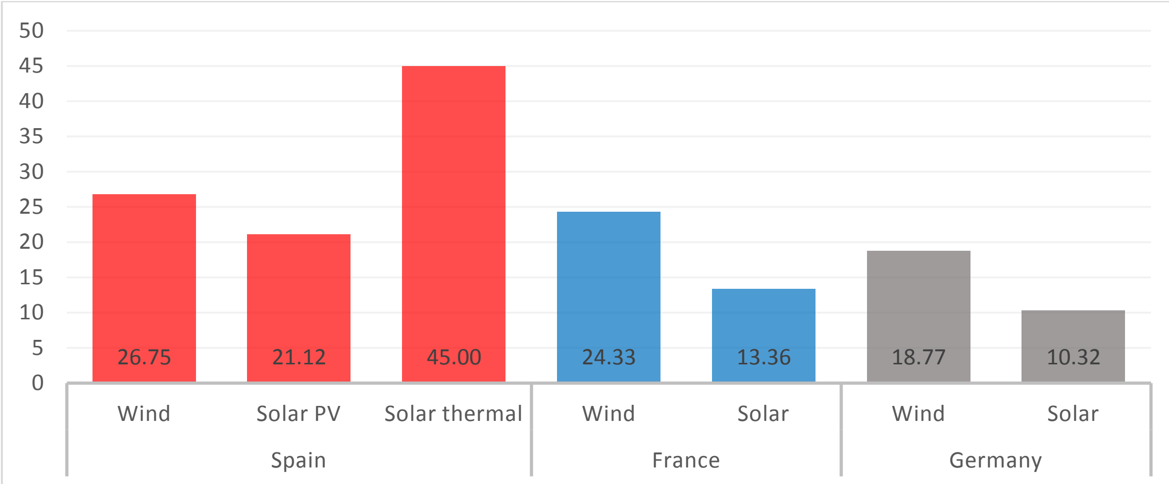

Figure 35 Capacity factors projection towards 2030

It can be seen that the solar thermal technology will in the future be the technology with the highest capacity factor among all the others. Nevertheless, since high temperatures are needed for the technology, only Spain may result in an adequate place for the installation of this kind of technology. That means that, even if the government, like it is nowadays, does not make important monetary contributions for the development of new plants, the technology by itself is a very interesting option for investors; it is expected that concentrated solar thermal technology covers by year 2050 11% of the global electricity mix (International Energy Agency, 2014).

6. Electrical interconnections

An electrical interconnected grid is fundamental for guaranteeing energy security in any electrical system, particularly in one with the characteristics of the European one, since the interstate integration of electrical grids give multiple advantages concerning operational security as well as energy trade (Häger, Rehtanz, & Voropai, 2014). An integrated system is able to improve the reliability of the electricity system, thus increase the quality of service and reduce power interruptions and productivity losses in the commercial and industrial sectors (European Commission, 2015). An integrated European electrical system may help the continent to reduce its dependency from other countries in energy terms due to a reduction on fuel imports and would at the same time reduce the need of installations to cover a higher peak generation capacity, since the plants of the integrated countries would operate at different times for different power needs.

Moreover, interconnections allow the grid to act as a storage facility, since the energy available in one part of the grid can be delivered to some other part immediately and, with a sufficient dimensioning, a complete integration of renewable technologies would be only possible by these means (Burger, 2012). Besides these advantages, an integrated electrical system would allow the producers to sell energy in international markets, so the competitiveness would also be boosted through international interconnections and an common integrated market.

One of the main objectives of the European Union in terms of energy interconnections is to achieve at least a 10% of capacity of interconnection for year 2020 and 15% for year 2030 for all member countries. That means that every nation should be able to transport 10% and 15%, respectively, of the electricity produced in their power plants across their borders to neighbor countries (European Commission, 2015). These measures would allow the member countries to increase their capacity of energy exchanges integrating them in a wide system that ensures the security of supply.

Nevertheless, several countries are far from achieving a 10% interconnection level in the EU and important amounts of money would be required to fulfill that objective. To date, France and Germany fulfill the objective of 10% of interconnection, so they will have no problem to achieve the 2020 objective, but Spain only a 3% level of interconnection, which represents a huge difference with the other studied countries. Nowadays there are two new Spain-Portugal interconnections planned to be completed before 2020, which mean a rise on the exchange power to 3 GW. Another project is a new interconnection between France and Spain which will double the exchange capacity of those countries. Another project is being planned through the Biscay Gulf which would rise the exchange capacity of the country to 4 GW, but, even with the successful implementation of these projects, the country will not achieve the 10% objective by year 2020.

The capacities for importing and exporting electricity are known as net transfer capacity (NTC) and their level depends upon the characteristics of interconnector lines, their availability and internal constrains on the power grids of each country. France has in Europe one of the most important systems for electrical exchanges, since it has borders with the most important countries in the continent in terms of electricity production and consumption. In year 2014, France exported more energy than any other country in the European Union (Réseau de transport d'électricité, 2015).

France has interconnection capacity of 2.6 GW to export to Germany and 3.6 to import from that country (capacity limited to 1.8 GW if upstream congestion on German network). This capacity is expected to rise in the next decade between 0.3 and 2 GW for export and also between 0.3 and 2 GW for import. In the case of Spain, France has an export capacity of 1.4 GW and 1.3 GW for import. With the new projects being built between the two countries, the capacity of France for export would be 3.6 GW and 3.7 GW for import.

With the objective of a regulated electrical system in the continent, the European Network of Transmission System Operators for Electricity (ENTSO-E) was created.

The main objectives of ENTSO-E are ensuring the security of supply in the continent as well as system reliability, the integration of renewable energy sources into the power system and the completion of the internal energy market, objectives which would lead to fulfilling the European Union objectives of affordability, sustainability and security of supply (ENTSO-E, 2014).

This association conglomerates 41 transmission system operators (TSOs) from 34 European countries, as shown in the next figure:

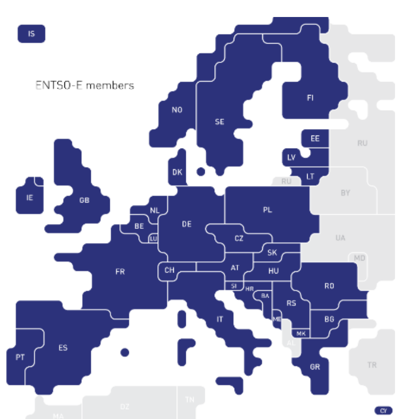

Figure 36 ENTSO-E geographical action area (ENTSO-E, 2014)

The main reasons that lead the TSOs to the interconnection of neighbor transmission systems were the following:

- Optimization of the installed capacity
- Improvement in security reducing the economic cost of failures in the electrical supply
- Improved control of the system frequency to minimize failures
- Share reservoir capacities thus reducing the required reserves
- Provide mutual help in the interconnected systems in case of need
- Improve the market conditions of the integrated systems in large scale
- Facilitate the large-scale integration of renewable energies through a higher flexibility of interstate operations

The European interconnected electrical grid has lead the continent to diversify its sources of electricity, thus increasing the energy security of the region (The Organisation for Economic Co-operation and Development , 2007).

But nowadays, several countries in the European Union are still considered as energetic isles, because of their scarce interconnection potential related to the national installed power. The cases for the three particular studied countries will be covert in the upcoming chapters.

For the studied countries, a comparison of the power peaks has been done between the daily maximum of the three countries each aisled, and the maximum of the three countries as a whole. The first number includes different hours since it is made in an individual base while the second one has only one hour since only a common measure is taken.

Two seasons are chosen for being compared, summer and winter, since the numbers are different for the energy needs in the countries.

Season	Day	Country	Max. daily value per country [MW]	Hour	Sume of 3 max. Values [MW]	Max. total daily value [MW]	Hour	Difference total/sume (%)	Average difference (%)
		Spain	38390	20:00					
	3.02	France	78738	**19:00**	178778	175193	19:00	97.99	
		Germany	61650	11:00					
		Spain	38636	20:00					
	4.02	France	78517	**19:00**	179063	176840	19:00	98.76	
		Germany	61910	11:00					
		Spain	37313	20:00					
Winter	5.02	France	80189	**19:00**	179272	177079	19:00	98.78	**98.65**
		Germany	61770	11:00					
		Spain	36989	20:00					
	6.02	France	77831	**19:00**	175630	172813	19:00	98.40	
		Germany	60810	11:00					
		Spain	36298	20:00					
	7.02	France	73989	19:00	173177	171993	11:00	99.32	
		Germany	62890	**11:00**					

Figure 37 Winter peaks for selected week

Season	Day	Country	Max. daily value per country [MW]	Hour	Sume of 3 max. Values [MW]	Max. total daily value [MW]	Hour	Difference total/sume (%)	Average difference (%)
		Spain	34278	**13:00**					
	14.07	France	45661	23:00	138739	137940	13:00	99.42	
		Germany	58800	11:00					
		Spain	34278	13:00					
	15.07	France	54834	13:00	148782	147045	12:00	98.83	
		Germany	59670	11:00					
		Spain	36271	**13:00**					
Summer	16.07	France	55782	**13:00**	151983	151303	13:00	99.55	**99.26**
		Germany	59930	11:00					
		Spain	36271	**13:00**					
	17.07	France	56984	**13:00**	153885	152745	13:00	99.26	
		Germany	60630	11:00					
		Spain	36235	13:00					
	18.07	France	57197	13:00	153582	152378	12:00	99.22	
		Germany	60150	11:00					

Figure 38 Summer peaks for selected week

Here is concluded that the difference between summing the maximum of the three countries and the maximum of the three countries as a whole is not important in terms of designing interconnections, since the average maximum is 98.65 and 99.26% in average for winter and summer, respectively.

6.2. System flexibility

In the electricity sector, new storage is needed only when there is a very high share of renewable energies (Agora Energiewende, 2014). During the next 10 to 20 years, the power system, integrating renewable technologies, will not require new power storage due to the flexibility of the grid as well as flexible power plants.

Germany is the country that, from the three studied ones, has the most structured plan to develop its power mix for the future. One of the main reasons for Germany to rely so much in renewables compared to other countries in such a small amount of time, is the belief of the government that flexible backup for renewable energies will be sufficient to replace the actual power curves, as it is stated in the next figure:

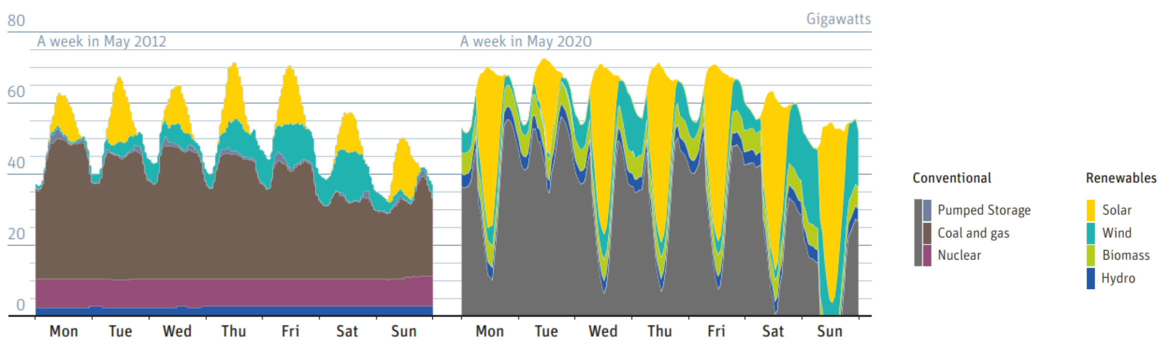

Figure 39 Estimated power demand over a week in 2012 and 2020, Germany (Heinrich Böll Stiftung, 2014)

This figure also explains why Germany will push through gas power plants in the upcoming years, since they represent fast dispatchable sources of energy compared to those plants of coal, oil or, the worst case, nuclear energy plants. But this not-stable situation of the wind turbines represents another challenge for the country's policies, since with this new schema, the gas power plants will not run as many hours as they used to, investing on them or even keeping those that are running nowadays is less attractive for the energy companies. The government has then proposed measures to subside not only the energy generated by the plants, but also the energy kept in standby.

In the proposed scenario it is completely understandable why Germany policy makers decided to shut down the nuclear power plants, because instead of helping the system, they may represent a threat for the adequate integration of other energy sources, such as solar and wind, which are the two most important sources of renewable energy for the country; they together will account 70% of the electricity production in 2020 and later, they will rise from 80 to 90%.

At the present time and as it has already been mentioned in this paper, Germany is the leading country in the energy transition in Europe. Considering that this country has been the major consumer in energy in the continent since several decades and the prognoses confirm the same tendency, the drastic change in the energy mix as well as this all new flexible system that is right now under construction will, in case of success, mark a watershed not only for Europe but for the whole world in the upcoming years.

6.1. Solar potential

One characteristic that may improve the use of renewable energies in the continent is the time shift that exists in the countries because of their geographical location. This is shown in the next chart for the case of Spain and Germany for two weeks, one in winter and other in summer:

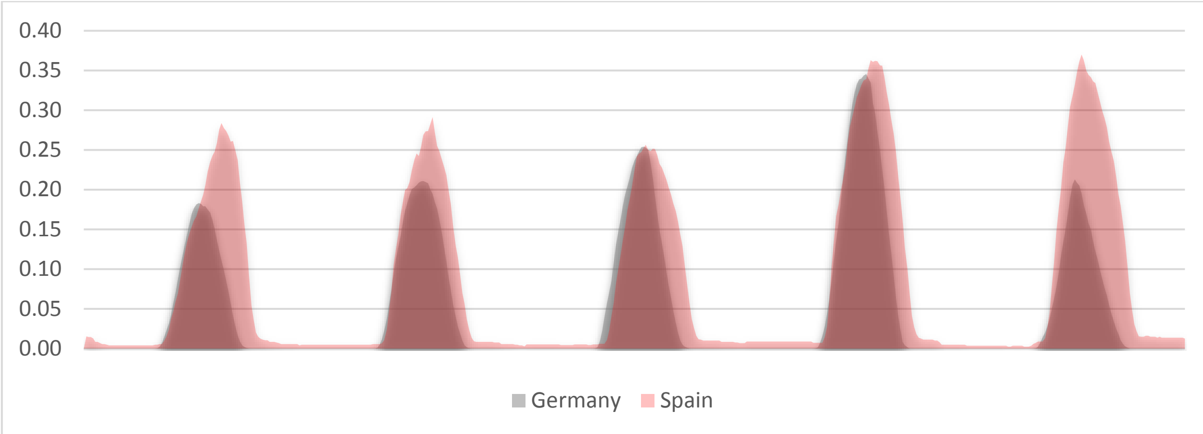

Figure 40 Electricity production from solar photovoltaic per installed capacity 04.02.2014-08.02.2014.

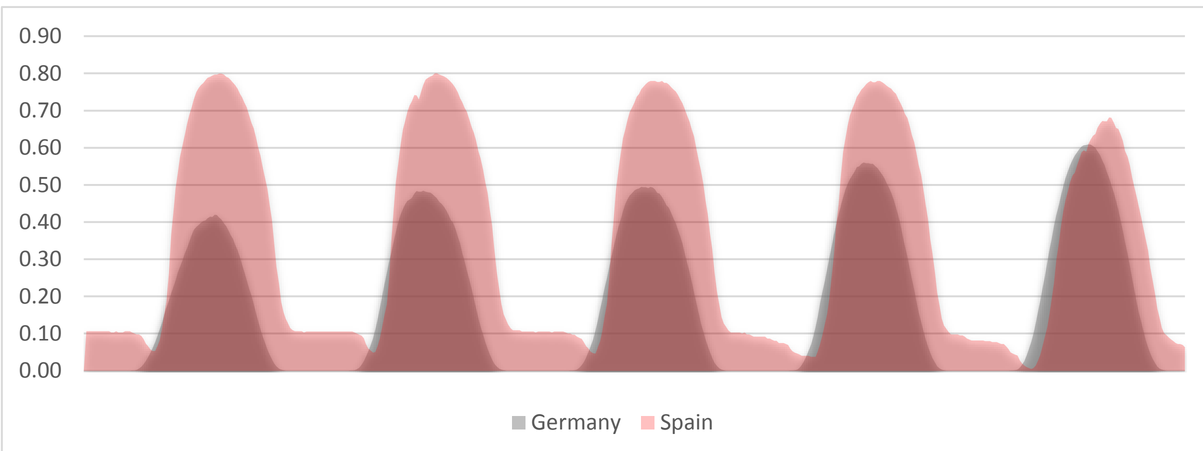

Figure 41 Electricity production from solar photovoltaic per installed capacity 17.07.2014-21.07.2014.

The graphs are in energy produced per installed capacity in order to make it easy to compare them. In both cases, the time shift of the curves peaks is approximately one hour. In the case of the second graph, the one in summer, it can be seen the effect of the solar thermal energy in Spain, since the energy produced by this source continues working even in the absence of sun for several hours.

The disparity on the light times is explained in the next figure, where the geographical position of the two countries is shown.

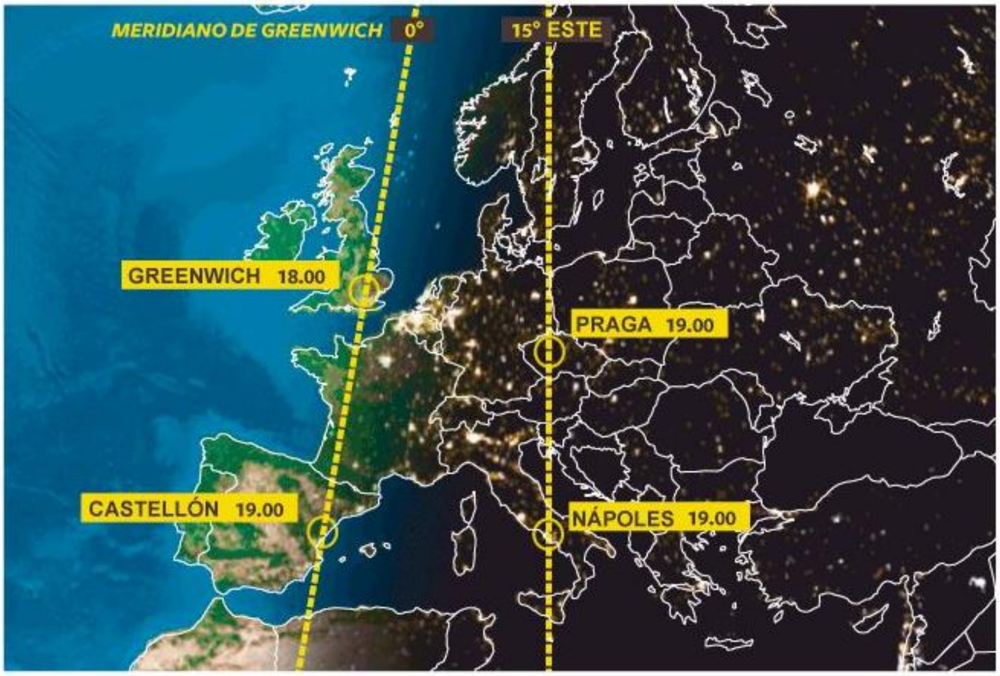

Figure 42 Hour disparity in Europe (El País, 2013)

Since most of the Iberian Peninsula is located in the western meridian, the country should have another time than the one of central Europe, like is the case of Portugal or the United Kingdom, but the reason of this homogeneity in time is attributed to historical and political causes that go back to the second world war times (El País, 2013).

As it has been stated, renewable energy resources are higher in Spain and Germany is the largest energy consumer in Europe, so the possibility of exporting energy from the Peninsula to central Europe is quite interesting for the electricity market in Europe.

In the next charts the consumption in Germany and the electricity production from solar sources is contrasted for winter and summer in year 2014 for two selected weeks:

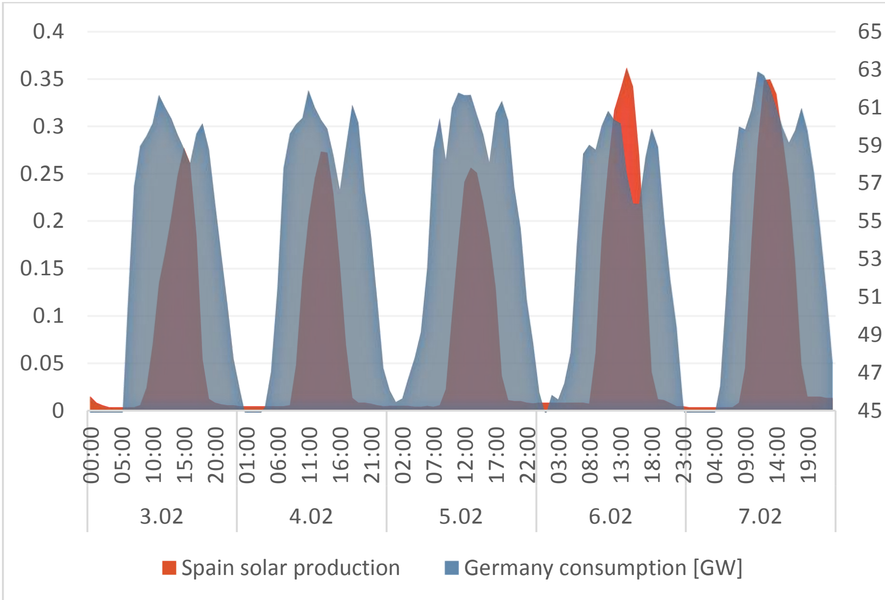

Figure 43 Solar production in Spain per installed capacity and power consumption in Germany 04.02.2014-08.02.2014.

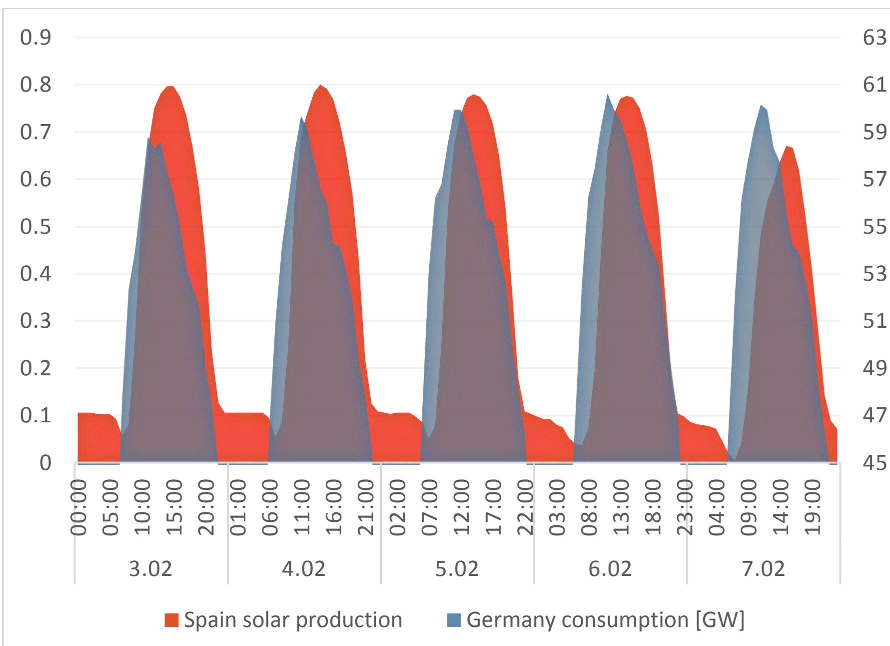

Figure 44 Solar production in Spain per installed capacity and power consumption in Germany 17.07.2014-21.07.2014.

If the imports of energy in Germany are considered, the next graphs come out for the selected winter and summer weeks:

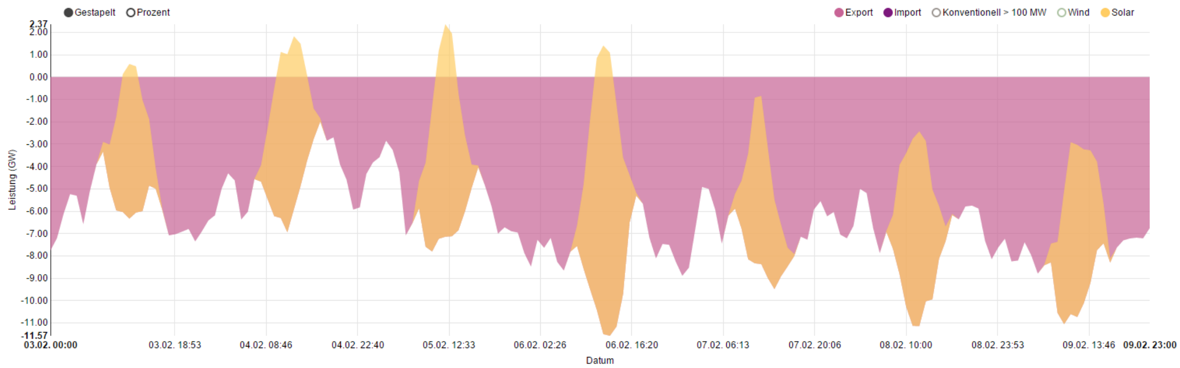

Figure 45 Germany solar electricity production, electricity import and export 03.02.2014-09.02.2014 (Fraunhofer-Institut für Solare Energiesysteme, 2015)

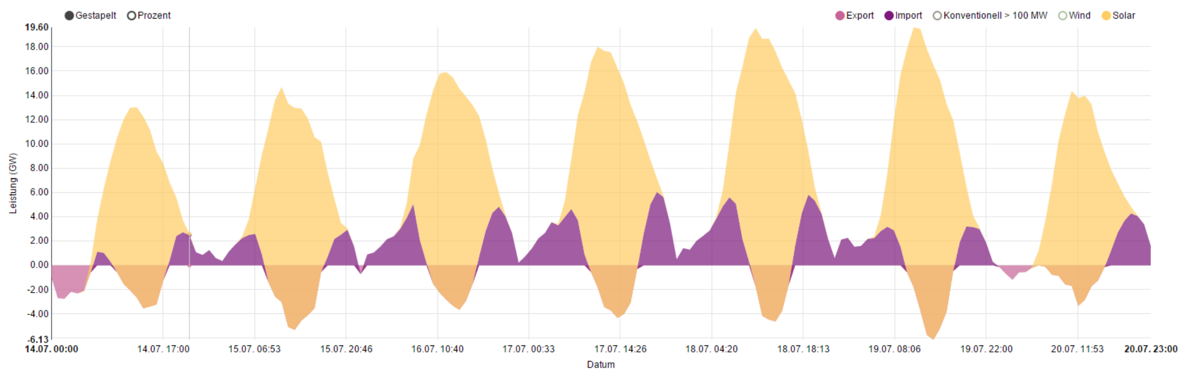

Figure 46 Germany solar electricity production, electricity import and export 14.07.2014-21.07.2014 (Fraunhofer-Institut für Solare Energiesysteme, 2015)

In both cases we can observe a direct correlation between the solar electricity production and the import-export exchanges. Then the sun is higher, the exports follow the same pattern while, more clearly in the case of the summer week, then the sun is not enough, the country requires of electricity imports from their neighbors.

Specifically for the case of France and Germany, the first one imports energy from the second one during high periods of photovoltaic generation in Germany, trade that may be enhanced when wind power generation is also high. On the other hand, France exports electricity to Germany at night and during periods of little wind.

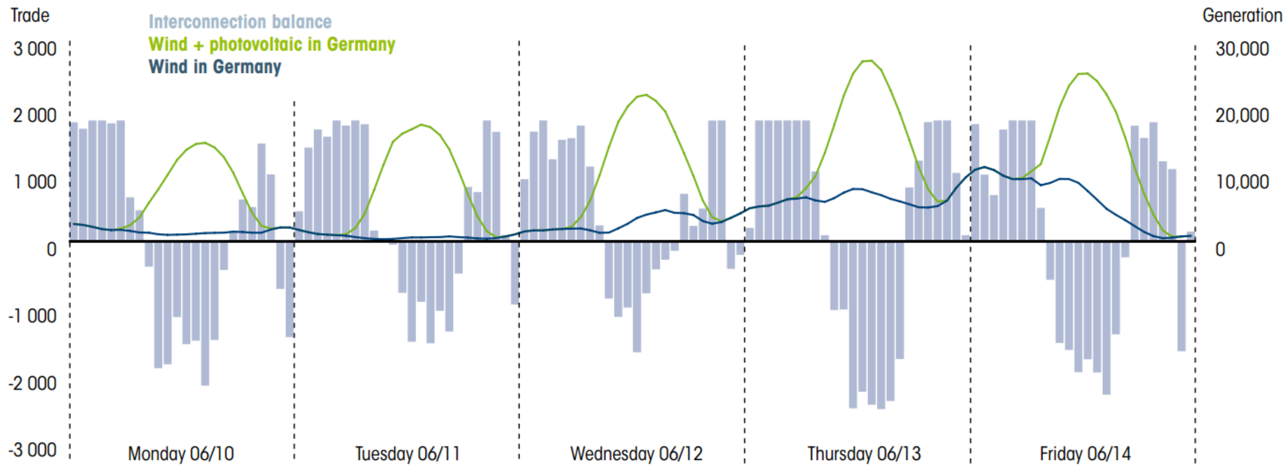

Figure 47 Comparative evolution of the interconnection balance on the Franco-German border and wind and photovoltaic generation in Germany over a week of 2013 (MW) (Réseau de transport d'électricité, 2014)

This information mean that the electricity exchanges are highly dependent on weather conditions due to the importance of the installed renewable energy plants and, if the planes for the enhancement of this kind of installations are fulfilled, in the future their importance will be even higher, especially in the studied countries because of the amount of energy they need to fulfill their needs.

With the available data, an approximation for Spain between solar photovoltaic and solar thermal has been made resulting in the following charts:

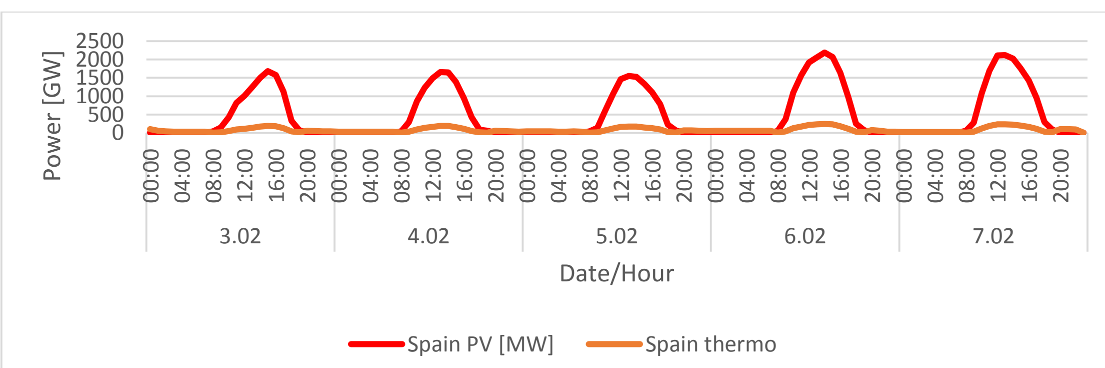

Figure 48 Spain solar PV and thermal power in winter

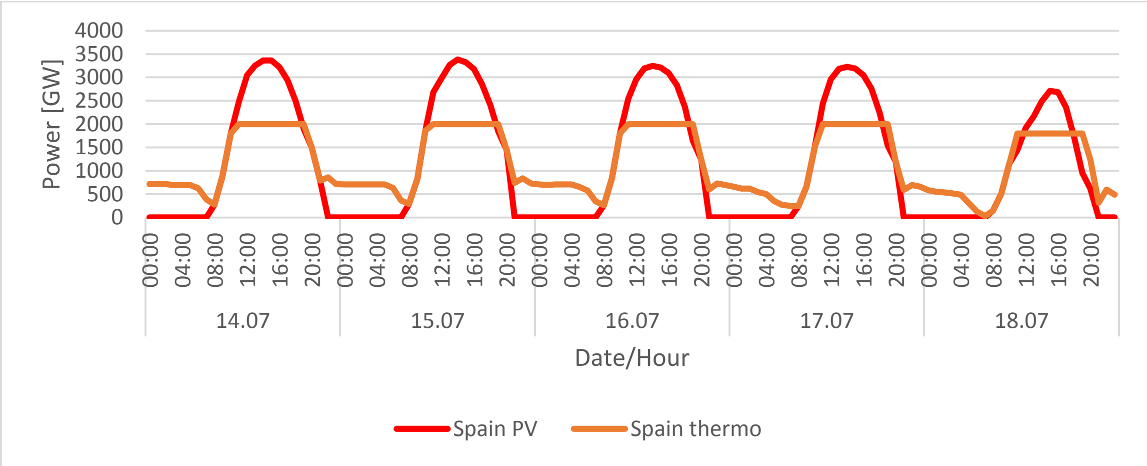

Figure 49 Spain solar and thermal power in summer

It can be observed that the importance of solar thermal is very high for summer while for winter does not really influence the total production of energy, a phenomena that is caused because the energy coming from solar thermal sources depends on the temperature and not in the radiation as in the case of solar photovoltaic energy. But in summer, the production of energy due to the solar thermal allows the system to keep producing energy even after the sun has set, a reason why the solar thermal will acquire a central importance in the upcoming years in countries where this technology can be used.

For the case of Germany, and considering the path that the country is following towards year 2030, the power of the country would seem as follows for winter and summer selected weeks:

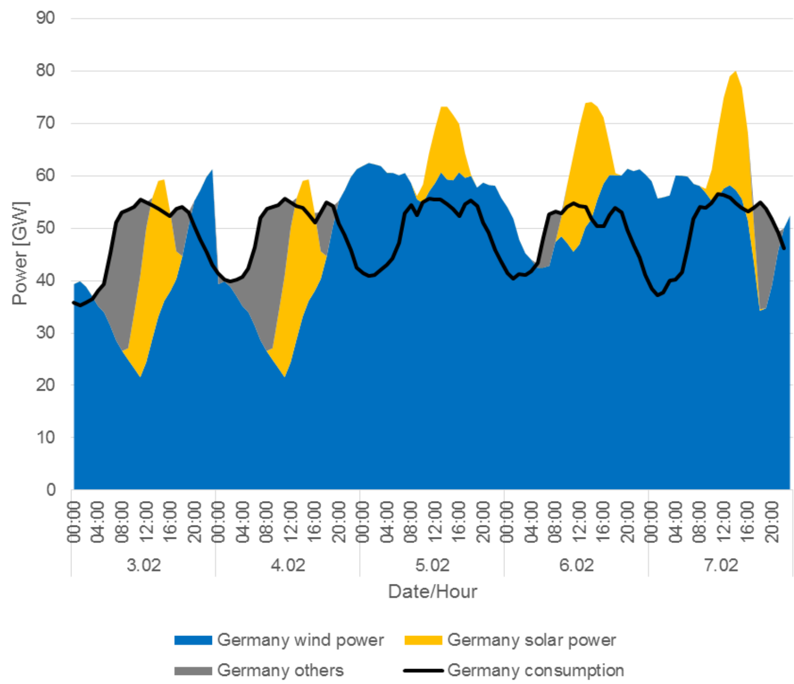

Figure 50 Germany power in winter 2030

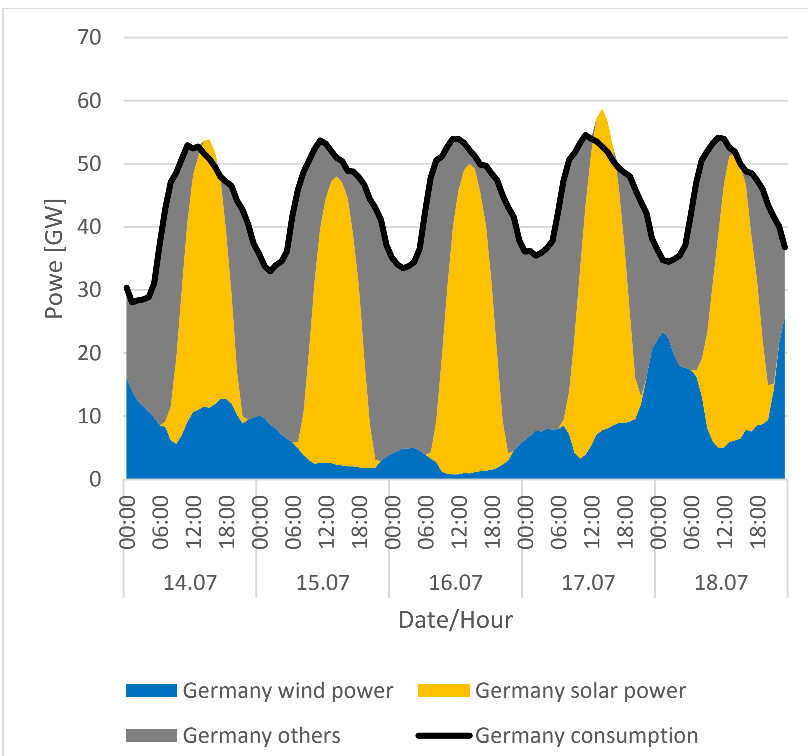

Figure 51 Germany power in summer 2030

In winter and due to the high amounts of winter energy during this season, the energy produced in the country would represent an excess, a quantity that would be able to be exported. In summer, there is more energy needed in order to fulfill the country's energy needs, a quantity that could be either produced in the country or could also be imported from other countries. This additional energy would seem as follows:

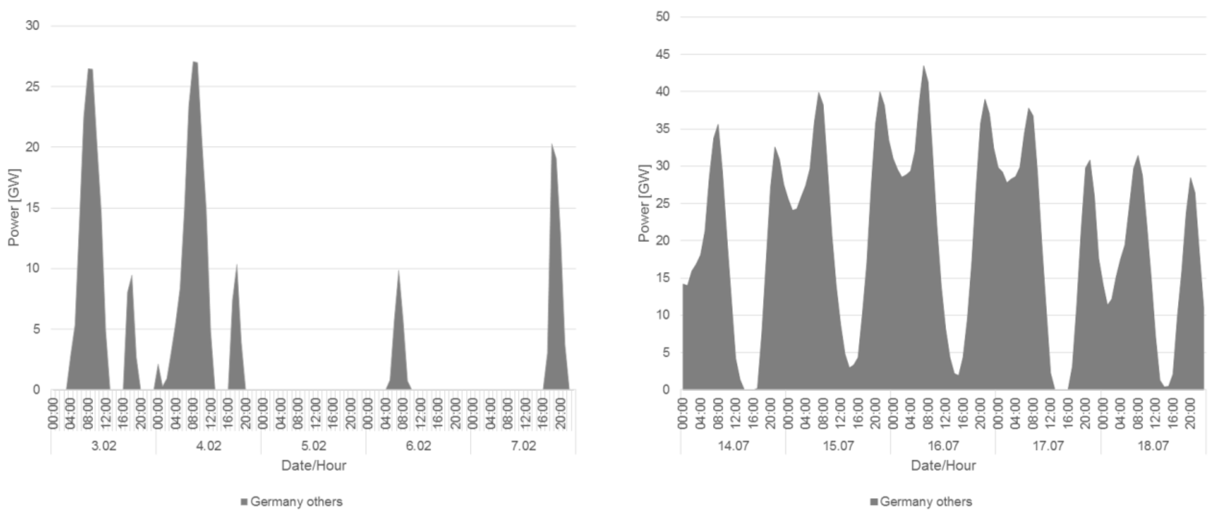

Figure 52 Additional energy needed in Germany in year 2030

With the purpose of interconnecting the system and comparing the additional power in Germany and the solar production in Spain, in order to see how the second one would help the first one, it may seem as in the following chart:

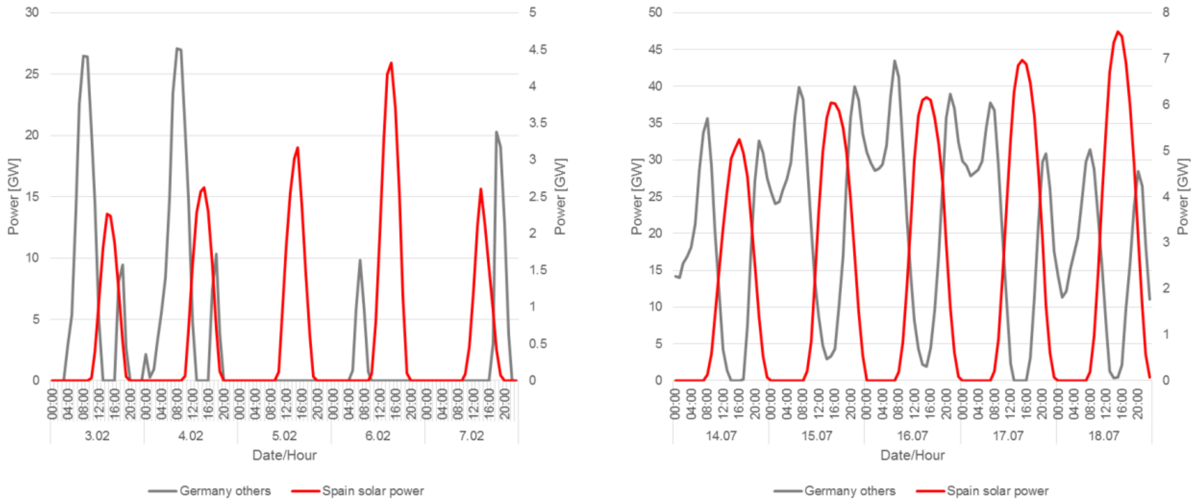

Figure 53 Additional power in Germany and solar production in Spain

For winter and summer, it can be observed that the Spanish solar production could, by itself help the energy need in Germany but not fulfill it completely. That is because there are two peaks in the energy consumption in Germany, one around 8:00 and the other one around 22:00. In the first one the sun has not risen yet in Spain while for the second one a more important help from energy production in Spain could be possible, but only through the use of solar thermal technology, which may allow the production of energy even after the sun is not shining anymore.

A comprehensive strategy that takes into account the importance of solar and wind technologies for the energy exchanges among the interconnected energy systems would carry benefits for optimizing the size of the new installations, considering also the difference of the potential of renewable energies among the studied countries, the whole system could also be optimized, installing the new plants in the regions where the production is higher and sending it to the regions where the energy is needed.

7. Alternative scenario towards 2030

In the last chapters it has been stated which are the main differences in efficiency in renewable technologies in the selected countries.

With the purpose of observing the benefits stated in the last sections regarding the higher capacity factors in both technologies, solar and wind power for the case of Spain, a new scenario towards year 2030 is proposed in this chapter.

The exemplification of electrical exchanges between Spain and Germany is particularly interesting due to the huge potential of renewable energies of the first one and the large energy consumption of the second one.

This alternative scenario consists of, starting with the same installed capacity in year 2014, installing all the new power in Spain instead of in Germany at with the objective of obtaining the same energy either from solar or wind power, assuming in principle that the installed capacity should be much less. With that purpose, the new installed power in Spain up to year 2030 does not play an important role since the only energy that will be studied is the one of the planed capacity of Germany.

Hence the hypothesis to be corroborated is that, in case that all the new projected power to be installed in Germany is installed in Spain instead, the energy gotten from these new installations would be much higher or, if the same energy would be produced, a much lower amount of installed power would be required in Spain than in Germany.

Considering that Spain has a much higher radiation than Germany, that the wind conditions are also more favorable in Spain and that Germany requires much higher levels of energy than Spain, as it has already been stated in the previous chapters, electrical energy being generated in Spain and transported to Germany would be the logical way to figure the energy flow between these two countries if only new renewable energy technologies are considered.

According to the presented information and with the available data, the energy produced in year 2030 by the new installed power would be 32.29 TWh for solar power and 47.81 TWh in Germany. If that same energy would be produced in Spain, the installed power would vary as follows:

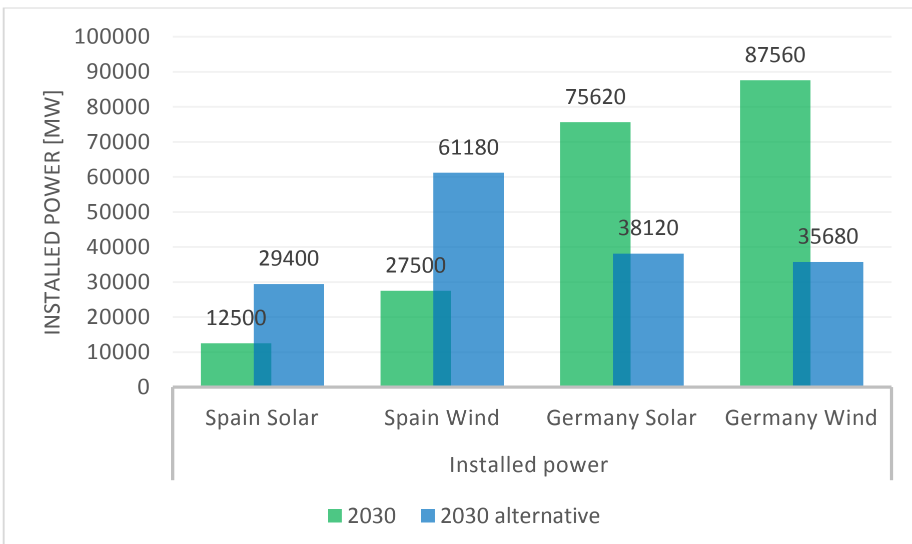

Figure 54 Installed power for obtaining the same energy in alternative scenario

That means that the new installed power according to the Germany plans and which would be 37500 MW of solar power and 51880 MW of wind power, if installed in Spain, would only be 16900 and 33680 MW, respectively. These figures mean a saving of 54.93% in the case of solar power and 35.08% of wind power.

Those numbers are estimated considering the current capacity factors for the studied technologies, but, as it has been stated in the last chapters, the capacity factors are supposed to be increased in the upcoming years, more importantly in the case of solar thermal power, technology that is only used in the case of the Iberian Peninsula for the studied countries.

If this alternative scenario would be implemented, the amount of working hours, as a measure of how effective would be the implementation of a technology by would seem as follows:

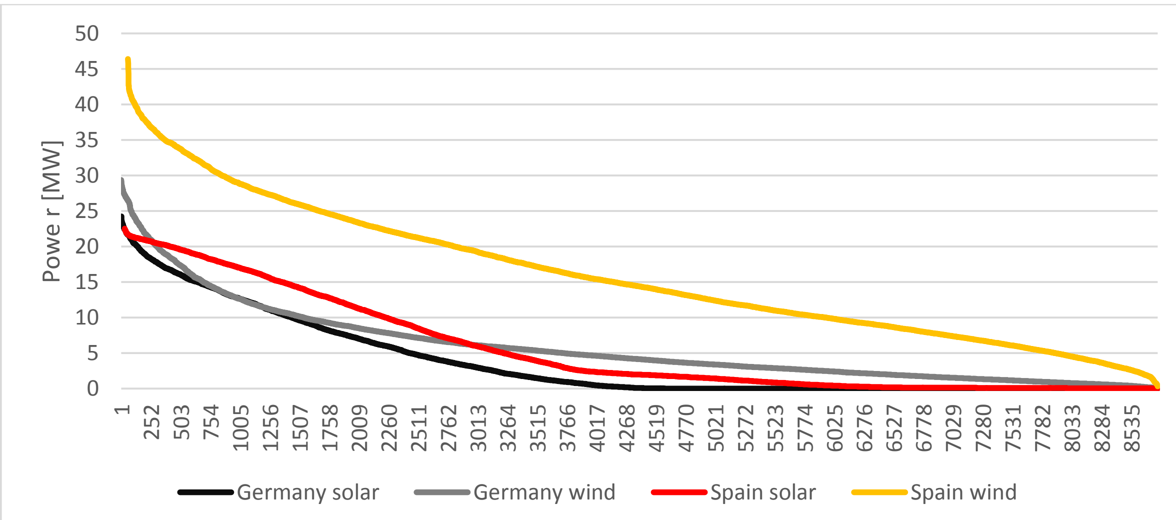

Figure 55 Working hours by technology in Spain and Germany in alternative 2030 scenario

This last graph suggests that the panorama in the alternative scenario would have wind in Spain as the technology producing the most of time, followed by wind energy in Germany. For the case of solar technology, Spain would also present a higher ratio of working hours compared to the case of Germany with a special influence of solar thermal technology that allows the production of energy even when the sun is not hitting the installations.

8. Conclusions and recommendations

The presence of renewable technologies in the power mix of the three studied countries will be crucial in the upcoming years. Even though their importance will not be the same for the three cases, the lack of conventional sources of energy will push the three countries to change their current power system to depend more and more on renewable energies to fulfill their respective energy needs.

Germany will lead in the continent with the most important amount of renewable technologies, both solar and wind. The German *Energiewende* is nowadays one of the most ambitious strategies at a national level and, considering that in terms of energy Germany is the most important country in the continent, the energy transition would lead to a whole new energy model based on renewable technologies.

France, despite the fact that will improve in their turn to the use of alternative energy, will still rely in the mid-term on nuclear power. But, because of the intermittent nature of the renewable technologies, a country that other nations may rely on in case of need, could represent a tremendous advantage for France compared to its neighbors.

Spain has the highest potential for renewable energies among the studied countries, characteristic that could lead us to think that it has also one of the best conditions in the continent for the production of solar and wind energies. Moreover, the production of solar thermal energy has only been developed in this country among the studied ones, fact that would mean, jointly with the prediction of a huge improvement of this technology in the future, that this technology could affect very importantly the way the country produces energy. Although all these conditions are present in the country, in the mid-term there is not a clear government strategy to explode them and there has not been either a high development in the recent years in this matter, a situation that may lead to a deadlock in the development of new technologies in the region. Spain has hence the potential to become a renewable energy power in the continent. In order to achieve that, three main topics should be covered:

A government policy that allows individual users to participate in the national energy production, as in the case of Germany for instance. That would increase the amount of available energy coming from solar panels and small wind power plants.

The installation of new solar thermal power plants using more modern technologies, particularly those of storing energy, since by those means it is expected that the country could be able to produce reliable energy coming from a renewable source and that energy would be produced at the time other countries require it, making it easier to export its excess.

Improve the interconnection system of the country, since for year 2020, the interconnection capacity of the country is not expected to reach even 10%, so more power lines should be deployed in order to export the produced energy within the country.

Finally, Europe in general will still depend in higher or lower proportion on alien sources not only in the mid but also in the long term. Nevertheless, an interconnected system will allow the member countries to share their strengths and there is where countries like Spain, possessing enviable renewable energies potential shall hurry up in the energy race to become a central player, not only for assuring its own energy security and the one in the European Union, but also to create jobs, improve its home industry and help the environment, a matter that concern us all.

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Màster en Enginyeria de l'Energia

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Suplents:

Observacions

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