Trabajo Fin de Grado
en Ingeniería de las Tecnologías Industriales

Influence of renewable energy plants in European electricity markets

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El tribunal nombrado para juzgar el Proyecto arriba indicado, compuesto por los siguientes miembros:

Presidente:

Vocales:

Secretario:

Acuerdan otorgarle la calificación de:

Sevilla, 2024

El Secretario del Tribunal

A mi familia

A mis maestros

Agradecimientos

En primer lugar, quiero dar las gracias a mis padres, por ser las personas que más me han apoyado y creído en mí desde el principio, por confiar en mis capacidades cuando ni yo mismo lo hacía y por nunca dejarme bajar los brazos cuando todo parecía que se derrumbaba.

Después, a mi hermana, gracias por ser mi compañera de vida, por estar ahí en cada paso que doy, por aguantarme cada día, por aconsejarme en mi toma de decisiones, por siempre querer lo mejor para mí, por ser mi mejor amiga y sobre todo gracias por ser siempre mi ejemplo a seguir.

Por último, agradecer a mi tutor, Miguel Ángel, por la gran ayuda prestada durante la realización del trabajo, por su predisposición a atenderme siempre que lo he necesitado y por su cercanía y amabilidad. Sin él, nada de esto hubiera sido posible.

Resumen

Este trabajo consiste en exponer la situación del mercado eléctrico en 4 países europeos: España, Noruega, Francia y Reino Unido, con el objetivo de poder remarcar las tecnologías utilizadas en cada uno de los países para la producción de energía eléctrica.

Al principio del trabajo aparece una introducción en la que se comenta la importancia que las energías renovables están teniendo en los mercados eléctricos de todo el mundo. Se explica también la necesidad de desarrollar estas tecnologías con el fin de poder alcanzar los objetivos medioambientales fijados por cada gobierno.

Los siguientes cuatro apartados hacen referencia cada uno de ellos a un país distinto. En cada una de estas secciones se explica detalladamente el funcionamiento de cada mercado, las principales tecnologías utilizadas, la evolución de los precios de la energía y futuras tendencias en el ámbito energético.

En el funcionamiento del mercado se trata de explicar el inicio de cada uno y los principales agentes que lo componen.

En las tecnologías utilizadas, se nombran aquellas que tienen una participación notable en la producción energética del país.

En la evolución de los precios de la energía se trata de dar una explicación de dicho precio teniendo en cuenta posibles crisis económicas o energéticas del país y las tecnologías con mayor porcentaje de producción anual.

Por último, en las futuras tendencias se trata de explicar cuáles van a ser las tecnologías que más se van a utilizar en los próximos años y si hay previsión de que los precios suban o bajen.

El sexto apartado consiste en una comparación entre los cuatro países. Se comparan las tecnologías utilizadas, las políticas energéticas, las estructuras de los mercados y las futuras tendencias energéticas de cada país. El objetivo de este apartado es poder resaltar las ventajas y los inconvenientes que presenta cada mercado eléctrico.

Y como conclusión, una última sección en la que se trata de hacer una recopilación de las ideas principales mostradas durante todo el trabajo y se presenta una posible línea de trabajo para el futuro.

Abstract

This project consists of an explanation of the electricity market in four different European countries: Spain, Norway, France and The United Kingdom. Its aim is to comment on the technologies used in each of the countries to produce energy.

At the beginning of the project there is an introduction where it is commented on the importance renewable energies have in electricity markets of the whole world. It is also explained the necessity to develop these technologies if the environmental goals of every government want to be achieved.

The next four sections refer to each one of the countries. In every of these sections it is explained how every market works, the main energy technologies of every country, energy price evolution and future energy trends.

In the working process of every market, it is explained the beginnings of it and the main characters which participate in it.

In energy technologies, it is mentioned those that have a significant role in energy production of the country.

In energy price evolution, it is explained every average annual price considering economic or energy crisis and technologies with the highest production percentage.

Finally, in future trends, it is mentioned the technologies which are going to be used in the future in the next years and if it is foreseen an increase or decrease in energy prices.

The sixth section consists of a comparison between the four countries. It compares the technologies used, energy policies, market structures and future trends of every country. The aim of this section is to remark on the advantages and disadvantages of every electricity market.

As a conclusion, there is a final section where there is a gathering of the main ideas showed during the project and it is presented a future work line.

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1. INTRODUCTION

Humans have been on this planet for 200,000 years. During that period of time, so many different situations have been faced. Working all together has always been the key to guaranteeing the survival of humanity. In the last few years, there has been a conflict that is forcing governments from all over the world to react. This conflict is, of course, energy. Nowadays, electricity has become essential for everybody. The reliance on electricity is growing every year and, in many countries, it is even seen as an issue.

Since energy was used for the first time, producing it has been one of the main goals for most countries. In its production process lots of materials have been used, to name a few; coal, oil, gas, uranium, etc. What all those sources have in common is that they are non-renewable, so in the future they are not going to be an option to produce energy. That is why humans have been struggling for decades to find a replacement for those non-renewable sources, until renewable sources came to mind. Renewables sources, as everybody knows, are, for example, wind, sun or water. These sources have always been used since the beginning of civilization to improve the quality of life.

So that is the situation today, a moment of change, which has been called energy transition. Not only these new technologies are being developed because of the future disappearance of non-renewable sources, but also due to the environment. According to the United Nations World Meteorological Organization, the global annual average temperature in 2023 was close to 1.5 degrees higher than pre-industrial levels [1].

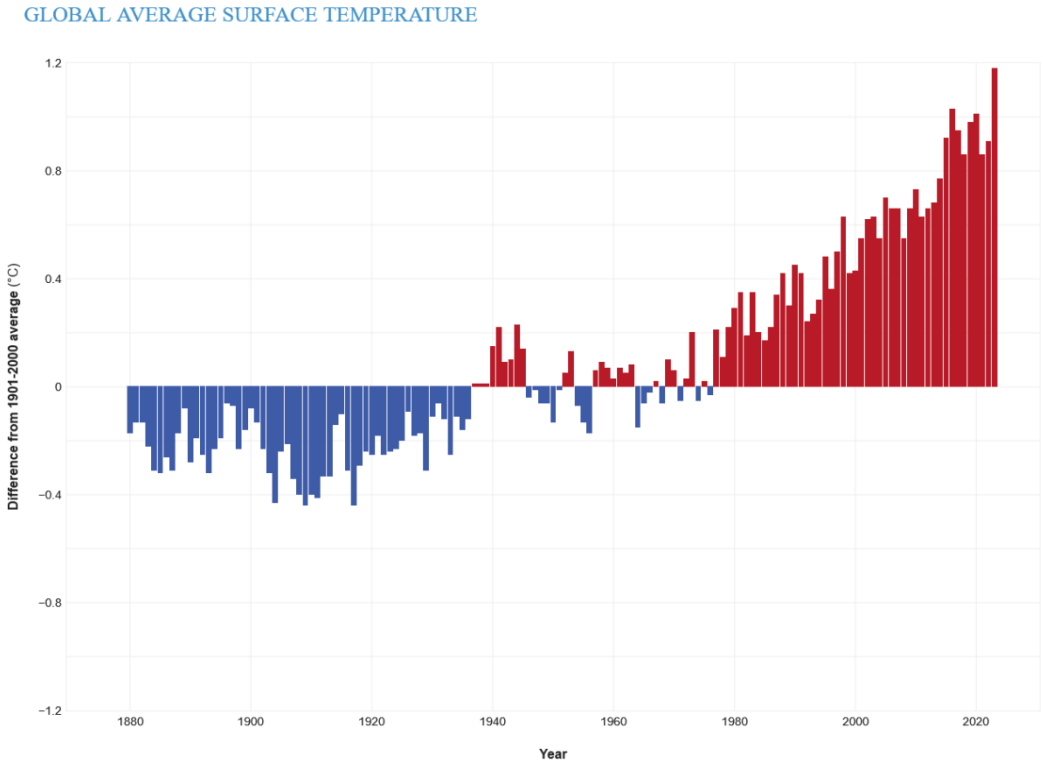


Figure 1. Global average surface temperature in degrees [2]

Figure 1 shows the increase in the global average surface temperature in degrees, from 1800 to 2020. In 1800, the temperature was below zero. In 1900, the effects of the first industrial factories appeared, so global temperature increased. Nowadays, the global average surface temperature sets a record almost every year. If nothing changes it is foreseen that the global temperature in 2030 will reach a value of 1.5 degrees [3].

This is a fact which most governments in the world are concerned about. Something must be done because the later a reaction is seen, the hardest it is going to be to solve the issue.

One solution they came up with is carbon neutrality by 2050. The idea is to achieve zero carbon emissions by 2050. That means that lots of industrial plants need to be replaced.

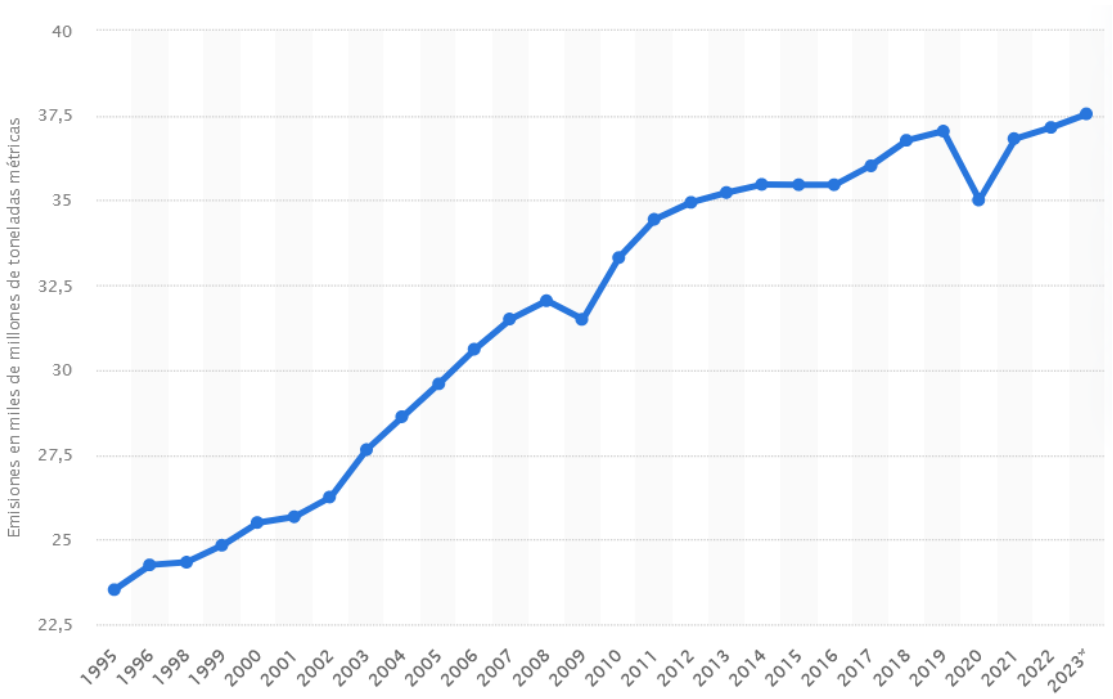


Figure 2. Global carbon emissions in billions of metric tons [4]

Figure 2 shows the global carbon emissions in billions of metric tons, from 1995 to 2023. In 2020 a decrease in the emission was achieved, but it was pointless due to its increase in the following years. It is obvious that carbon neutrality is an ambitious goal.

Every country has its own aims and programs to achieve them, but what all of them are aware of is the importance of renewable energies in their plans. In the future, it is foreseen that the percentage of renewable energies in the installed capacity is going to increase every year. This can be very well seen in Spain, where renewable energies have suffered a huge rise in recent years.

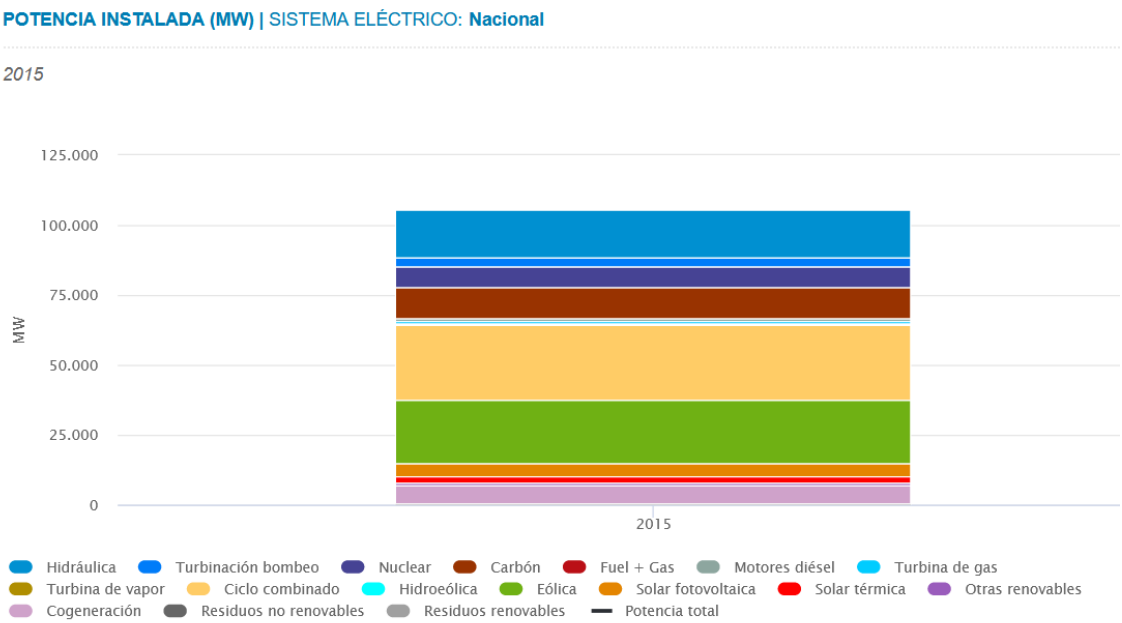


Figure 3. Installed power in MW of Spain in 2015. [5]

In figure 3 you can observe the installed power in MW of Spain in 2015, noticing the differences between technologies.

2015
Hidráulica: **17.043 MW**
Turbinación bombeo: **3.331 MW**
Nuclear: **7.573 MW**
Carbón: **10.962 MW**
Fuel + Gas: **8 MW**
Motores diésel: **811 MW**
Turbina de gas: **1.149 MW**
Turbina de vapor: **483 MW**
Ciclo combinado: **26.636 MW**
Hidroeólica: **11 MW**
Eólica: **22.929 MW**
Solar fotovoltaica: **4.684 MW**
Solar térmica: **2.304 MW**
Otras renovables: **887 MW**
Cogeneración: **6.253 MW**
Residuos no renovables: **456 MW**
Residuos renovables: **153 MW**
Potencia total: **105.674 MW**

Figure 4. Installed power values in MW of every technology of Spain in 2015. [5]

These are the installed power values in MW of every technology in 2015.

Comparing them to the 2023 results, some changes are noticeable.

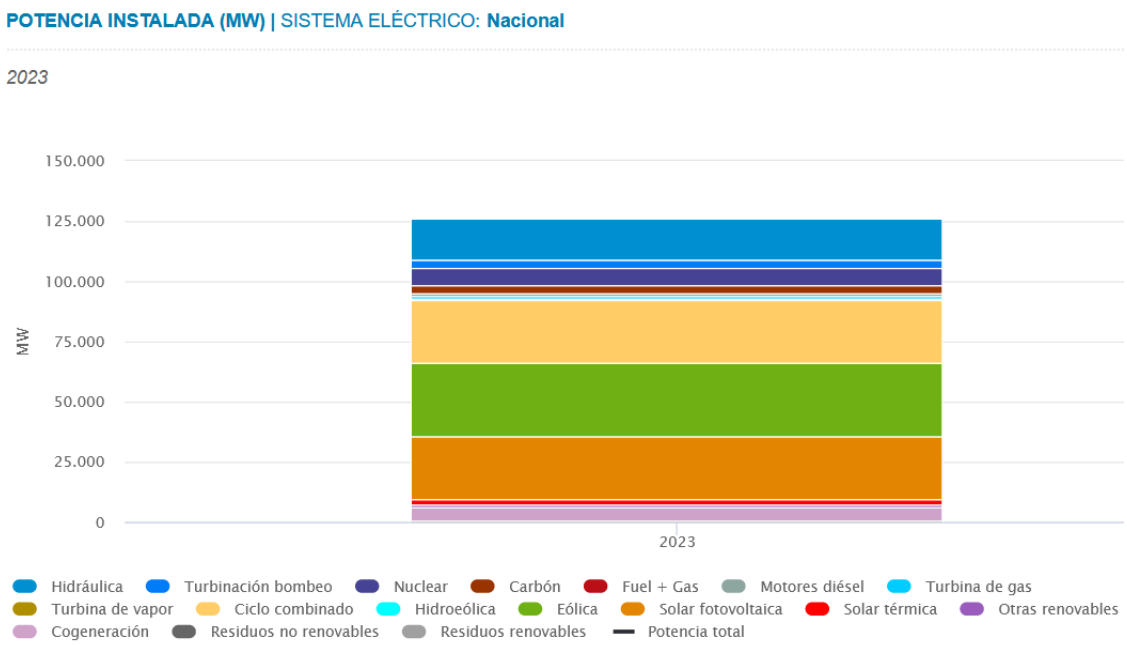


Figure 5. Installed power in MW of Spain in 2023. [5]

2023
Hidráulica: **17.097 MW**
Turbinación bombeo: **3.331 MW**
Nuclear: **7.117 MW**
Carbón: **3.464 MW**
Fuel + Gas: **8 MW**
Motores diésel: **769 MW**
Turbina de gas: **1.149 MW**
Turbina de vapor: **483 MW**
Ciclo combinado: **26.250 MW**
Hidroeólica: **11 MW**
Eólica: **30.866 MW**
Solar fotovoltaica: **25.756 MW**
Solar térmica: **2.304 MW**
Otras renovables: **1.097 MW**
Cogeneración: **5.585 MW**
Residuos no renovables: **426 MW**
Residuos renovables: **170 MW**
Potencia total: **125.883 MW**

Figure 6. Installed power values in MW of every technology of Spain in 2023 [5]

The first thing you notice is that coal power plants installed in 2023 almost 8.000 MW less than in 2015, as a result of the measurements that appeared to achieve carbon neutrality.

On the other hand, there has been an increase in installed power in the two most important renewable technologies of Spain, photovoltaic solar and wind energy. Wind energy installed power has suffered a growth of almost 8.000 MW. Although wind energy has been a priority, it is nothing compared to photovoltaic solar energy. It has increased its installed power to more than 21.000 MW, making it one of the most crucial technologies in the country. Due to the climate conditions of Spain, this technology is going to play a crucial role in energy transition in the country.

Renewable energies are being used because of the reduction they make in carbon emissions. They also have some other advantages. The most remarkable two are:

- Renewables energies cheapen the electricity price. Wind and solar photovoltaic are not manageable energy, so they have preference to sell what they produce, in order to use the biggest amount of their energy and not waste any. Due to meteorological conditions, they can only produce at certain times of the day, therefore their prices are very low to make sure they participate in the market.
- The other remarkable positive effect is the zero residues produced during the process. For example, nuclear energy is very cheap, but it has the huge disadvantage of the amount of waste that appeared during its generation.

To have an idea of the countries which have the highest and the lowest electricity prices, in the graph below you can compare many countries and have a general knowledge about the places where the electricity market is the most surprising, in a negative or positive way.

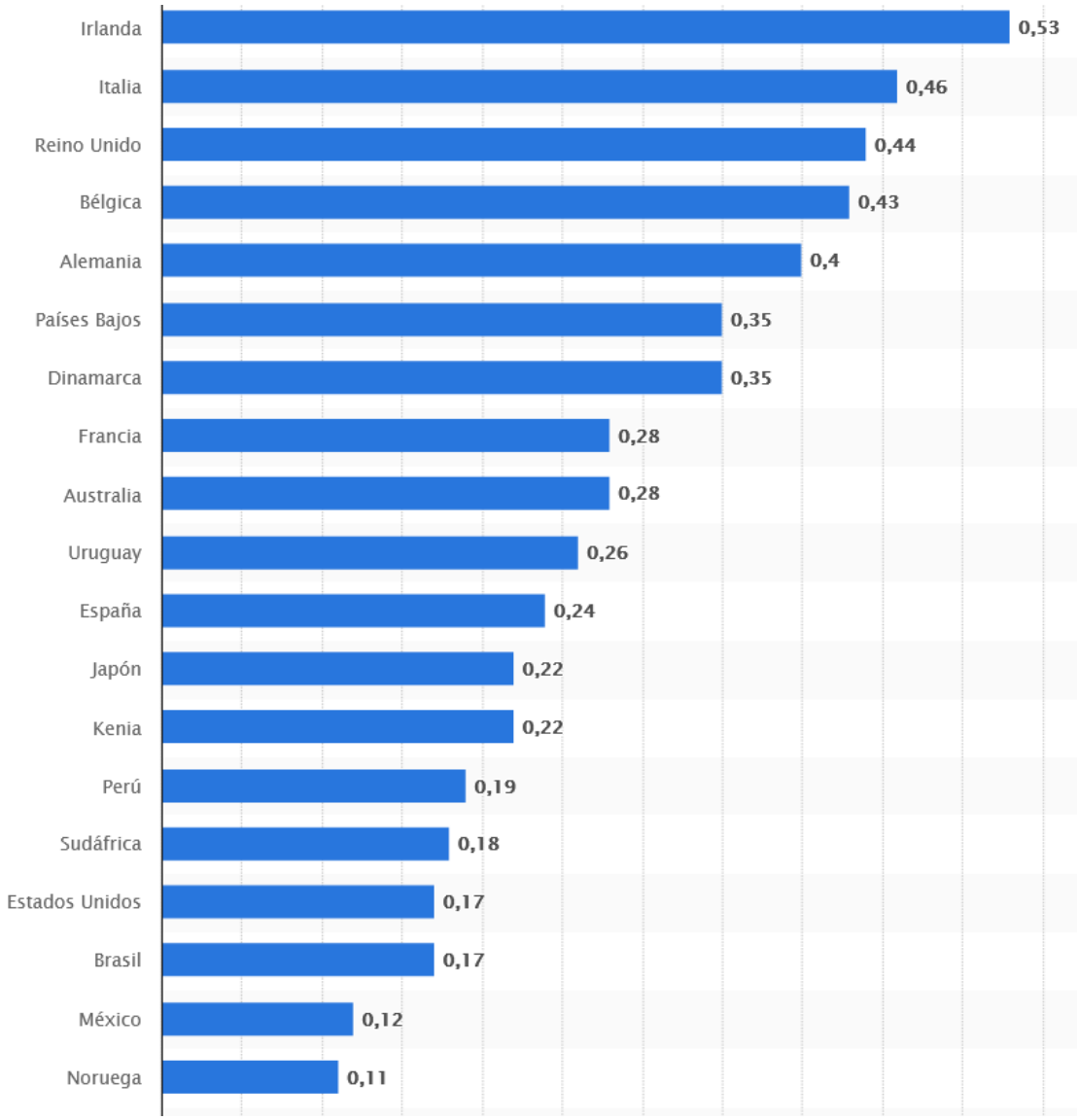


Figure 7. Household prices worldwide in September 2023 in U.S. dollars per kilowatt-hour. [6]

Figure 7 shows the household electricity prices worldwide in September 2023 in U.S. dollars per kilowatt-hour.

In this study, we are going to compare the energy price of four different countries from Europe. The four countries we are going to discuss are: Spain, Norway, the United Kingdom and France.

Spain is also a good example to show the importance that wind and photovoltaic energy can have in the development of a country.

Norway has one of the cheapest prices in the world, as you can see in the chart. In Europe it is where you can find the cheapest electricity energy. The reason why energy prices are so low is because of renewable energies, remarking the hydroelectric power. They have a lot of nuclear energy too. Another outstanding aspect of this country is the level of pollution,

which is one of the lowest in Europe.

On the contrary, The United Kingdom has one of the highest prices. This is a particular situation because it is a big country, but it is an island. Connections with other countries are much more difficult due to the distance and the surface. It is obvious that it is always going to be easier to build a connection on the ground than on water. That makes it hard to use energy from other countries, so they need to be more self-dependent than the rest.

Finally, France is a good example to show the consequences of having a significant reliance on a non-renewable energy. France is a country where nuclear energy is their first producer. When they tried to reduce it, in favor of other technologies, the electricity price increased to values never seen before in the country.

Apart from comparing their electricity prices, an explanation of the reasons why the price is high or low is going to be given. The impact of renewable energy on household prices is also going to be remarked, as the most important technologies in every country. Keeping all this in mind, negative and positive aspects of every technology will be highlighted.

The main goal of this project is to be useful to understand the huge impact renewable energies have on the electricity market. It also points out negative and positive aspects of every technology. Moreover, the analysis of each country is helpful to be aware of the variety of technologies you can use to produce the energy needed. Of course, the advantages and disadvantages of every strategy will be remarked. One of the characteristics of this study is that it does not focus on only one country or situation. Comparing different strategies facilitates seeing the wood for the trees and that is essential to comprehend that there is not only one right way to proceed.

This project is structured in five different sections. The first four are going to explain the current situation of the four countries, the most used technologies and the future situation that is foreseen.

In every country, special details of them are going to be remarked.

For example, in Spain it is remarkable the penetration of wind and solar energy. Also, the prices of zero euros or even negative.

From Norway, how low is the energy price.

In the third section, The United Kingdom’s market is particular because of its interconnections.

In the fourth one, France is suffering a difficult situation currently, its energy prices are setting historical records.

Once the four countries have been explained properly, the aim of the fifth section is to compare the four different situations, pointing out the advantages and disadvantages of each one and try to create an ideal one where the price would be steady and affordable.

2. SPAIN

2.1. Introduction

The Spanish electricity market is a crucial key in the economy and development of the country. It has suffered many changes through the years to become the complex structure that it is now. It includes from energy generators to consumers. Transmission, distribution and suppliers of electricity also play a vital role in the process.

This market first appeared in 1998 [7], when the electricity sector was liberalized. This was a huge change because before that there were only a few companies involved and, after the liberalization, competitiveness increased.

The increase in competitiveness resulted in a decrease in energy prices. If it was a monopoly, the price would increase due to the lack of other offers. But if there are many generators the situation changes. Their aim is to sell their energy, so they need to set a more competitive price than the rest of them, to make sure their offer is going to be on the market. That results in a lower price for the consumer.

Since energy is produced until it is consumed, it experiences a long journey. Energy is produced by generator companies in energy plants. Once it is produced, it is necessary to transport it to consumers. That is when transmission and distribution play their role in the process. They are in charge of bringing electricity to all the consumers.

To understand what can affect energy prices, an explanation of how the market works is needed. On the one hand, every generator company must make an offer to sell the energy they produce. This offer must contain the price and the amount of energy they are selling.

On the other hand, supply companies make an offer too. In the offer appears the amount of energy they want to buy and the price they are willing to pay.

Both offers must be made for every hour of the day. OMIE (Spanish Division of the Iberian Market Operator) receives all the offers and thanks to a matching process it sets a price for every hour of the next day.

One of the aims of renewable energy is to decrease energy prices. The main reason why they

can do that is because of their low costs. The sources used are meteorological conditions, so the price is zero. That is why the price is lower, because they do not need to offer at a high price in order to be economically profitable.

2.2. Market evolution

To prove it, a comparison between the average prices and the percentage of renewable installed capacity in different years is required.

The average energy price in 2012 was 47.23 €/MWh [8].

Figure 8. Distribution of installed capacity in Spain in 2012 [8]

In the distribution of the installed capacity, the most remarkable aspect is the little percentage of renewable technologies.

Comparing it, for example, to the next year, 2013, some changes can be observed. The average energy price of 2013 was 44.26 €/MWh [8].

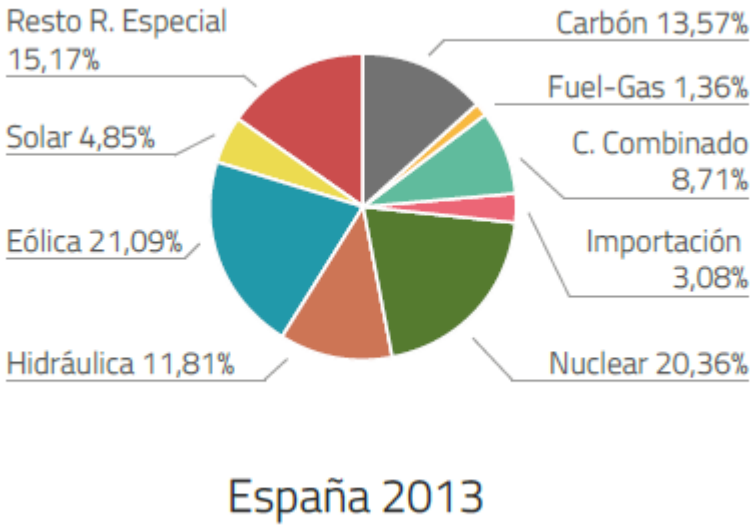


Figure 9. Distribution of installed capacity in Spain in 2013 [8]

As can be seen in figure 9, the percentages of renewable energies increased a lot in only one year. Solar, wind and hydraulic suffered a rise in its installed capacity what resulted in a decrease in the average energy price of that year.

In the year 2014 the average energy price was 42.13 €/MWh [8], and the distribution of the installed capacity followed the trend, increasing the amount of renewable energy.

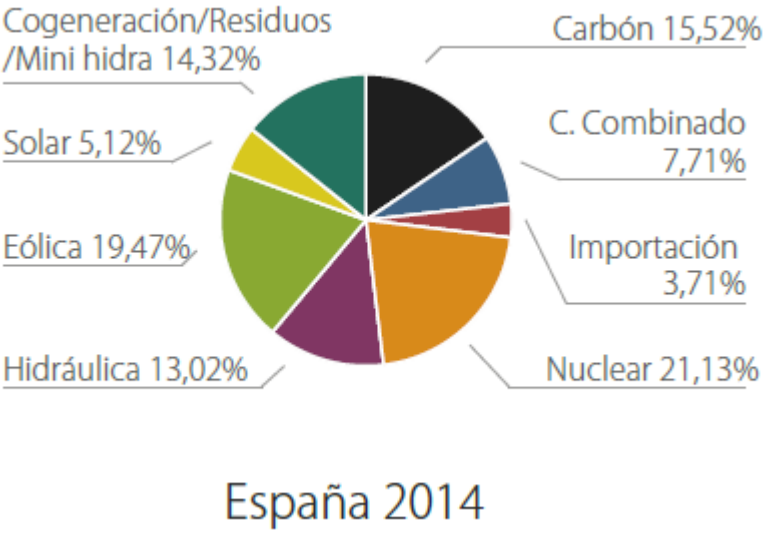


Figure 10. Distribution of installed capacity in Spain in 2014 [8]

In 2015 the situation changed. The average energy price reached a value of 50.32 €/MWh [8]. This increase in the price is easy to explain looking at the percentage of the installed capacity.

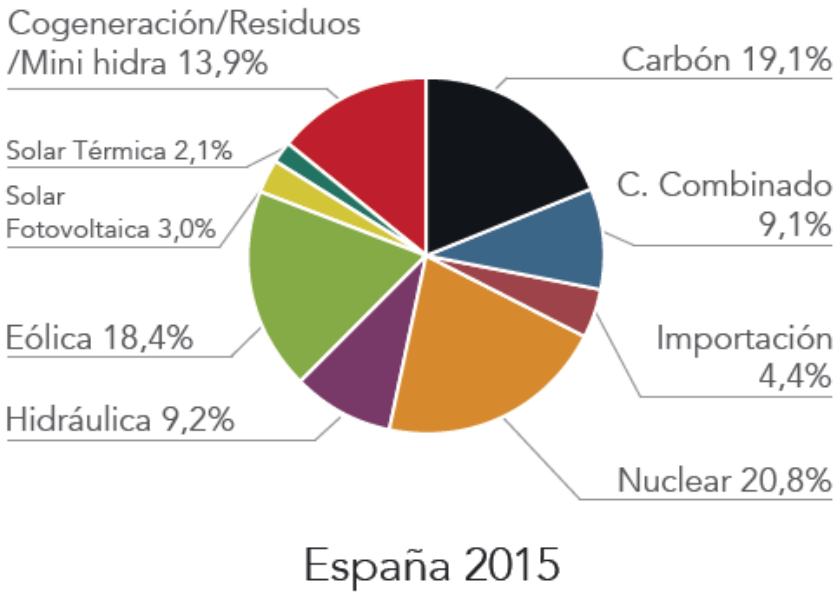


Figure 11. Distribution of installed capacity in Spain in 2015 [8]

As can be observed, hydraulic energy decreased by almost 4 %. Wind energy also reduced its percentage of installed capacity and solar energy was the only renewable one which stayed steady. Due to the reduction of renewable energies, technologies like coal, combined cycle. Using those technologies raised the price.

This year was the first one where solar photovoltaic and thermal solar energy were first differentiated. This was because of the huge increase solar photovoltaic experienced that year. Thermal solar energy was not seen as profitable as photovoltaic, so inversions on those projects decreased in favor of photovoltaic ones.

Then in 2016 the average energy price was 39.67 €/MWh [8], one of the lowest in history.

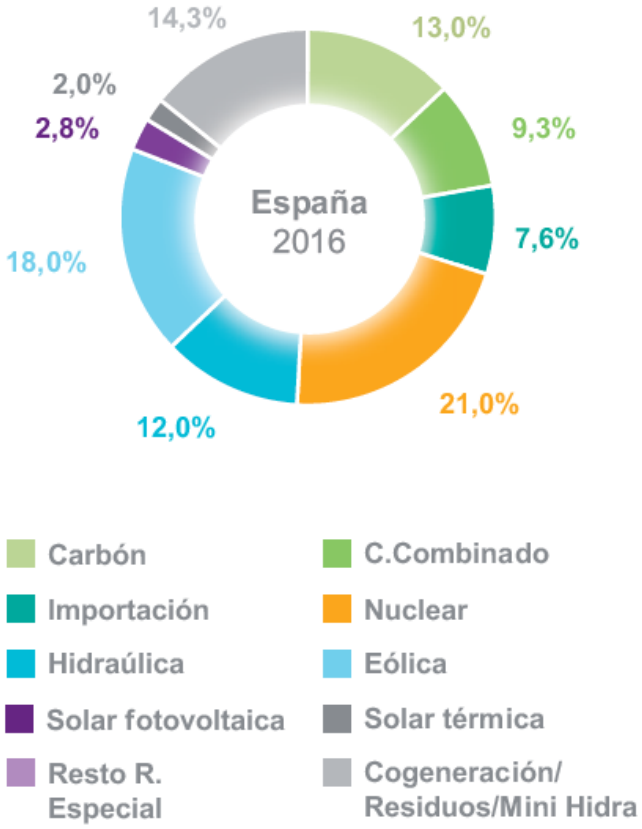


Figure 12. Distribution of installed capacity in Spain in 2016 [8]

As can be appreciated in figure 12, everything stayed steady except for hydraulic and imports, which increased, and coal that decreased. Imports are energy obtained thanks to the interconnections to other countries such as Morrocco, France and Portugal. Those facts resulted in a high decrease in energy prices, because renewable energies took back their importance in the energy system.

These imports are very useful for Spain. Cheaper energy can be bought in other countries and transported through electricity grids that connect the countries. It can also be seen as a huge battery, where energy can be stored, sell it when there is an overproduction, and make use of it, buy it when there is an increase in the demand, what most of the time cheapens energy prices.

But in 2017 the price was high again, 52.24 €/MWh [8].

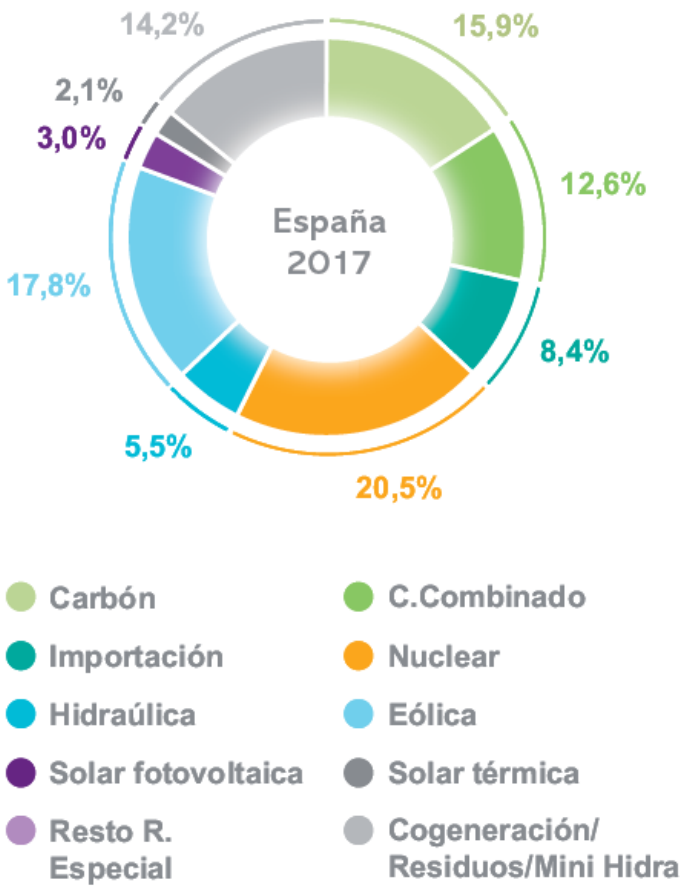


Figure 13. Distribution of installed capacity in Spain in 2017 [8]

The remarkable facts this year were that hydraulic and wind energy reduced their percentages and coal and combined cycle increased. That meant a rise in nonrenewable energies and a reduction in renewable ones, which resulted in a growth of the price.

Although, if the price in 2017 was high, in 2018 it became the highest of the decade reaching a value of 57.3 €/MWh [8]. It increased 9 % from the previous year's price.

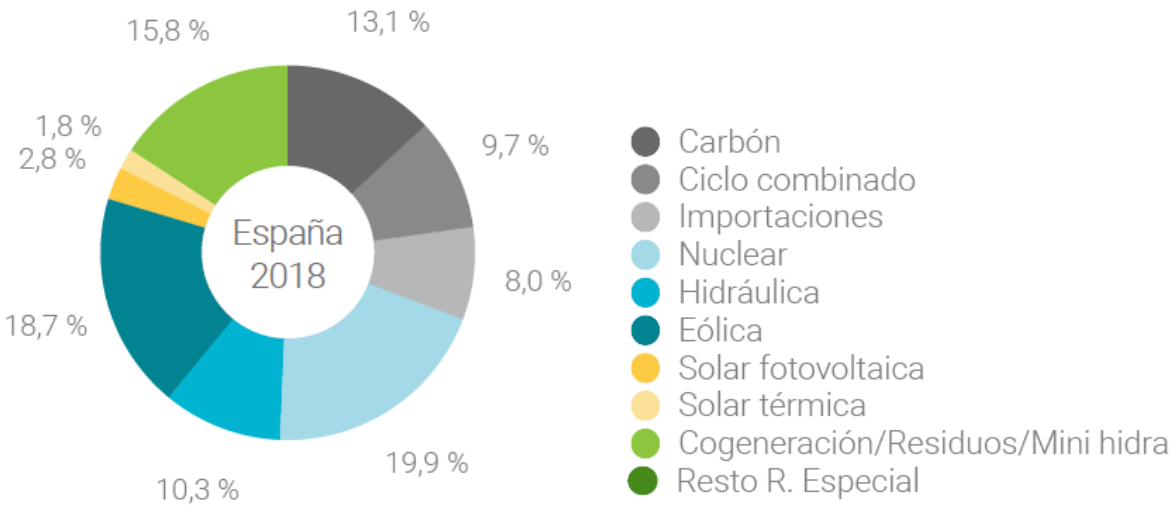


Figure 14. Distribution of installed capacity in Spain in 2018 [8]

In this year there was a reduction in coal and combined cycle and an increment in hydraulic and wind energy. With this information the regular thing would be a decrease in energy price, but that was not what happened.

The main reason to explain this particular situation is the increment in the price of CO_2 emission allowances. Coal and combined cycle plants must pay fines for the CO_2 emission they emit during the production process. Hence, although the amount of installed capacity of coal and combined cycle reduced their values, the prices in their offers were higher because it was more expensive for them to generate the energy they sold, due to the increase in the price of CO_2 emission allowances.

The situation changed again in 2019, when the average energy price was 47.68 €/MWh [8].

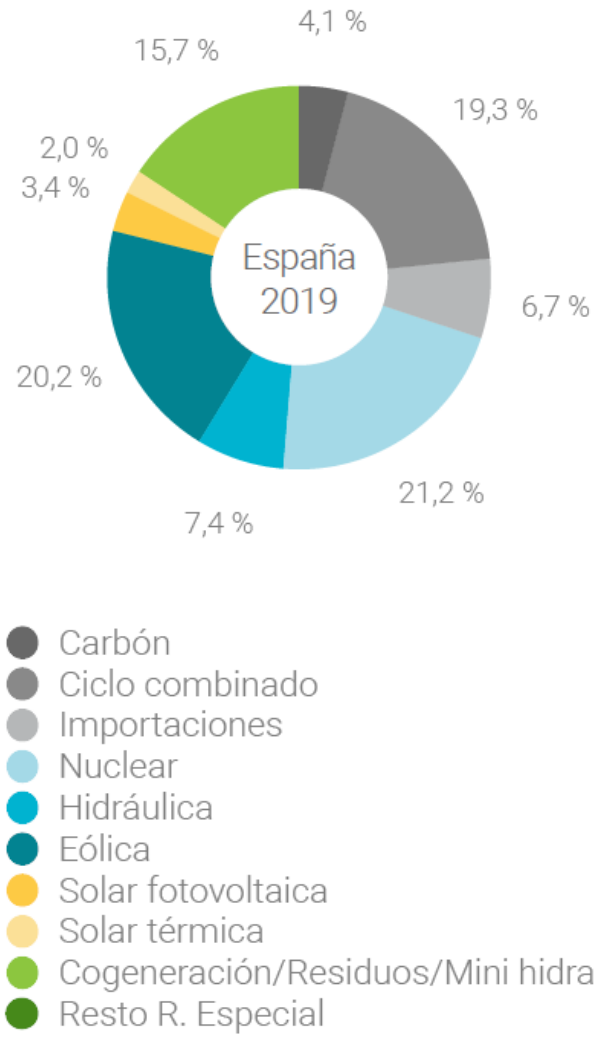


Figure 15. Distribution of installed capacity in Spain in 2019 [8]

In this year hydraulic energy reduced its percentage but solar, pointing out that photovoltaic energy reached the 3 %, and wind rose their values. Also, CO_2 emissions suffered a decrease, so the energy price reduced to a value which followed the trend experienced in the previous years.

The next year, 2020, the price registered was 33.96 €/MWh [8], one of the cheapest of all times. It suffered a decrement of 29 %.

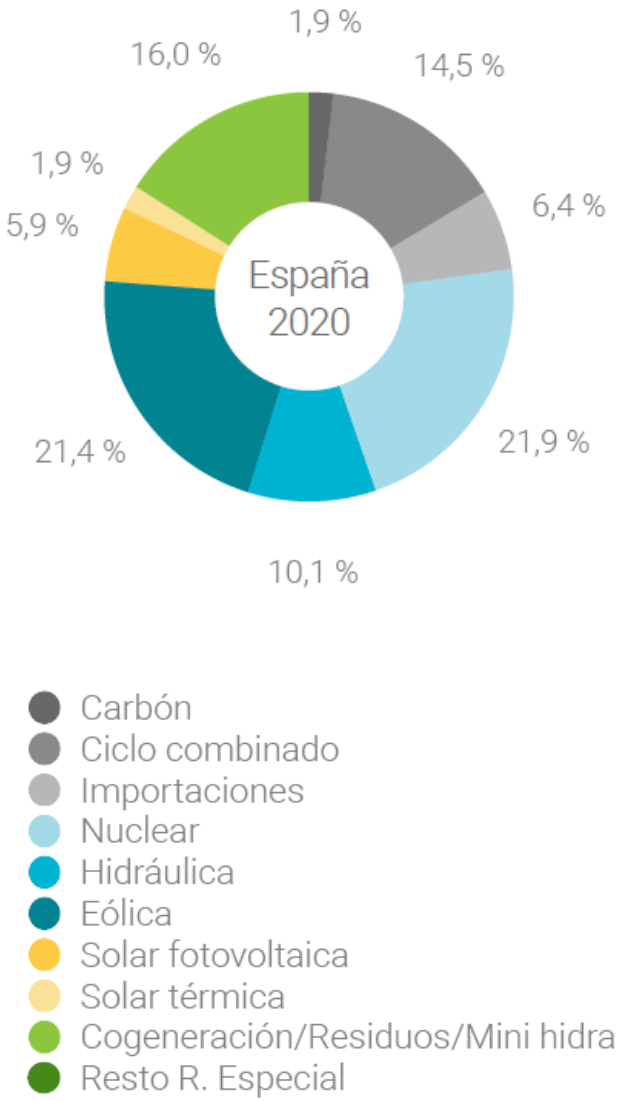


Figure 16. Distribution of installed capacity in Spain in 2020 [8]

On the one hand, as can be observed in the figure, nonrenewable energies like coal and combined cycle decreased their amounts of installed capacity.

On the other hand, renewable energies increased their percentages. Hydraulic reduced its value in favor of wind and photovoltaic solar, whose growth was increasing every year.

During that year quarantine took place, so it brought an unusual situation for us which had an impact in all the economic sectors, including the electricity one.

The impact it had is obvious, a reduction in energy demand. If everybody was locked at home and could not commute to their workstation, there was a lower necessity of energy. Imagine for example the case of a cinema. During quarantine nobody was allowed to leave their houses, so business like cinema which depends on the physical presence of people, had to close temporarily.

All these facts resulted in a decrease in energy prices.

Then the next year, 2021, one of the highest prices in the history of the electricity market was registered, 111.93 €/MWh [8].

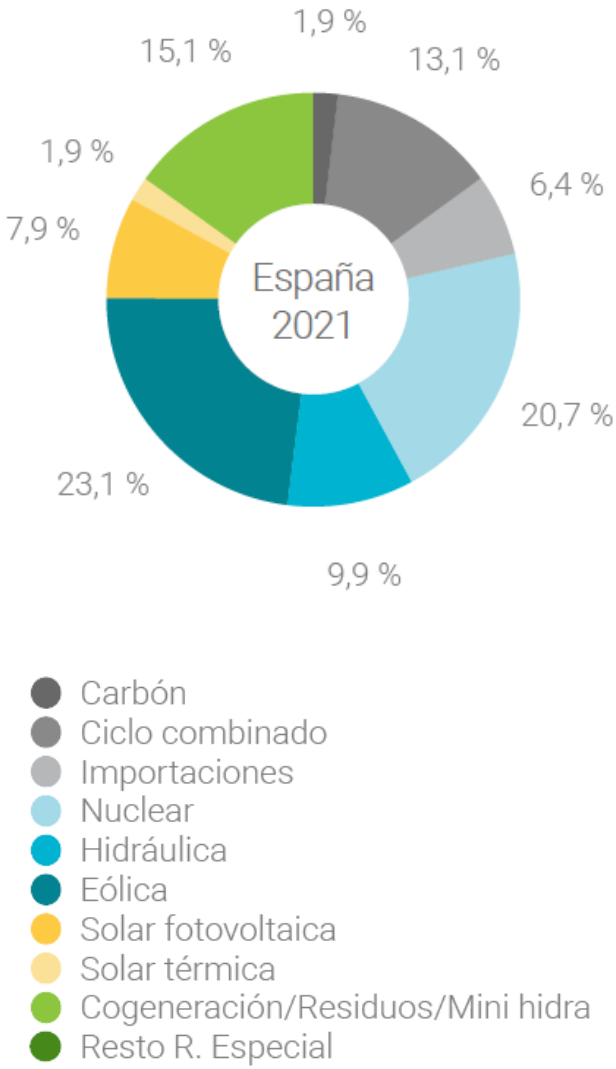


Figure 17. Distribution of installed capacity in Spain in 2021 [8]

This year followed the trend of the previous one, a decrement in coal and combined cycle energy and an increment in wind and photovoltaic energy. Therefore, the energy price should have reduced again, but that was not what happened.

In this year the price of the imports increased, reaching a value of more than twice the previous year one.

Another aspect that needs to be remarked on is the natural gas price. In 2021 it started

growing and registering values never seen before [9].

Natural gas has a crucial role in the market, because combined cycle can be considered as the technology which sets the energy price.

Non-plannable forms of energy like photovoltaic and wind have preference to sell their energy in the market, that is because they cannot produce whenever they want, they depend on meteorological conditions. Nuclear energy takes always part in the market because they sell their energy for a low price to make sure it is sold. For this type of plant is not profitable to stop production when the price is low, due to the high cost of resetting its components.

Most of the time, these technologies whose prices are low, are not enough to cover market demand. That is when combined cycle appears. Their energy is going to be bought because it is required to, so they offer it at a high price. If gas natural price increases, combined cycle will increase their selling offer too.

That is why energy price reached such a high value in 2021.

Things did not get better in 2022. The average energy price was167.52 €/MWh [8], the most expensive one in the history of the electricity market.

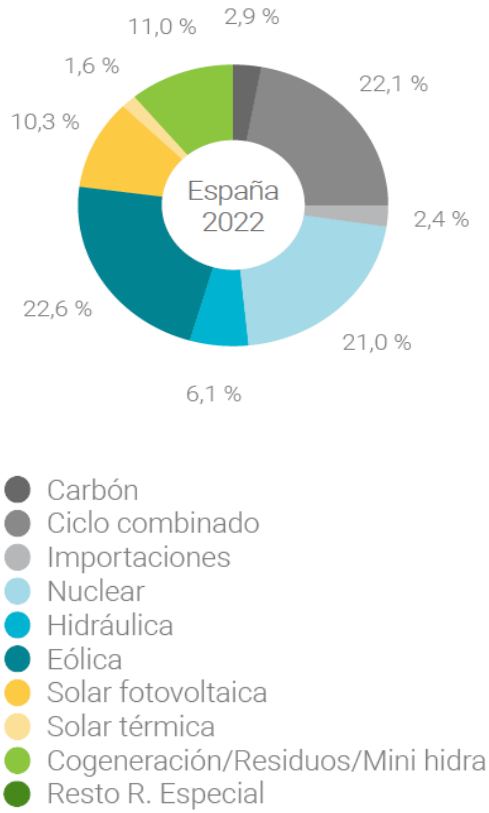


Figure 18. Distribution of installed capacity in Spain in 2022 [8]

The main reason to explain this outrageous price is the increase in the natural gas price [10]. This increment is because the conflict between Russia and Ukraine. This shortage of supply was a tool for political pressure.

What is more, meteorological conditions did not help either. Summer was a dry season, and we suffered a lack of wind too. That is why hydraulic and wind energies reduced their values of installed capacity and the only renewable energy which grew was photovoltaic one. Due to this decrease in renewable energies, technologies like coal and combined cycle were necessary to cover demand.

That is why the price grew that much and reached a value that is never going to be forgotten.

In 2023 the price was almost half of the previous one, 87.10 €/MWh [8].

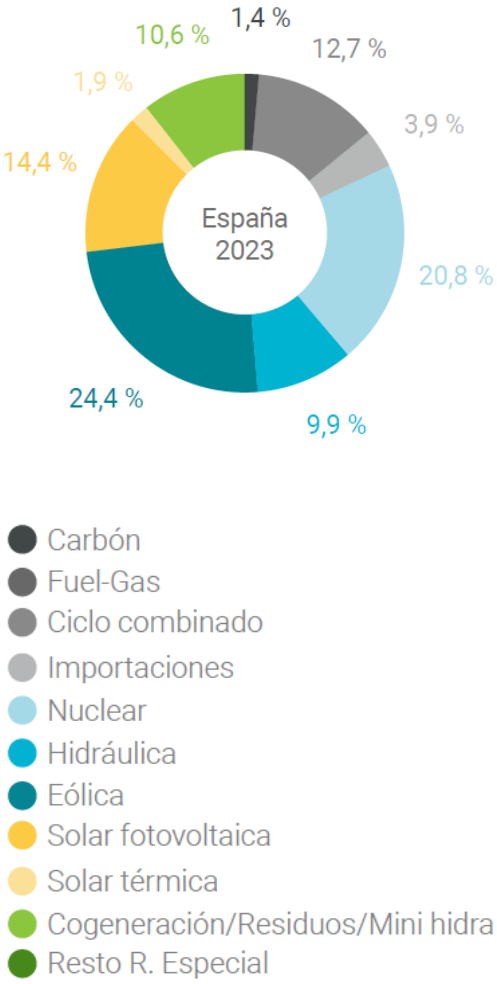


Figure 19. Distribution of installed capacity in Spain in 2023 [8]

As can be seen in figure 19, renewable energies increased their percentages while coal and combined cycle reduced them.

This increment in renewable energies added to the fact that the gas price was decreased, resulting in a more usual price but still far from what it used to be.

The year 2024 has started following the trend we had in 2023, reducing the average energy price, increasing renewable energies and decreasing nonrenewable ones.

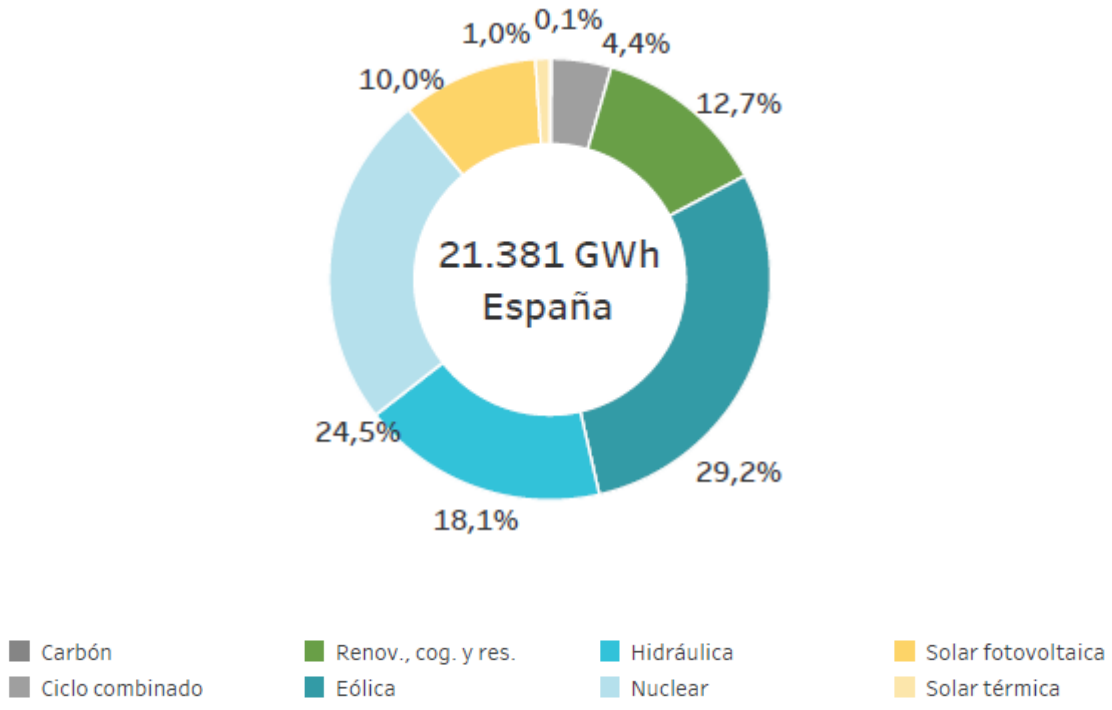
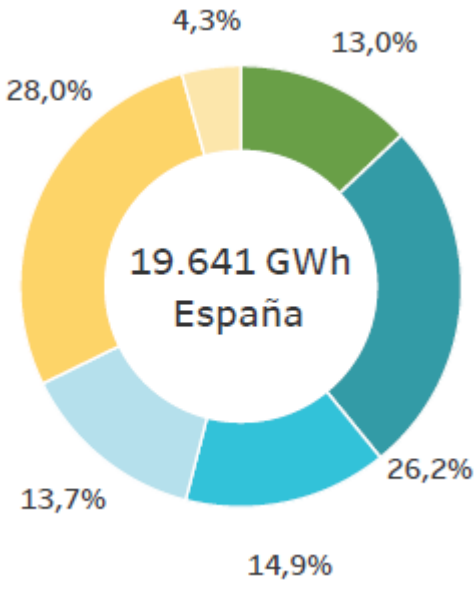


Figure 20. Distribution of installed capacity in Spain in January 2024 [8]

In January the price was 74.10 €/MWh [8].



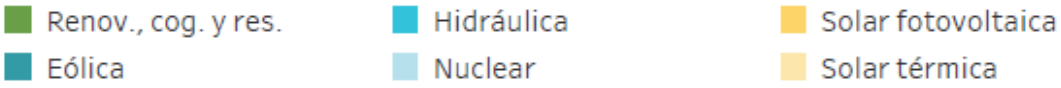


Figure 21. Distribution of installed capacity in Spain in May 2024 [8]

In May the average price was 30.40 €/MWh [8].

Comparing these two months, the importance of photovoltaic energy is remarked. As can be seen hydraulic and wind energy decreased and nuclear energy too, technologies which cheapen energy prices. But photovoltaic installed almost a third part of the total capacity, so combined cycle and coal were not necessary. That is the main reason why the energy price this month was so low.

2.3. Technologies evolution

To understand the evolution of energy in Spain it is unavoidable to analyze the development of the most important technologies used. In terms of contribution to the electricity market, there are five technologies that highlight upon the rest. These five technologies are coal, combined cycle, nuclear, wind, solar and hydraulic.

Firstly, non-renewable energies like coal and combined cycle have been reducing their contribution to the installed capacity during all these years while nuclear energy has stayed steady.

The combined cycle has always had the same percentage of contribution, an average of 12 %, but in 2024 it has suffered a major decrease, and it is not even appearing in the percentages of contribution to the installed capacity in some months like May.

The reduction in the importance of coal in the production of energy proves that measurements for decarbonization are being followed. The decrease from a 18.63 % in 2012 to a 1.4 % in 2023 shows that Spain is leaving apart this technology, whose cost and pollution are not ideal for the bright energy future.

Nuclear energy is the steadiest technology of all. It has always had a value similar to 20 % of the installed capacity. The reason why it has always had a significant participance is that its price is low because of the necessity they have of being part of the market, so production is not interrupted.

Secondly, renewable energies have increased their installed capacity during all these years. Wind energy has done it gradually, while photovoltaic energy with giant steps. Since it first appeared in 2015 with a 3 %, it has grown so fast. It has become one of the biggest technologies in terms of installed capacity.

Hydraulic energy, instead, has stayed steady installing an average of 10 % of the total capacity.

The year 2024 has started with an unusual situation. Some hours a day, energy price is zero

or even below sometimes. That is what happened on the first of April.

Figure 22. Energy price in Spain on the first of April 2024 [8]

As can be seen in figure 22, energy prices reached values very close to zero during almost the whole day. The explanation why this happened for the first time on the first of April, and it has been repeating for some days, is simple.

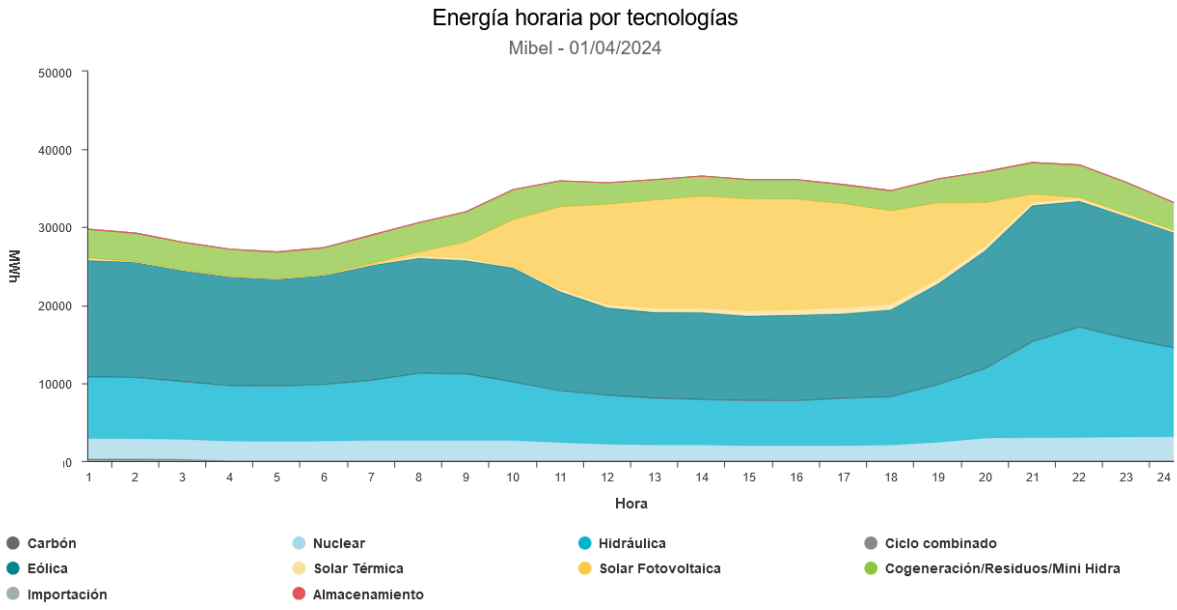


Figure 23. Hourly energy by technology in Spain on the first of April 2024 [8]

Energy prices drop sharply when the offer is bigger than the demand, the same happens in any other market. In the case of the first of April, apart from the offer being higher than the

demand, meteorological conditions played an important role. On this day, a great storm, called Nelson, arrived and brought wind and rain so it helped wind and hydraulic energy. Also, photovoltaic energy produced during the day. All that added to the fact that it was holiday in some parts of Spain, what decreased the demand, made that day to become a milestone for electricity market.

When energy prices are below zero euros, it may be because energy producers, foreseeing that prices are going to drop, offer their energy at a very low price, even below zero, instead of not being part of the market. If they do not sell their energy, they will lose the money invested to produce it.

Nuclear plants even prefer to sell their energy at a very low price rather than interrupting production, because restarting a nuclear reactor is expensive.

There are some renewable plants which receive a subsidy to generate energy so although the energy price is low, if they are going to get paid for producing energy it is still a profitable situation.

2.4. Future trends

In the future [11], the trend towards the growth of renewable energies is going to continue. Currently, Spain is one of the fifteen higher consumers of green energy. In 2022 green energy represented 42.2 % of the energy national mix and in 2023 that value rose to 50.8 %. It is foreseen that in 2024 this value will increase again and reinforce the idea that Spain is following a trend which in the future will bring lower energy prices and help to achieve all the environmental goals.

Apart from renewable energies, the government is also investing in other technology which is considered to be the solution to stabilize energy prices. This technology is ESS, Energy Storage Systems. These systems work with the idea of storing energy when the price is low and then using it when the price is high. The system that is most being developed lately is BESS, Battery Energy Storage System. Although some new projects use this technology, ESS is still a challenge that needs to be developed properly.

3. NORWAY

3.1. Introduction

The Norwegian electricity market is well-structured and liberalized. It is characterized by the huge amount of renewable energy, remarking hydraulic energy which is crucial to achieve their generation goals.

This market is part of one of the biggest electricity markets in the whole world, the Nord Pool which operates in the Nordic and the Baltic countries. It is known for being one of the cheapest markets in the world. The countries taking part of this market are Norway, Sweden, Finland, Denmark, Estonia, Lithuania and Latvia.

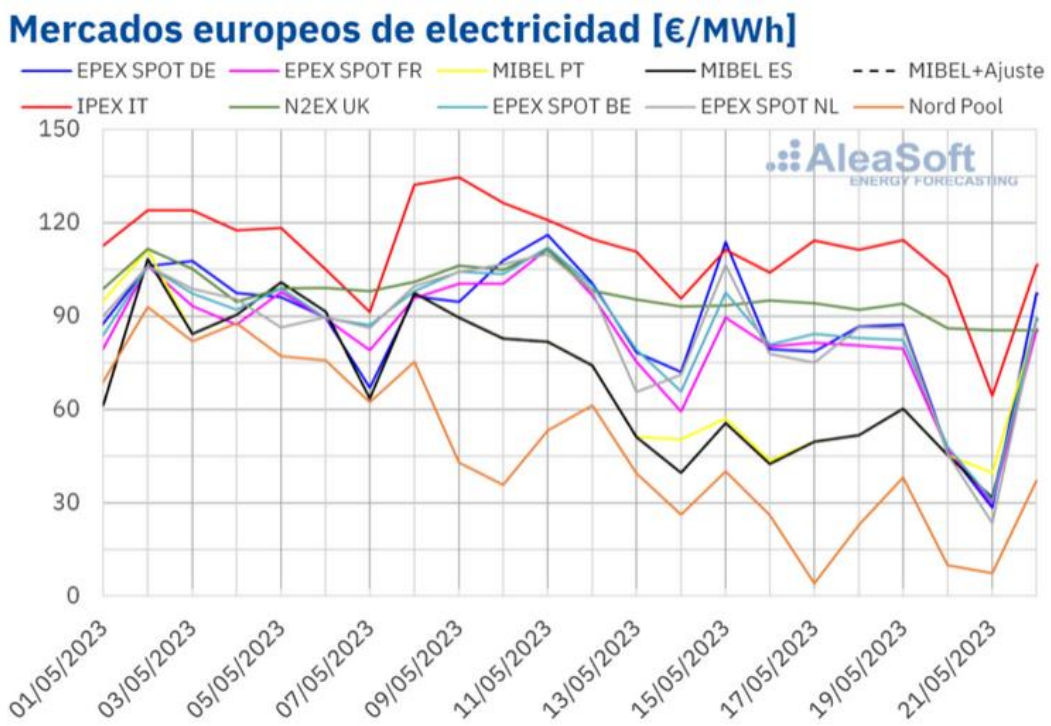


Figure 24. Energy prices of different European markets €/MWh in 2023 [12]

Figure 24 shows the electricity price of the European markets for each month in 2023. As can be

seen, Nord Pool was the market in Europe with the lowest price.

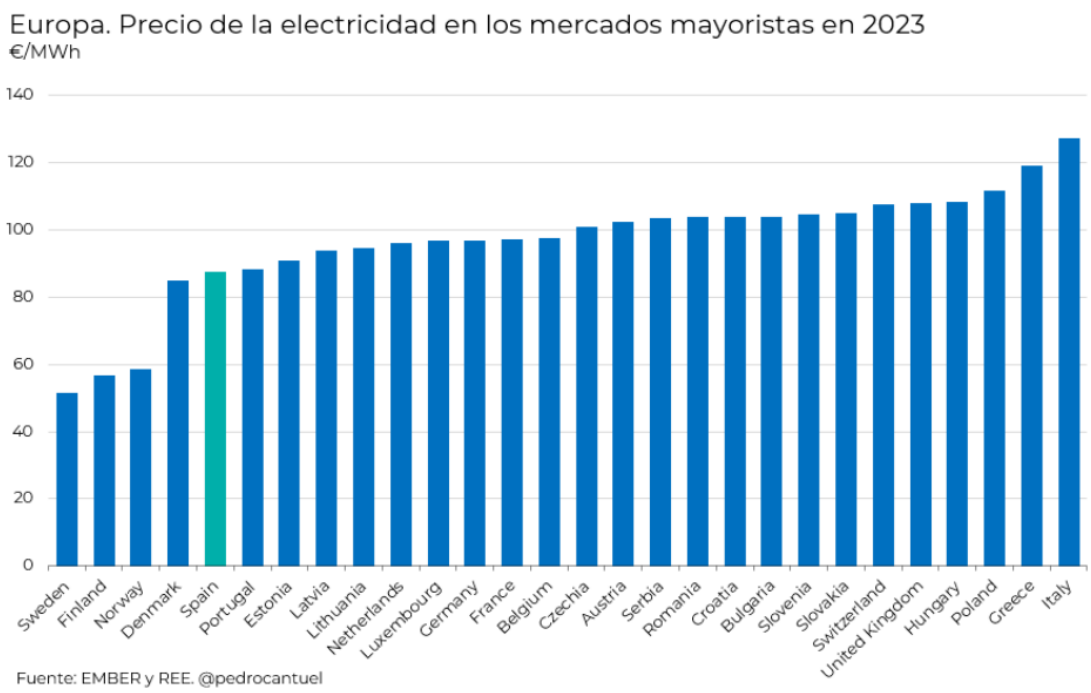


Figure 25. Energy prices of different European countries in €/MWh in 2023 [13]

To emphasize the fact that Norway has one of the lowest energy prices in Europe, in figure 25 appears the average electricity price of every European country in the year 2023. The first four countries are part of the Nord Pool.

From the generation to the final energy consumption, there are four remarkable steps:

3.2. Generation

The first is generation and takes place in the electric plants. Hydraulic energy represents the highest production of electricity in Norway, more than any other technology. To be aware of the importance of this technology in the generation mix, in 2021 Norway had 1660 hydroelectric power stations. These plants produced 34813 MW of the total installed capacity [14].

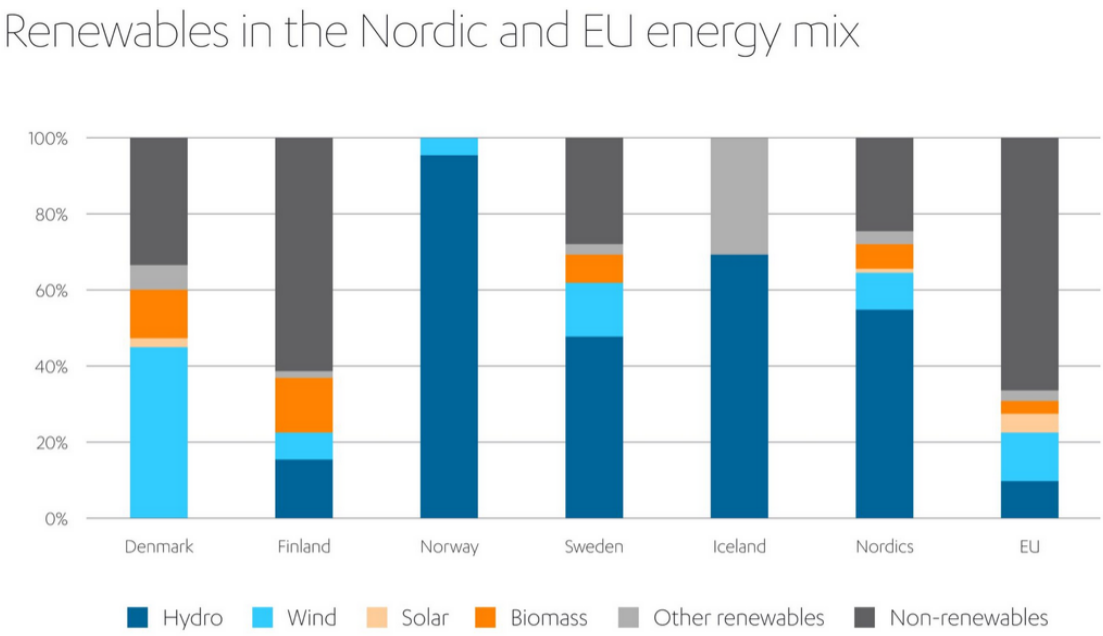


Figure 26. Percentages of energy technologies used in energy mix in different European countries [15]

In figure 26 appears the percentages of installed capacity during 2019 for some Nordic countries. Due to the massive amount of hydraulic energy generated, it is possible to meet the demand nearly just with this technology.

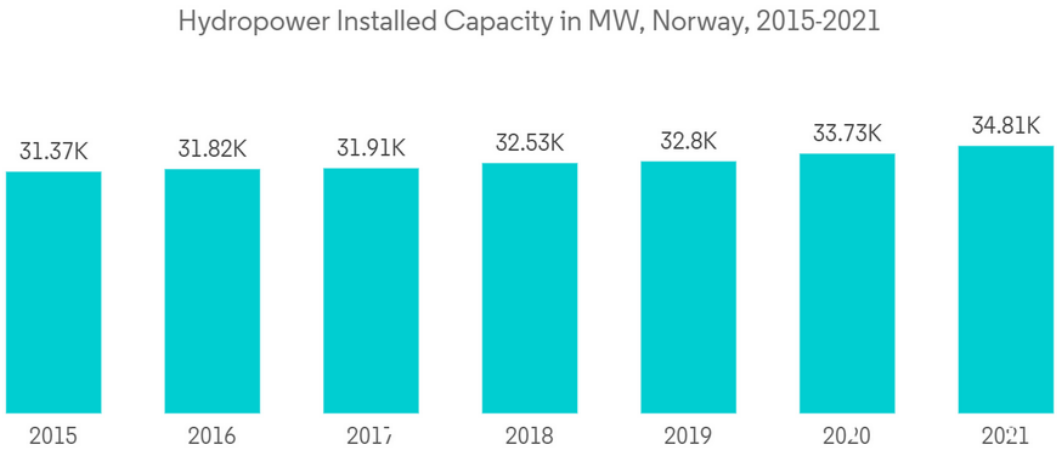


Figure 27. Hydropower installed capacity in MW in Norway from 2015 to 2021 [14]

Figure 27 shows the growth in hydropower installed capacity from 2015 to 2021, a very similar value to that currently installed.

The reason why this technology is vital for the country is topographic. There are abundant valleys and steep rivers, that makes it suitable for hydraulic generation. Norway has more than 1000 water reservoirs for energy storage with a capacity higher than 865 TWh. The biggest one is named *Blåsjø* and has a capacity of 7.8 TWh [16].

It is foreseen that hydraulic energy will continue with its dominance, but solar and wind energy

will increase every year.

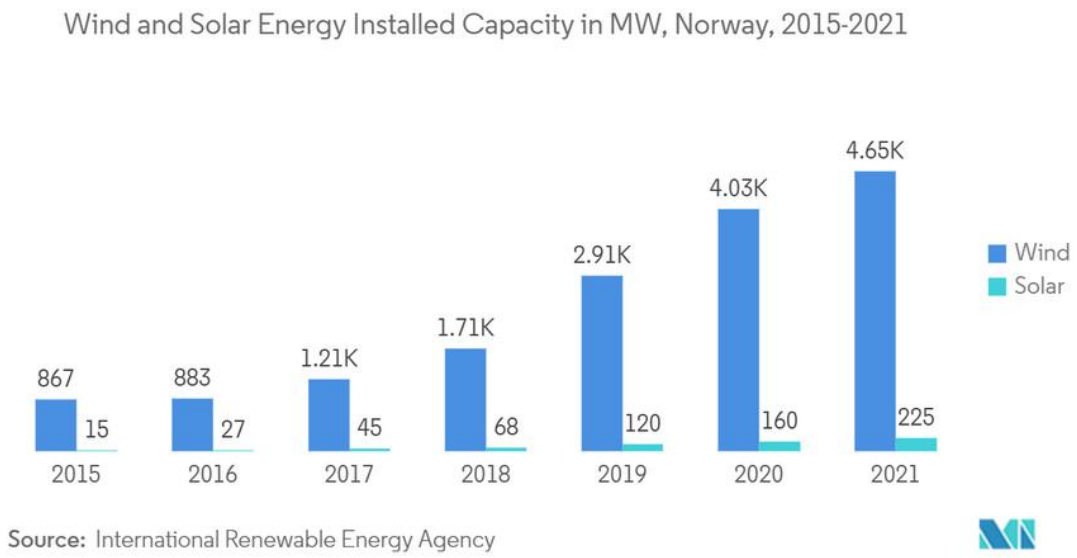


Figure 28. Wind and solar installed capacity in MW in Norway from 2015 to 2021 [14]

As can be seen in figure 28, there has been a huge increment in wind energy during the last years. Solar energy is increasing too, but at a more reduced speed.

Wind energy has suffered an increase of more than 3500 MW in only 6 years, while solar energy has risen its value from 15 MW to 225 MW.

Norway – Electricity Generation					
Date	**Installed Capacity (MW)**	**Generation (GWh)**	**Renewable Installed Capacity (MW)**	**Renewable Generation GWh**	**Renewable Percentage (%)**
2022	40.54	143.383	38.204	143.102	99.8
2021	40.296	157.05	37.96	156.345	99.55
2020	39.091	153.887	36.552	152.171	98.88
2019	36.986	131.831	34.502	129.65	98.35
2018	35.469	144.944	32.986	142.456	98.28
2017	34.325	147.374	31.721	144.958	98.36

2016	33.887	147.299	31.278	144.785	98.29
2015	33.957	141.958	30.961	139.649	98.37
2014	33.815	140.242	30.901	137.527	98.06
2013	33.602	132.633	30.651	130.032	98.04
2012	32.975	145.661	30.013	143.177	98.29
2011	32.197	125.262	29.28	121.502	97
2010	31.784	122.150	28.923	117.598	96.27

Table 1. Norwegian electricity generation [17]

Table 1 shows the amount of installed capacity and generation in Norway from 2010 to 2022. It also includes the percentages of renewable energy in the installed capacity and generation. It has been growing every year due to the recent increment of solar and wind energy.

An important company which manages many of the hydraulic plants in Norway is Statkraft, and it is one of the biggest renewable energy producers of Europe. This company is not restricted to operate in Norway with hydropower energy. It has plants in many territories and manages also solar and wind facilities.

3.3. Transport

The second step is energy transport. Statnett [18] is the market operator and is also in charge of energy transmission. It owns the electricity grids and makes sure that there is always a balance between consumption and production.

3.4. Distribution

The third one is energy distribution. There are many companies which have jurisdiction. They operate regionally, to be able to distribute energy to all the consumers in an easier way.

3.5. Electricity market

Finally, the last step is the Norwegian electricity market. As explained before, it is part of the Nord Pool. Statnett is the market operator, so one of its duties is to establish energy prices.

In the Norwegian electricity market, there are two characteristics that makes it one of the cheapest in Europe:

First, the big amount of renewable energy produced. These technologies supply 98 % of the electricity consumed.

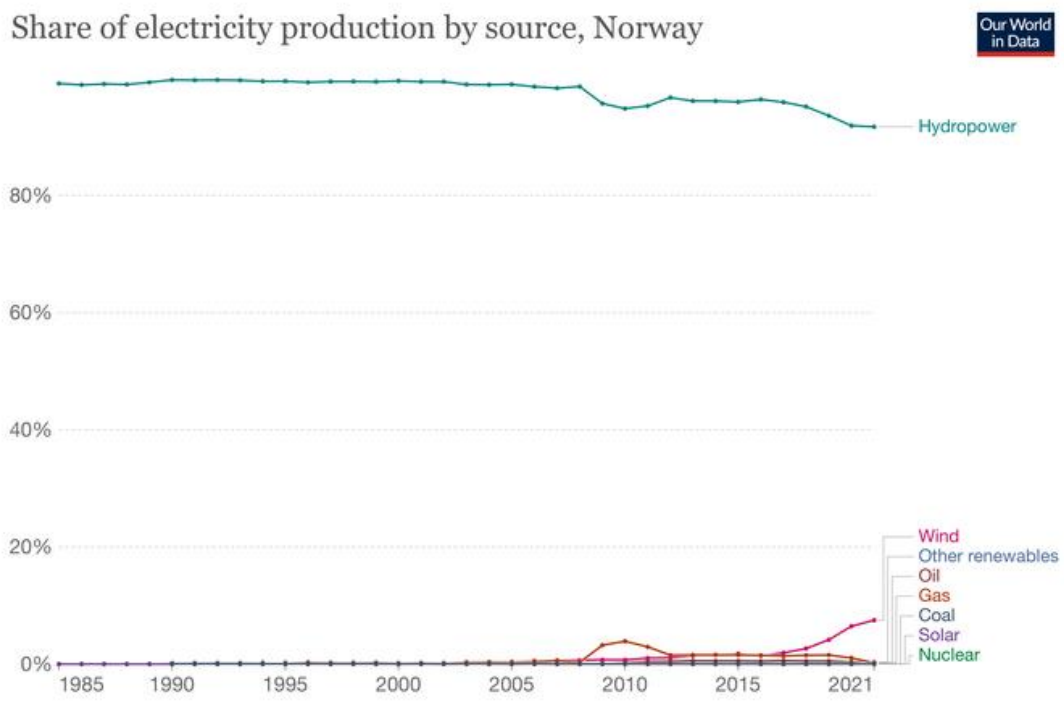


Figure 29. Share of electricity production by source in Norway [19]

Figure 29 shows the percentages of electricity production from 1985 to 2021 in Norway. Hydropower supplies almost enough energy to cover the demand and in the last years wind energy production has increased its value.

Secondly, its international interconnections. Because of being part of the Nord Pool, it has many connections to the other countries of this huge market, what makes it very easy to export and import energy from these countries whenever required.

In 2021 Germany and Norway connected their electricity markets thanks to NordLink [20], a 623 kilometers submarine cable to help Germany and other European countries in the energy transition.

Figure 30. NordLink [21]

Nordlink connects the Norwegian city of Tonstad to the German region of Wilster.

Both sides benefited from this contract. Germany can buy cheap and green energy and Norway is becoming one of the most important energy suppliers in Europe.

Apart from the connection with Germany, Norway has many other countries, like for example, the United Kingdom. This is possible because the renewable energy Norway produces is hydraulic, a manageable technology that can be used whenever it is necessary. If its major asset was wind or solar energy, there would be a problem because it is unknown if the energy produced is going to be higher or lower than what it was established.

Due to these characteristics, this market is considered to be one of the most profitable in the world.

3.6. Carbon emissions

A negative aspect is carbon dioxide emission, unlike what can be expected. This amount of carbon emission is due to the fossil fuels industries, whose oil and gas activities emit greenhouse gases.

<< 2021	Comparativa: Emisiones de CO2 2022			
Países	CO2 Totales Mt	CO2 Kg/1000$	CO2 t per capita	Var.
Dinamarca [+]	29,159	0,08	4,99	-5,00%
Trinidad y Tobago [+]	29,217	0,81	21,17	-0,16%
Nueva Zelanda [+]	32,371	0,14	6,58	-7,07%
Hong Kong [+]	32,439	0,08	4,24	-6,30%
Eslovaquia [+]	35,233	0,20	6,46	-2,82%
Túnez [+]	35,915	0,27	2,96	1,26%
Suiza [+]	36,105	0,06	4,11	-1,96%
Azerbaiyán [+]	37,130	0,24	3,62	-0,87%
Finlandia [+]	37,325	0,14	6,64	-4,74%
Myanmar [+]	37,394	0,17	0,67	-0,09%
Irlanda [+]	37,786	0,07	7,61	3,71%
Suecia [+]	37,850	0,07	3,69	-1,11%
Baréin [+]	37,955	0,50	21,31	-1,74%
Portugal [+]	41,282	0,11	4,07	4,78%
Noruega [+]	42,284	0,11	7,62	-5,32%
Ecuador [+]	46,107	0,24	2,59	5,90%
Hungría [+]	47,292	0,14	4,95	-7,76%
Bulgaria [+]	50,103	0,29	7,32	10,17%

Figure 31. Carbon emissions in 2022 in different countries [22]

In figure 31 appears the amount of carbon dioxide emitted in cubic tons in some countries in the year 2022.

As it can be seen in the graph, Norway is far from being one of the lowest carbon emission countries in Europe. Because of that, Norway was one of the first countries to ratify the Paris agreement whose main goal is to reunite all the nations to try to set the world on tracks towards the emission reduction and restrict global warming between 1.5 and 2 degrees above preindustrial levels [23].

Norwegian goal is reducing emissions at least 50 % in 2030, in comparison with the levels of 1990.

Norway – CO_2 Emissions			
Date	**Total CO_2 mt**	**Co2 kg/1000$**	**CO2 per capita**
2022	42.284	0.11	7.62
2021	44.243	0.12	8.04
2020	43.361	0.13	7.96
2019	44.607	0.13	8.26
2018	45.749	0.13	8.55
2017	46.348	0.14	8.74
2016	46.328	0.14	8.82
2015	47.225	0.14	9.08
2014	46.384	0.14	9.02
2013	46.232	0.15	9.11
2012	45.649	0.15	9.11
2011	46.121	0.15	9.32
2010	47.163	0.16	9.65

Table 2. Norwegian carbon emissions [24]

Table 2 shows the amount of CO_2 emitted in Norway from 2010 to 2022.

In 1990 carbon emissions were 36.455 metric tons. It is going to be hard to achieve its goal because instead of a reduction in the amount of emission, it has increased. But it is a fact that from 2010 to 2022 the tendency, which can be observed thanks to the data, is a reduction in carbon dioxide emissions.

3.7. Energy price

The most remarkable aspect of this market is its price. As can be seen in the figures above, Norway has one of the cheapest energy prices of Europe. To explain this fact, it is important to have in mind the most used technologies to produce energy in this country.

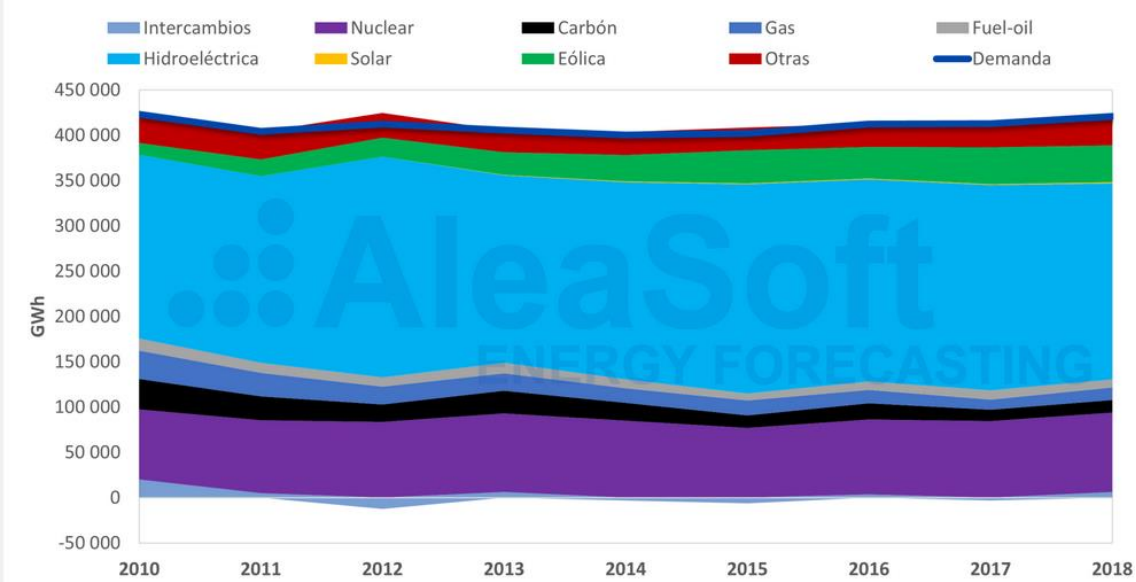


Figure 32. Energy technologies in Norway from 2010 to 2018 [25]

Figure 32 shows the different technologies used in Norway to produce energy from 2010 to 2018. As can be seen in the graph above, hydraulic energy is the most important one.

Solar and wind energies have been growing a lot these last years and the tendency for the next years is to continue with that increment.

Coal, oil and gas play a minor role, but its production is the main reason why CO2 emissions need to be reduced.

The other important technology is nuclear energy.

Norway – Energy Prices		
Date	**Energy price without taxes (€/kWh)**	**Energy price (€/kWh)**
December 2023	0.1521	0.1866
June 2023	0.1683	0.1919
December 2022	0.2751	0.2302
June 2022	0.2005	0.1994
December 2021	0.1752	0.2206
June 2021	0.1326	0.1826
December 2020	0.0927	0.1322
June 2020	0.0954	0.1355
December 2019	0.1264	0.1744
June 2019	0.136	0.1867
December 2018	0.1382	0.1907
June 2018	0.1254	0.1751

Table 3. Norwegian energy prices [26]

These are the energy prices in Norway from 2018 to 2023 in €/kWh. In 2021 and 2022 prices increased because of the consequences of Covid and the increment in gas price and the taxes for carbon emissions.

Energy prices are coming back to their regular values and the tendency for the future is to

continue with this reduction.

Prices are low because almost 100 % of the energy produced is renewable, what decrease the prices. Nuclear energy is also vital when renewable energies cannot cover the demand. This technology is non-renewable but is non-manageable too so that cheapens energy prices.

4. FRANCE

4.1. Introduction

France is the seventh global economic power and 31 of its companies [27] are among the 500 most powerful enterprises in the world like for example Orange or Airbus.

Característica	2022	2023*	2024*	2025*	2026*	2027*
Estados Unidos	25.464,48	26.854,6	27.741,12	28.765,96	29.902,87	31.091,59
China	18.100,04	19.373,59	20.881,37	22.407,69	24.035,81	25.722,41
Japón	4.233,54	4.409,74	4.526,48	4.731,5	4.923,43	5.077,12
Alemania	4.075,4	4.308,85	4.446,47	4.635,16	4.822,11	4.947,32
India	3.386,4	3.736,88	4.062,15	4.403,35	4.765,55	5.153,01
Reino Unido	3.070,6	3.158,94	3.375,22	3.573,61	3.792,71	4.015,52
Francia	2.784,02	2.923,49	3.018,89	3.133,4	3.232,74	3.321,71
Rusia	2.215,29	2.062,65	2.118,25	2.159,05	2.206,01	2.234,73
Canadá	2.139,84	2.089,67	2.178,82	2.280,96	2.385,4	2.492,36
Italia	2.012,01	2.169,75	2.217,75	2.285,28	2.347,43	2.406,85
Brasil	1.924,13	2.081,24	2.210,62	2.321,85	2.449	2.587,52
Australia	1.701,89	1.707,55	1.720,12	1.787,45	1.854,39	1.929,68
Corea del Sur	1.665,25	1.721,91	1.792,73	1.870,63	1.949,78	2.033,33

Figure 33. Global economic powers [28]

Figure 33 shows the countries with the biggest estimated GDP (Gross Domestic Product) from 2022 to 2027. As it can be seen, France is in seventh place.

The French electricity market is one of the biggest and more complex in Europe. During the 90's the market was liberalized [29], what allowed the entrance of new companies and opened energy generation and trade up to competition.

4.2. Nuclear energy

The most remarkable aspect is the number of nuclear plants in this country.

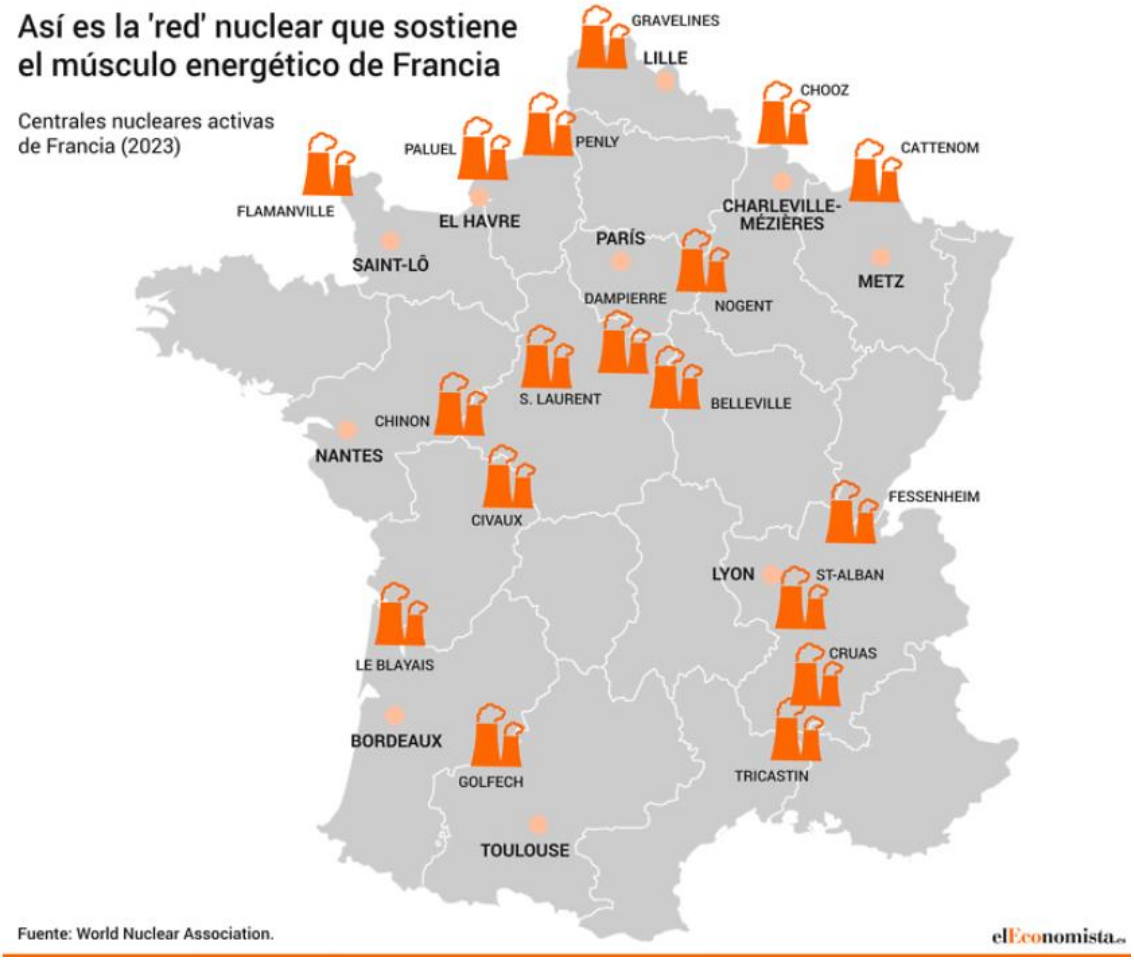


Figure 34. French nuclear reactors [30]

Figure 34 shows the active nuclear plants in France in 2023.

This market is characterized by the huge amount of nuclear energy. France has 56 nuclear reactors scattered throughout its territory as it can be seen in the previous image.

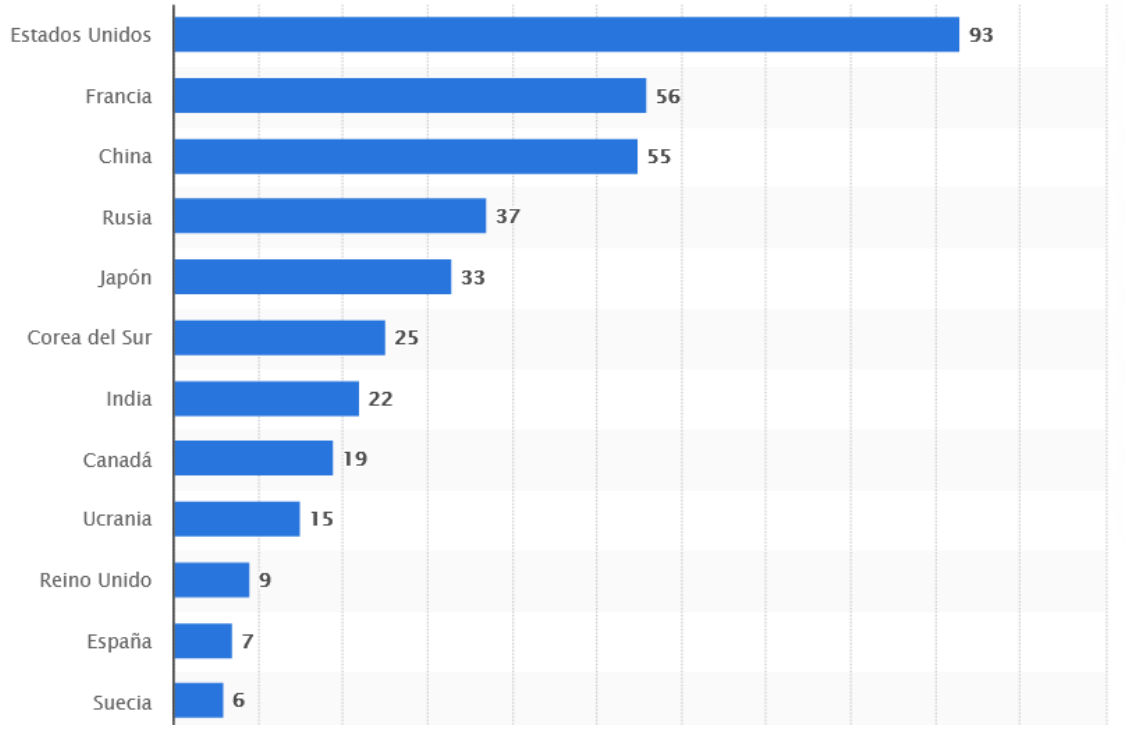


Figure 35. Countries and their nuclear reactors [31]

Figure 35 includes a list of the countries with the highest number of active nuclear reactors in 2023, being France the territory with the highest number in Europe.

The importances of nuclear power in France can be deduced given that 69 % of the electricity demanded in France is covered by this energy [32].

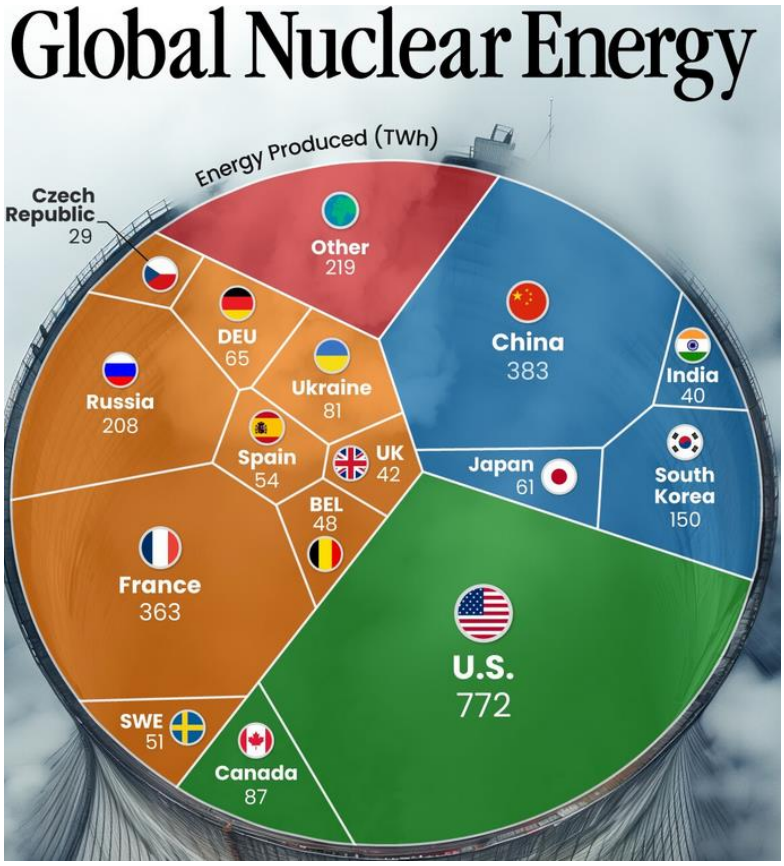


Figure 36. Global nuclear energy [32]

In figure 36, it can be seen the amount of nuclear energy produced in TWh in 2021. France is extremely superior to any other country in Europe.

To explain the main reason why nuclear energy plays such an important role in French energy generation, it is necessary to talk about the 70's crisis [33].

In 1973 the Arabian block of the Organization of Oil Exporting Countries (OPEC) declared an oil embargo against western nations because of the support they gave to Israel during the Yom Kippur war. This punishment measure led into an increment in oil prices, which was a total disaster because Japan, the United States and Europe consumed oil massively during those years. European countries had a huge dependance on this source.

Due to the unaffordable oil price and the supply problems, many countries tried to reduce their oil consumption giving more importance to other technologies. The United States and Canada opted for burning wood residue and France aimed for nuclear energy.

This situation has always been the same in France, nuclear energy has been in charge of producing 70 % of the energy consumed. But this scene changed in 2022 [34].

French nuclear generation disrupted in 2022 due to long maintenance stops and restrictions, because of rivers pollution. Nuclear energy reduced its production from 70 % of energy consumed to 40 %.

During that time, France was forced to import energy from the closest countries. This situation turned out to be a total disaster. As a result of these adverse events, wholesale price per megawatt increased 10-fold in one year. This panorama caused a huge commotion in France,

where people went out to the streets to manifest against the measurements imposed by the government.

The activity of 32 nuclear reactors stopped and production decreased drastically. In 2022 nuclear generation reached a value of 282 TWh, the lowest production level in three decades.

This situation continued at the beginning of 2023 but once the maintenance stops finished, nuclear energy started to produce as it was usual.

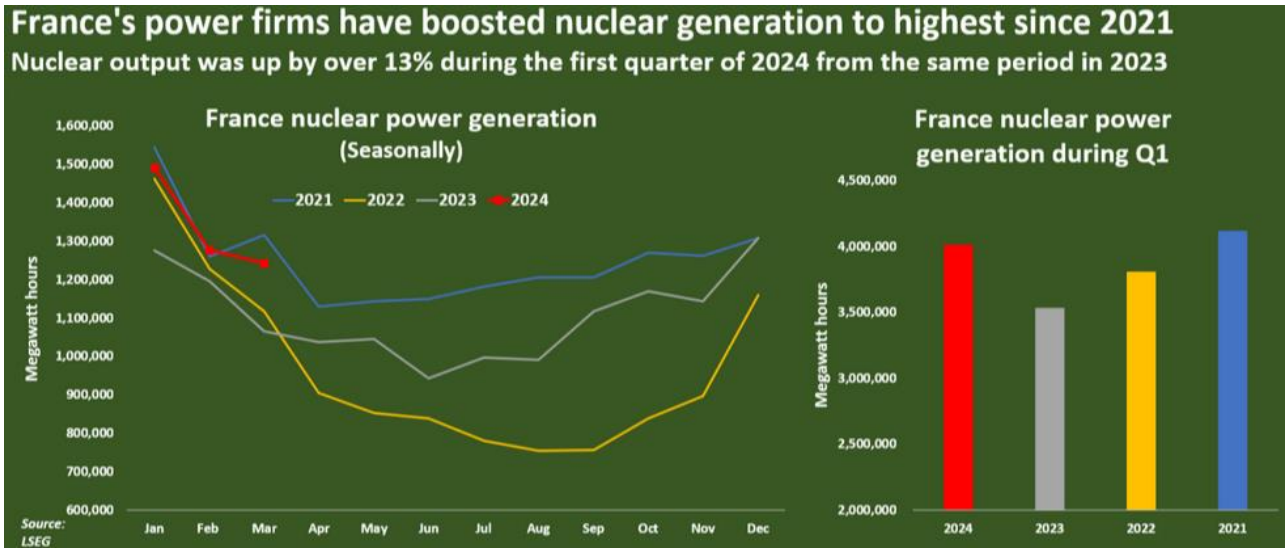


Figure 37. French nuclear power generation [35]

In figure 37 can be seen the nuclear production for every month from 2021 to 2024. The generation decreased in 2022 after the first quarter and did not come back to usual values until the end of 2023.

Nuclear energy production reached its highest value in three years during the first quarter of 2024.

4.3. Energy supplier

Another important characteristic is that France has become in 2024 the biggest energy supplier in Europe [30]. The total electricity sales in the first three months of 2024 have been 19684 GWh. Experts from LSEG (London Stock Exchange Group) estimate that the total annual sales will be 122.6 TWh, compared to 58.5 TWh of 2023. That means an increase of 141 %.

The demand in France has reduced this first quarter of the year because of the unusual warm weather in these months. 2023 has been the second hottest year in France since 1900, with an average temperature of 14.4 degrees. It is foreseen to keep growing in the next years. It can be expected to increase 2 degrees in 2030, 2.7 degrees in 2050 and 4 degrees in 2100 [36].

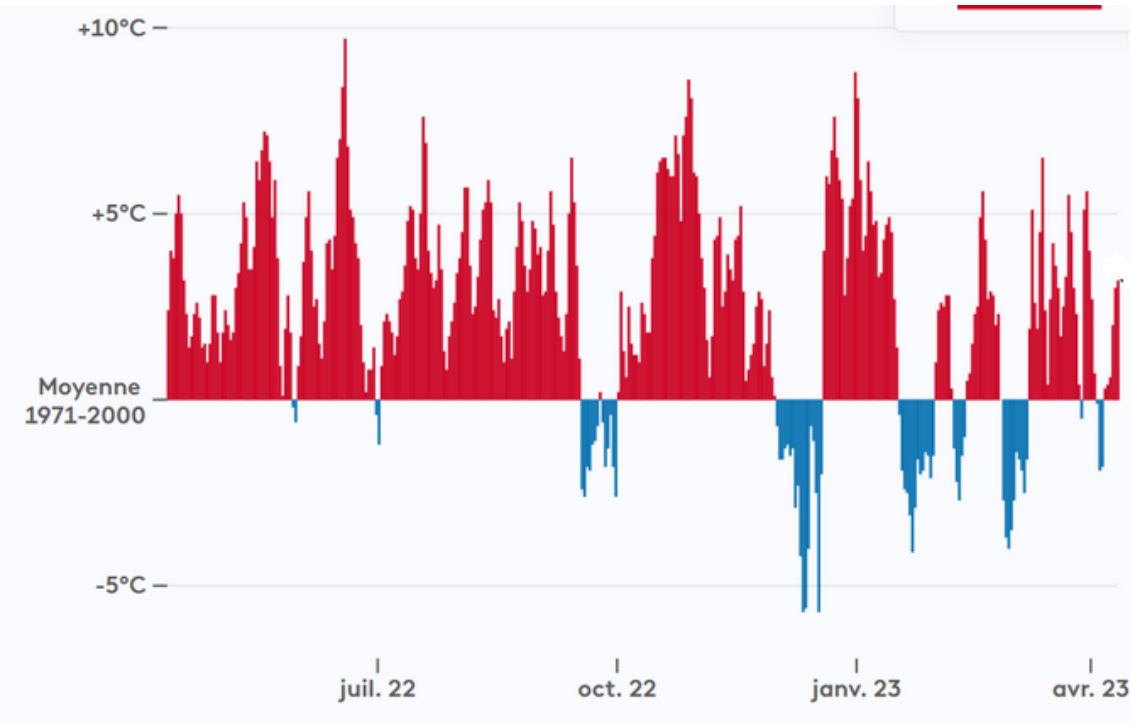


Figure 38. Surface average temperature in France [37]

In figure 38 appears the daily average temperatures deviations in one year in France compared to the average temperature between the years 1971 and 2000.

Due to this demand reduction, there was a major excess of energy production, what has allowed France to export much more energy than previous years. Germany and Italy have been the main customers.

4.4. Energy price

Thanks to all these aspects which affect directly to the French electricity market, its energy price has varied a lot in the recent years.

France – Energy Prices		
Date	**Energy price without taxes (€/kWh)**	**Energy price (€/kWh)**
December 2023	0.2161	0.2591
June 2023	0.1893	0.23
December 2022	0.1723	0.2204
June 2022	0.1566	0.2092
December 2021	0.1356	0.2022
June 2021	0.1289	0.1946
December 2020	0.1292	0.1958
June 2020	0.1242	0.1893
December 2019	0.1260	0.1913
June 2019	0.1148	0.1778
December 2018	0.1168	0.1799
June 2018	0.1134	0.1748

Table 4. French energy prices [38]

The table 4 shows the different energy prices in France from 2018 to 2023. As can be seen, it has been growing every year. In the last quarter of 2022 and in 2023 it reached a high level by historical standards.

This panorama made France to become one of the most expensive countries in Europe, in terms of energy price.

Energy Price		
Countries	**Date**	**Energy Price (€/kWh)**
Germany	December 2023	0.402
Ireland	December 2023	0.3794
Belgium	December 2023	0.3778
Liechtenstein	December 2023	0.3587
Denmark	December 2023	0.3554
Cyprus	December 2023	0.3452
Italy	December 2023	0.3347
Czech Republic	December 2023	0.3151
Latvia	December 2023	0.2774
Austria	December 2023	0.2748
France	December 2023	0.2591
Netherlands	December 2023	0.2515
Finland	December 2023	0.2403
Spain	December 2023	0.2347
Estonia	December 2023	0.2339

Greece	December 2023	0.2309
Portugal	December 2023	0.2299
Lithuania	December 2023	0.2223

Table 5. Energy price in different countries [39]

In table 5 appears the energy price of some European countries in December 2023.

Figure 39. French energy price 09/04/2024 [40]

Figure 39 shows the hourly energy price of the 9th of August of 2024. Energy prices have reduced their value compared to previous years because nuclear production is coming back to what it used to be.

4.5. Technologies

In France, five technologies are part of energy generation [41]. These technologies are coal, natural gas, oil, nuclear energy and renewable sources.

The renewable source France has invested the most in is hydraulic energy. In 2020 it meant 10.84 % of the total consumption. In 2020 only 19 % of its energy was generated by renewable sources, a fact that reinforce hydraulic is the most important one. It is true that hydraulic energy is the most used renewable source, but it has not grown much in the last years. In 2011 France produced 8.06 % of its energy thanks to hydropower, so it has increased 2.78 % in almost 10 years.

On the other hand, wind and solar energy are becoming more important every year. In 2011 wind energy meant 2.18 % of its total energy and in 2021 this value increased to 6.68 %. Something similar is the case of solar energy, which has grown from 0.41 % in 2011 to 2.67 % in 2021.

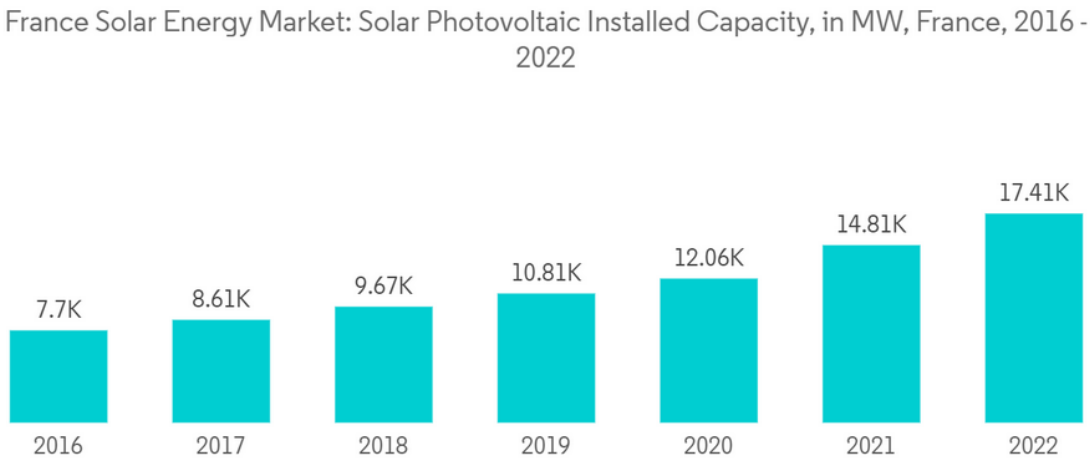


Figure 40. French solar photovoltaic installed capacity in MW from 2016 to 2022 [42]

Figure 40 shows the installed capacity of solar energy in MW in France from 2016 to 2022. As can be seen, it has been growing every year and the tendency is to continue with this growth.

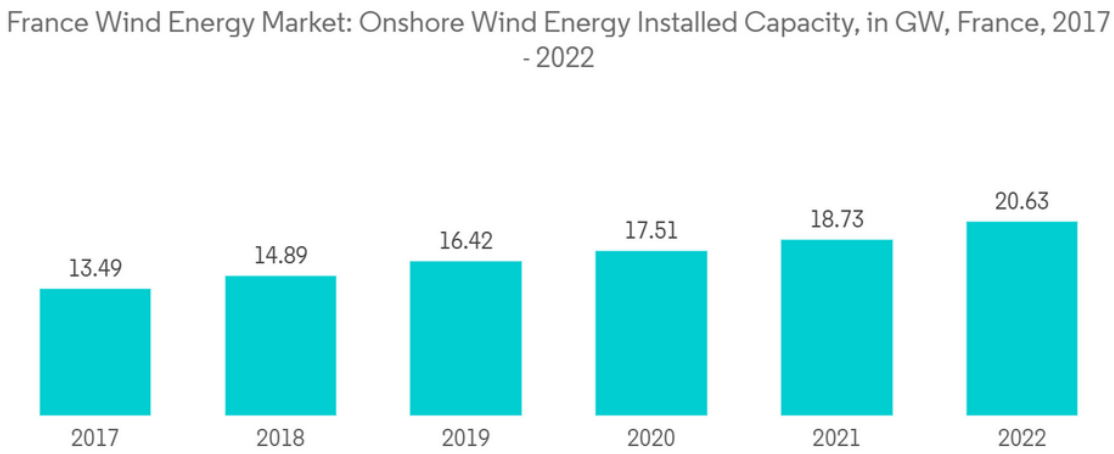


Figure 41. French onshore wind energy installed capacity in GW from 2017 to 2022 [42]

Figure 41 shows the installed capacity of wind energy in MW in France from 2017 to 2022. It is

the same situation as that mentioned for solar energy, it is expected to keep increasing in the following years.

4.6. Carbon emissions

Another remarkable aspect of the production is that the carbon emissions have been reduced from 376.595 metric tons 2010 to 315.299 in 2022, due to the increase in renewable energies.

France – CO_2 Emissions			
Date	**Total CO_2 mt**	**Co2 kg/1000$**	**CO2 per capita**
2022	315.299	0.1	4.76
2021	324.765	0.11	4.92
2020	286.339	0.1	4.36
2019	321.67	0.1	4.91
2018	327.685	0.11	5.02
2017	338.585	0.11	5.21
2016	335.017	0.11	5.18
2015	331.962	0.12	5.15
2014	326.944	0.11	5.09
2013	359.784	0.13	5.63
2012	365.248	0.13	5.74
2011	363.302	0.13	5.74
2010	376.595	0.14	5.98
2009	369.319	0.14	5.89
2008	381.963	0.14	6.13
2007	388.64	0.14	6.27

2006	395.79	0.15	6.43
2005	406.273	0.15	6.63
2004	404.118	0.16	6.64
2003	403.468	0.16	6.66
2002	398.836	0.16	6.62
2001	404.199	0.16	6.75
2000	399.918	0.17	6.71

Table 6. French carbon emissions from 2000 to 2022 [43]

In table 6 appears the CO2 emissions in France from 2000 to 2022. As can be seen, this value has been reducing every year because of the priority that other technologies have had in production.

5. THE UNITED KINGDOM

5.1. Introduction

The UK's electricity market is one of the most sophisticated in Europe. Its liberalization took place in the 90's, the aim was to increase competition, to improve efficiency and to reduce the price for the customers.

5.2. Generation

Energy generation in this country is very diversified. Many technologies contribute to production. In 2023 more than half of the energy produced came from low-carbon sources, meaning 55.65 % [44]. The most important technologies are wind, nuclear, biofuel, solar energy, natural gas and coal.

Wind energy is the technology which has been growing the most in recent years, reaching a peak value of 26.02 % of the energy generated in 2023.

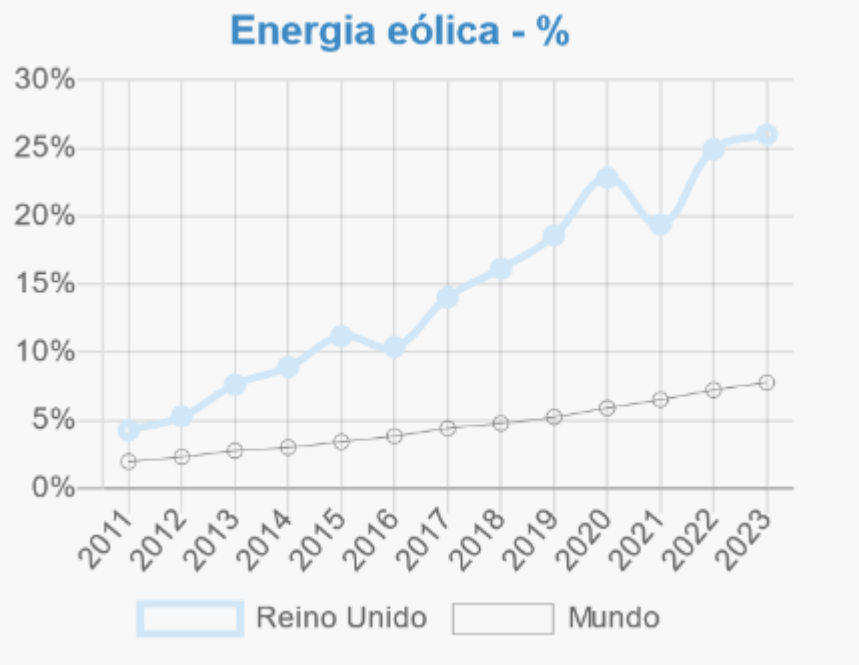


Figure 42. Percentage of wind energy from the energy generated in 2023 in the UK [44]

Figure 42 shows the percentage of wind energy produced in the UK and the average in the rest of the world from 2011 to 2023. As can be seen, the UK is above the average in this technology what makes it one of the most dependent countries on this technology in the world.

Nuclear plants generated 13.03 % of the energy produced in 2023.

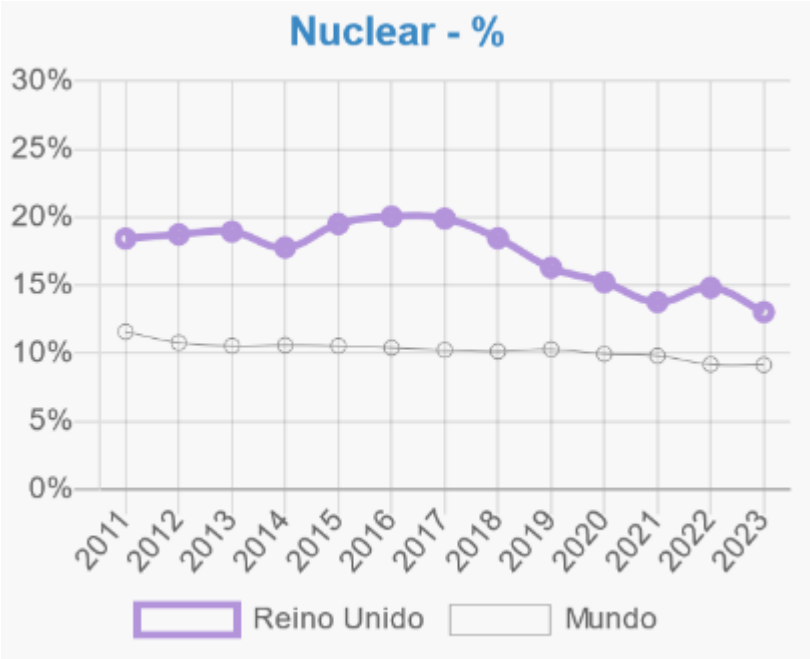


Figure 43. Percentage of nuclear energy from the energy generated in 2023 in the UK [44]

It can be observed in figure 43 the percentage of nuclear energy produced in the UK and the average value in the rest of the world from 2011 to 2023. Although it has been decreasing every year, this rate is still higher than the world's average.

Solar energy is not as important as other technologies in the UK. In 2023, only 4.26 % of the energy generated was produced in solar plants.

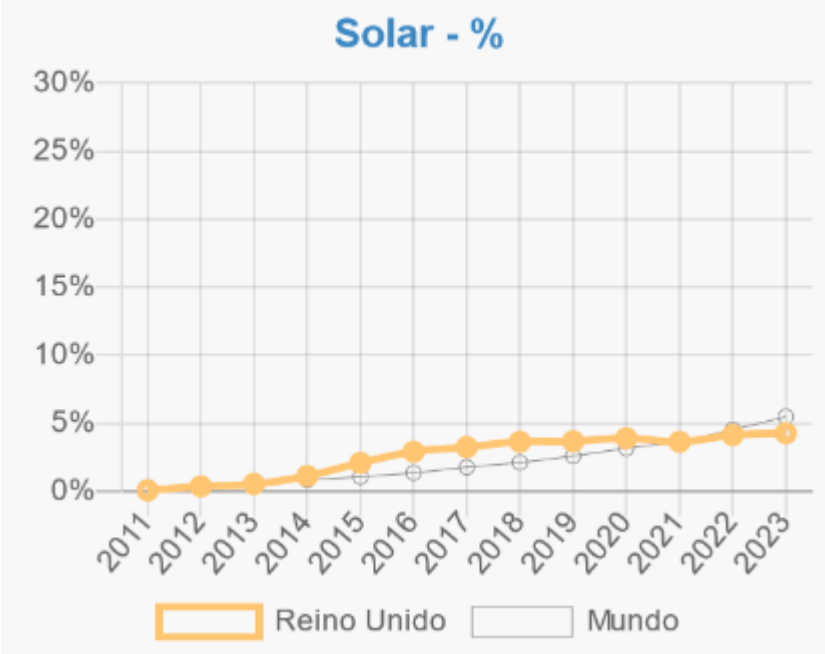


Figure 44. Percentage of solar energy from the energy generated in 2023 in the UK [44]

Figure 44 shows the percentage of solar energy produced in the UK and the average in the rest of the world from 2011 to 2023. From 2015 to 2020 UK's solar production was higher than the world's average, but in 2022 and 2023 the higher inversion in this technology led to a global growth, which was not totally followed by the UK.

Biofuels are also crucial, they meant 10.68 % of the energy produced in 2023. The higher producer was natural gas with 34.88 %, very far from the other fossil fuel, coal, with 1.24 %.

The United Kingdom is a country whose electricity market relies on energy import. In 2023, 7.39 % of the energy consumed was from other countries [45]. Comparing this value to the Spanish one, which is 3.9 %, and having in mind that Norway and France are two of the biggest energy exports in Europe, so their percentage is lower, UK's percentage is the highest.

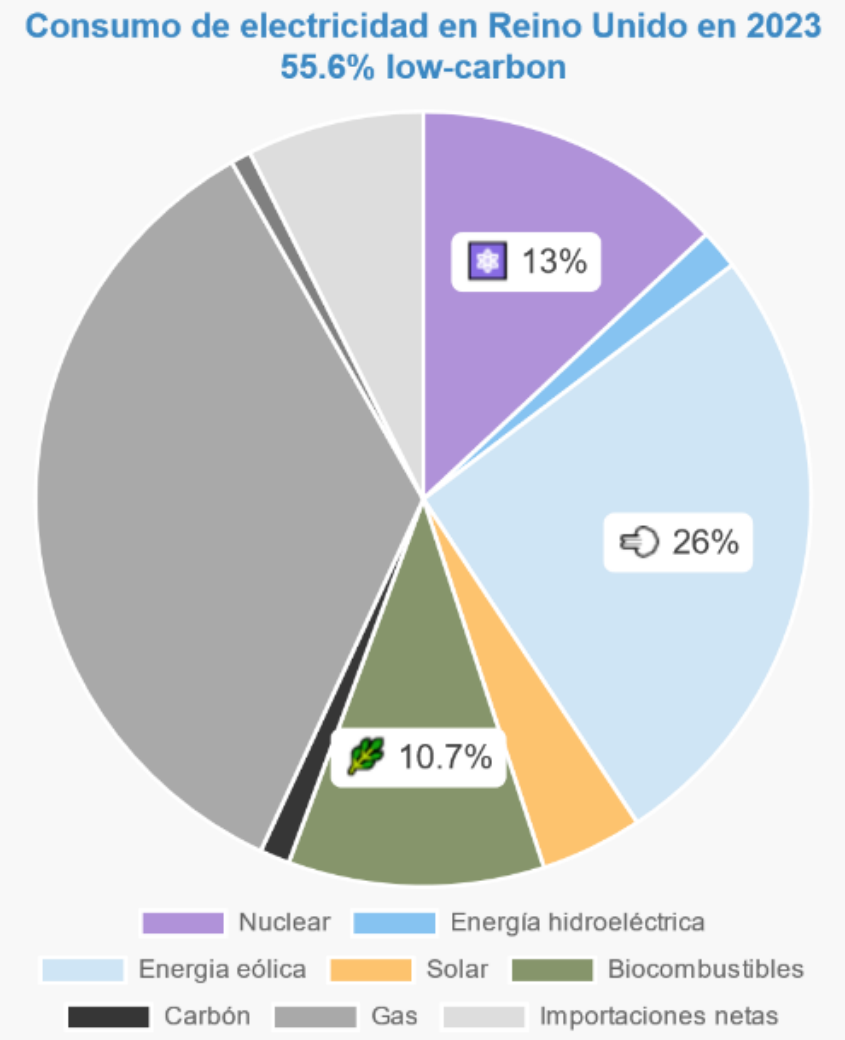


Figure 45. Electricity consumption in the UK in 2023 [44]

In figure 45 can be seen the technologies that have a significant impact on energy consumption in 2023 and the corresponding percentages of energy consumed.

Comparing this graphic to the one from 2010, energy transition can be deduced. Also, it is easy to appreciate the huge impact that renewable energies have had on our society in such a short period of time.

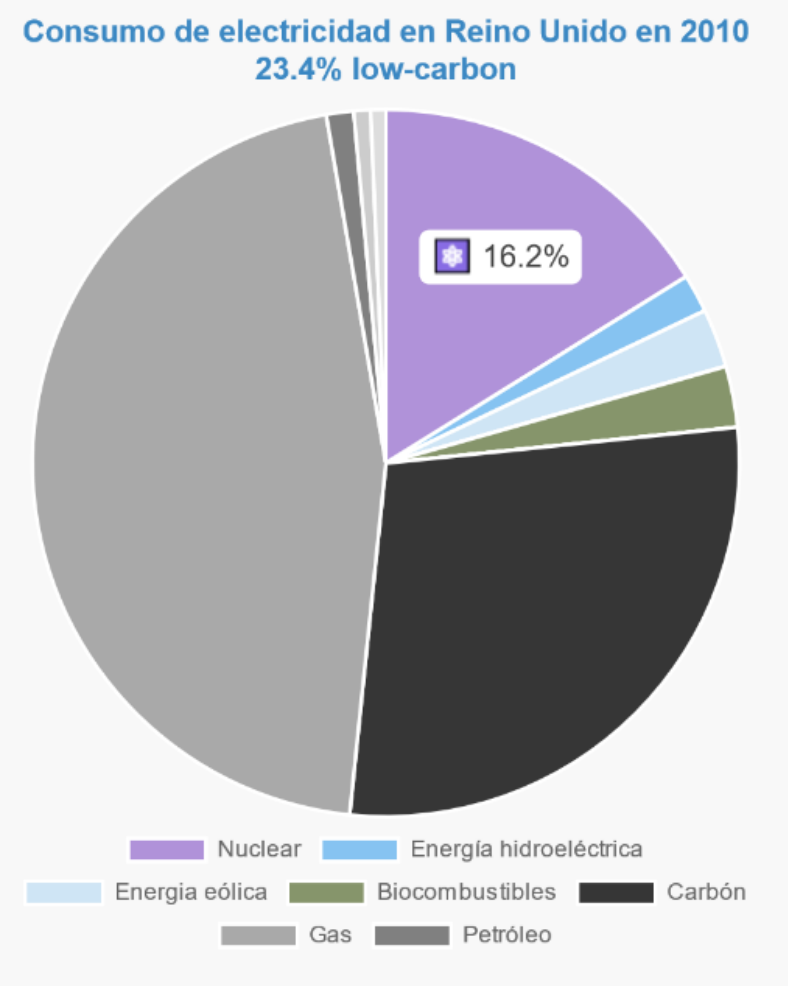


Figure 46. Electricity consumption in the UK in 2010 [44]

In 2010 almost half of the energy consumed was produced in natural gas plants and a third of the electricity used was generated in coal industries. Renewable energies only appear in this graphic thanks to the little contribution of wind and hydraulic energy. In 2018 the situation changed.

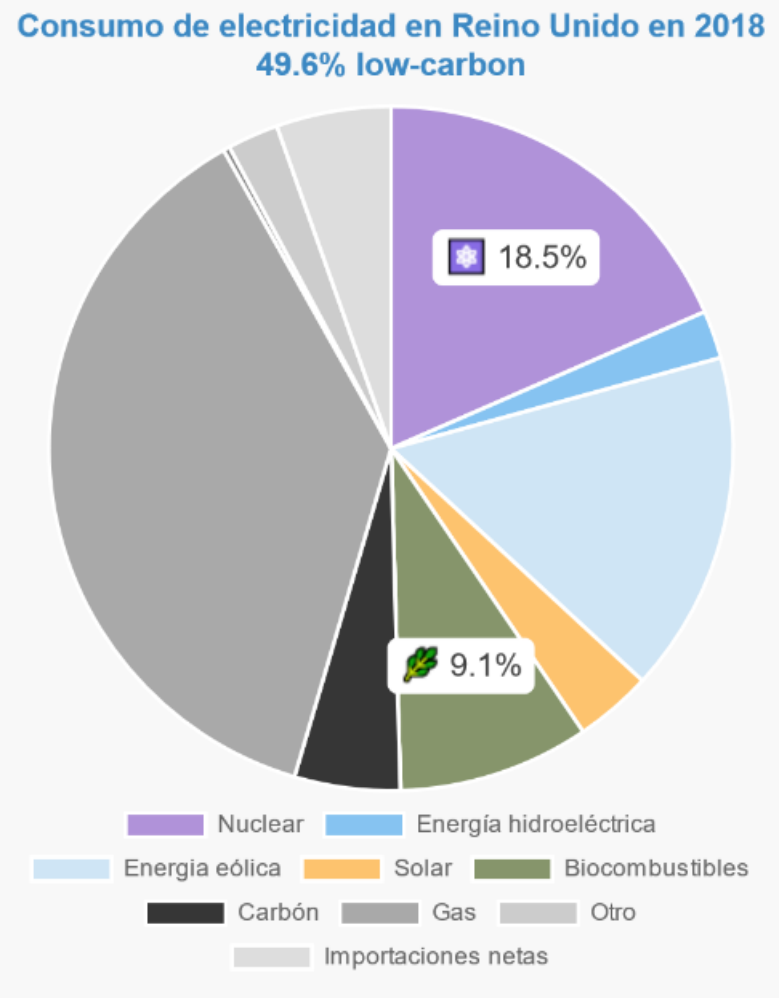


Figure 47. Electricity consumption in the UK in 2018 [44]

In 2018, it can be seen the tendency in the last years, where the main goal has been to reduce carbon emissions, replacing coal production with renewable energies like solar and wind, which have become more important every year.

5.3. Imports

Imports play a crucial role in the energy supply in the UK [45]. In 2022 the UK imported 3.89 bn $ in energy, what made it become the tenth importer in the world. The main imports came from Norway, 980 M $, Netherlands, 916 M $, France, 865 M $, Belgium, 810 M $, and Ireland, 317 M $.

The United Kingdom is a big island in the Atlantic Ocean. Due to this geographical condition, it is way more complicated to establish interconnections with other countries.

In 2021 the UK and Norway connected their electricity markets thanks to a submarine cable named North Sea Link [46].

Also, in 2022 the British company Xlinks [47] presented the idea of building a submarine cable which will connect Morocco and the UK. The length of the cable will be 3800 km and is set to supply energy to cover 8 % of the demand. This cable will connect a wind and solar plant which is going to be built in Guelmim with the UK.

Figure 48. UK-Morocco power project [47]

As it can be seen in figure 48, the cable will connect the south of Morocco to Devon, UK. This cable was meant to be a measure to recover from the crisis of 2021.

5.4. Energy price

In the year 2021 all the European countries suffered a huge crisis because of the consequences

of COVID and the war between Ukraine and Russia. Due to these situations, energy prices have reached values never seen before.

In the UK, the situation was different. In 2018 the government approved a measure called energy price cap [48]. The energy price cap is the maximum amount of energy suppliers that can charge customers for each unit of energy and standing charge if the client is on a standard variable fee. For example, from the first of July to 30 September the energy price cap is set at 1.568 pounds per year.

Ten trading companies of electrical energy busted because they could not face this panorama where they had to buy expensive energy from the producers and then sold it to the customers at the energy price cap so most of the times, they lost money or the benefit they obtained was not enough.

The government has been struggling with energy prices for the last years. Particularly, in the last year the UK had the highest energy price of Europe.

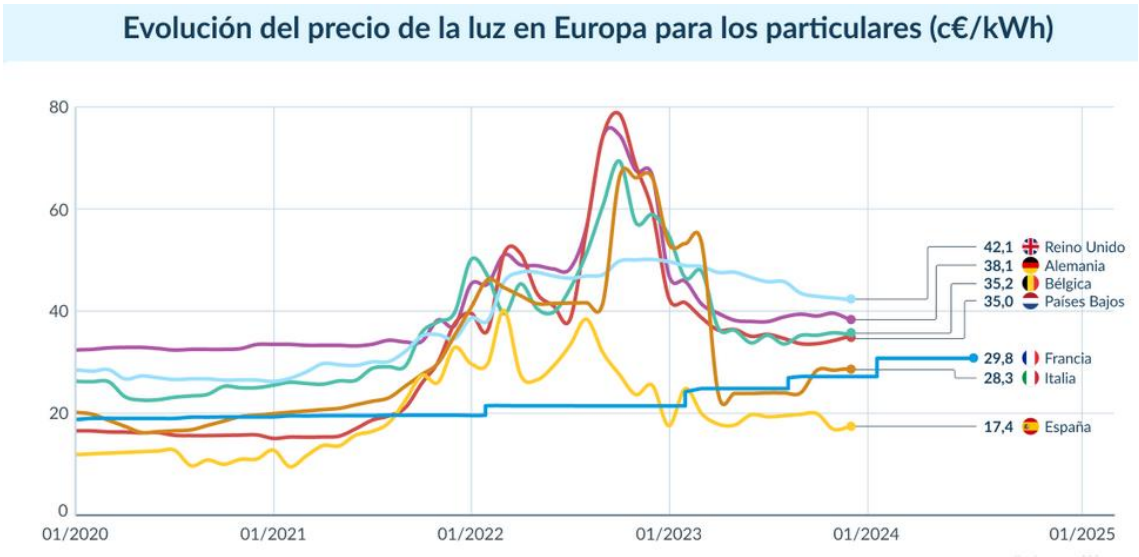


Figure 49. Energy price evolution in Europe [49]

As can be seen in figure 49 the tendency of the European countries is to reduce the price while in the UK the price is decreasing but not as much as in other countries. The prices remained steady during 2022 due to the energy price cap.

The UK – Energy Prices		
Date	**Energy price without taxes (€/kWh)**	**Energy price (€/kWh)**
December 2020	0.1532	0.2203
June 2020	0.1532	0.2203
December 2019	0.1512	0.221
June 2019	0.1450	0.2122
December 2018	0.1401	0.2024
June 2018	0.1347	0.1887
December 2017	0.1344	0.1856
June 2017	0.1344	0.1766
December 2016	0.1479	0.1831
June 2016	0.1576	0.1951
December 2015	0.1808	0.2183
June 2015	0.1759	0.2125

Table 7. UK's energy price from 2015 to 2020 [50]

In table 7 appears the energy prices in the UK from 2015 to 2020. The prices have always been steady.

5.5. Future trends

The tendency [51] the UK wants to follow in the following years is to keep increasing low-carbon technologies to produce energy. To do that, the main goal is to increase renewable energies like

solar and hydraulic.

Wind technology is the first producer of renewable energy in the UK. Although it can be improved, it is not the most important focus of attention.

Solar and hydraulic energy are foreseen to grow in the next year to continue with the reduction of carbon emissions and to try to achieve the UK’s goals for energy transition.

6. COMPARISON

In the comparison of the electricity markets of the four countries considered in this work, there are four aspects which need to be remarked. These four points are energy technologies, energy policies, market structure and future trends.

6.1. Energy technologies

Technologies used in every country depend on several aspects. Renewable energies, for example, depend on the meteorological conditions of the corresponding country. For instance, if there is a country with sunny weather, solar energy is going to be more developed than in a country where this technology is not as profitable.

Non-renewable energies depend on the primary sources that countries can most easily obtain.

Firstly, in a country with a high number of coal mines, coal is going to be a technology with a big contribution to the generation.

Secondly, if there is a country which has not any profitable source, imports become crucial in the electricity system. In the case of Europe, many of the countries use Russian natural gas because in their own territories it is impossible to obtain this source, and without it, it would be impossible to produce enough energy to cover the demand.

6.1.1. Spain

In Spain, renewable energies are becoming more crucial every year. It is important to highlight the role solar and wind energy play in energy production. Due to Spanish meteorological conditions, these two renewable sources are the most profitable ones.

Wind energy [52] was the most important energy generation technology in Spain in 2023, generating more than 30000 MW, which meant 24.4 % of the demand coverage. In Spain there are more than 22000 wind turbines which produced more than 61000 GWh. Spain is the fifth highest country in terms of wind production in the world after China, The United States of America, Germany and India.

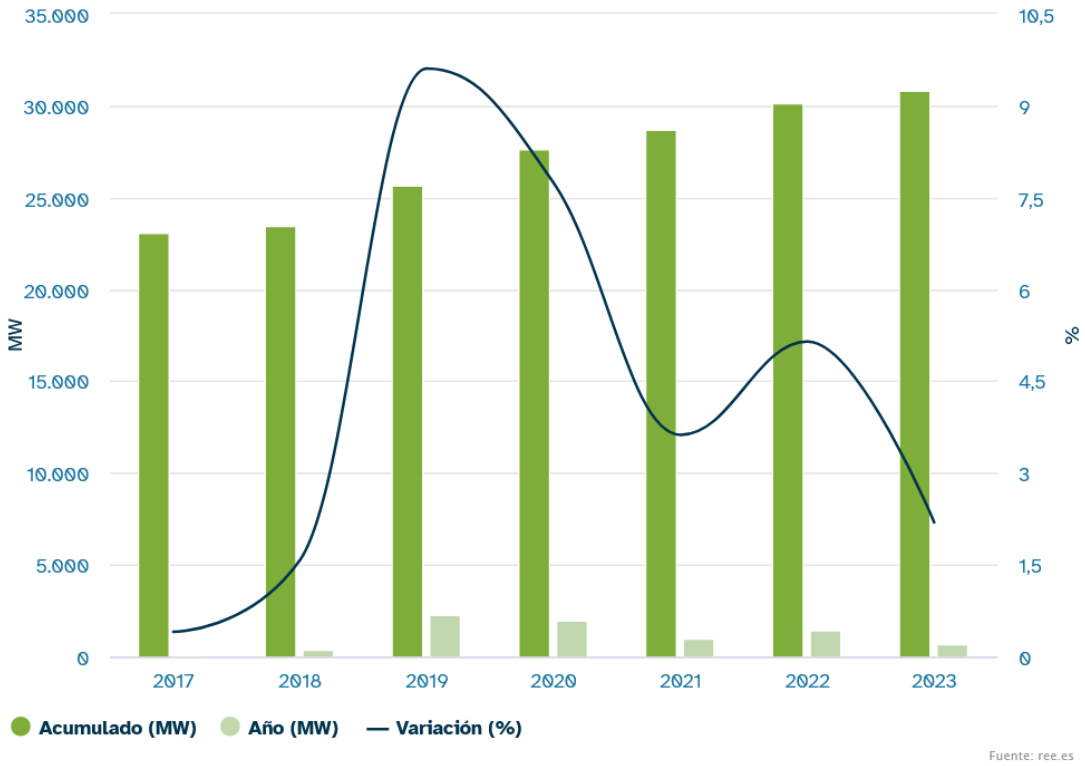


Figure 50. Wind energy evolution in Spain [53]

Figure 50 shows the evolution of wind energy in Spain. This source has been growing every year and it is expected to keep this trend.

Photovoltaic energy has increased a lot in recent years [54]. In 2023 it grew 28 %. In this year, Spain incorporated 5594 MW of photovoltaic energy to electricity generation mix.

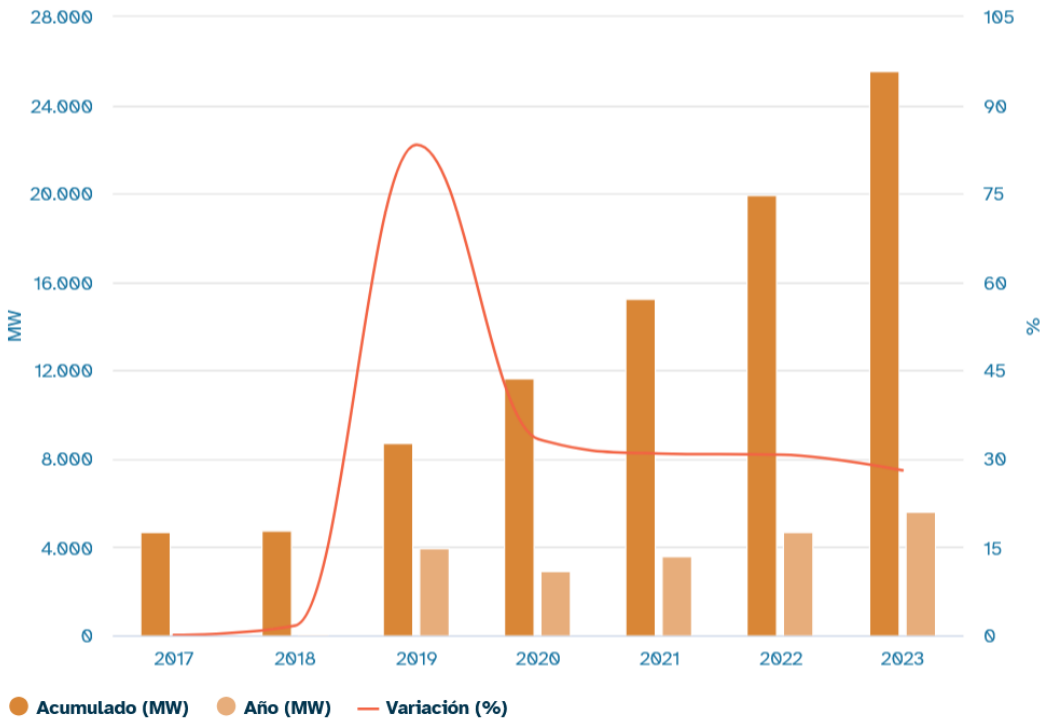


Figure 51. Solar energy evolution in Spain [55]

In figure 51, it can be seen the photovoltaic solar production in recent years. In 2023 it reached a historical record, 25549 MW.

Apart from these two renewable sources, the other important technology used is nuclear energy [56].

The development of the nuclear energy in Spain started in the 60's with the construction of the firs nuclear plant José Cabrera, commonly known as Zorita. Nowadays in Spain there are 7 active nuclear reactors. This technology produces every year between 55000 and 60000 GWh, meaning more than 20 % of the electricity consumed in the country.

6.1.2. Norway

In Norway energy production is not as diverse as it is in Spain. Almost 100 % of electricity generation comes from renewable energies. In this country, also due to its meteorological conditions, the most used renewable source is water. Hydraulic energy is the most commonly used technology in the country [57].

Because of these facts, Norway is considered one of the most sustainable countries in the world. The government supports this technology because it is considered to be the easiest way to achieve energy transition and decarbonization, which every country is looking for.

The other remarkable aspect of the Norwegian electricity market is the amount of energy exported every year. Almost all the energy produced in this country is renewable, reducing the energy price and easing the gathering methods. That is why many Europeans countries like the UK or Italy choose importing energy from this country.

6.1.3. France

French electricity market is not diversified either. Most of the energy consumed is produced in nuclear plants. That has always worked properly for them but nowadays what every country is aiming for is to have a green electricity system where there is no room for nuclear energy.

Energy prices have always been steady and not high, but in 2022, due to maintenance stops and restrictions, the situation changed, and the prices reached historical peak values.

This situation showed the consequences of depending too much on one technology exclusively. If this source cannot be used for a period of time that is going to increase energy prices because other technologies which are not usual participants in the market will be necessary to cover the demand.

After this situation happened, French government has started to invest a lot in recent years in renewable energies. Solar photovoltaic and wind energy are growing in order to decrease the reliance on nuclear energy.

6.1.4. The United Kingdom

The most remarkable aspect of the UK's electricity system is its variety. That is the characteristic which differs it from other countries like Norway or France, where there is one technology that cover almost totally the demand.

The most used technology is a non-renewable source, natural gas. Biofuels and nuclear energy also play an important role in generation. There is only one renewable energy that makes a significant contribution, wind. That is why energy prices in this country are high because its production depends a lot on non-renewable energies. Also, imports are crucial and difficult due to the fact that the UK is an island, so it is more complex to build connections with other countries to receive their energy.

6.2. Energy policies

In all these four countries governments are trying to establish policies to achieve the goal of energy transition and total decarbonization in 2050.

Spain adopted in March 2021 a law to reduce polluting emissions and increase the importance of renewable energies in electricity production. The idea behind this concept is to stop generation coming from carbon and nuclear plants, what might lead to a green generation. This policy is named the integrated national energy and climate plan, in Spain known as PNIEC [58].

Norway does not need to change its energy production system because it is already a green one. Apart from not having polluting emissions from its plants, this country is also a leader in electric vehicles [59].

In 2023, 82.38 % of the new cars sold in Norway were electric. The government's idea is to have zero emissions in 2025. This is why people with electric cars have certain benefits like parking or toll discounts.

In France the real issue to achieve a green energy system is nuclear plants. That is the reason

why in 2015 the government approved the Energy transition law for green growth [60].

The aim of this law is to change its energy production system to a more sustainable one which ensures its economic development. The idea is to replace nuclear plants with renewable ones like solar or wind. To do so, the government established some measures:

- Reducing 40 % of emissions of greenhouse gas from 1990 to 2030.
- Reducing 50 % of final energy consumption in 2050 from the reference value of 2012.
- Reducing 30 % of primary energy consumption in fossil fuels in 2030 from the reference value of 2012.
- Increasing to 32 % the participance of renewable energies in the electricity consumed in 2030 and make them to mean 40 % of the energy produced.
- Diversifying electricity generation and reducing to 50 % the importance of nuclear energy in the electric mix in 2050.

The United Kingdom has approved laws to invest in energy infrastructures, in development of offshore wind plants and in improving the electricity grids.

In 2023 the UK's government approved an energy law [61] which will provide this country with a more efficient energy system and will also help to keep energy prices low.

Offshore wind [62] is the technology which has grown the most in the last years in the UK. This country heads the ranking of the highest number of offshore wind energy installations in the world.

British's coastline location, weather conditions and geology make the UK one of the best places in Europe to develop this technology.

The UK's government has taken advantage of this situation to use this technology as the essential key to achieve zero emissions goal. In 2030 the aim is to have 50 GW of installed capacity from offshore wind and 5 GW of those from floating offshore wind energy.

6.3. Market structure

This aspect is the most similar one. These four countries have a liberalized electricity market.

In the Spanish case, OMIE is the market operator and is in charge of organizing all the purchase and sell offers to establish the energy price of every hour of the next day.

In Norway, the Nord Pool oversees the energy system and is responsible for the proper functioning of the electricity market. In this country, it is important to remark the connections with other countries because Norway is one of the biggest energy suppliers in Europe due to its cheap energy.

France has a peculiarity in its market [63]. French energy system uses electricity from a public company, EDF (Électricité de France), reducing energy prices because there is a part of the energy that is offered at a fixed price, regardless of the market price.

EDF produces 97 % of the electricity in the country. This company uses nuclear energy, that is why the price is low. To allow the other companies to compete with such a low price, in 2010 the French government established that EDF sold some of the energy at a fixed price and the

rest must depend on the market price. That measurement finished with this energy monopoly and other companies can now be part of the energy system. That is the ideal situation because if the number of offers increases, the price is going to be cheaper than before.

It is also important to remark that, like Norway, France is one of the biggest energy suppliers in Europe.

Finally, the UK has the most complex electricity market of these four. Its price is the highest and that is why the government came up with the measurement of the energy price cap.

Every year it is improving its situation, diversifying its production, trying to have as many generation options as possible.

In this country imports play a crucial role in the electricity market. Due to the fact that The United Kingdom is an island it is hard to build connections with other countries, but it is necessary to obtain the amount of energy required and to get cheap energy from other countries.

6.4. Future Trends

It is essential to have in mind the future energy trends in these four countries. It is an easy way to see if the government and the inhabitants are doing well with the actual system. If a country needs to make a lot of changes it means that the situation is not the most appropriate one, and if only some little changes are required that means that the market can continue to develop following the same trends.

All these four countries have the goal to achieve decarbonization in 2050, so all of them share the idea of erasing coal plants and replacing them with renewable ones.

They also share the idea of having a green electricity system where all the energy consumed comes from renewable sources. One of the reasons for this measurement is to reduce carbon emissions.

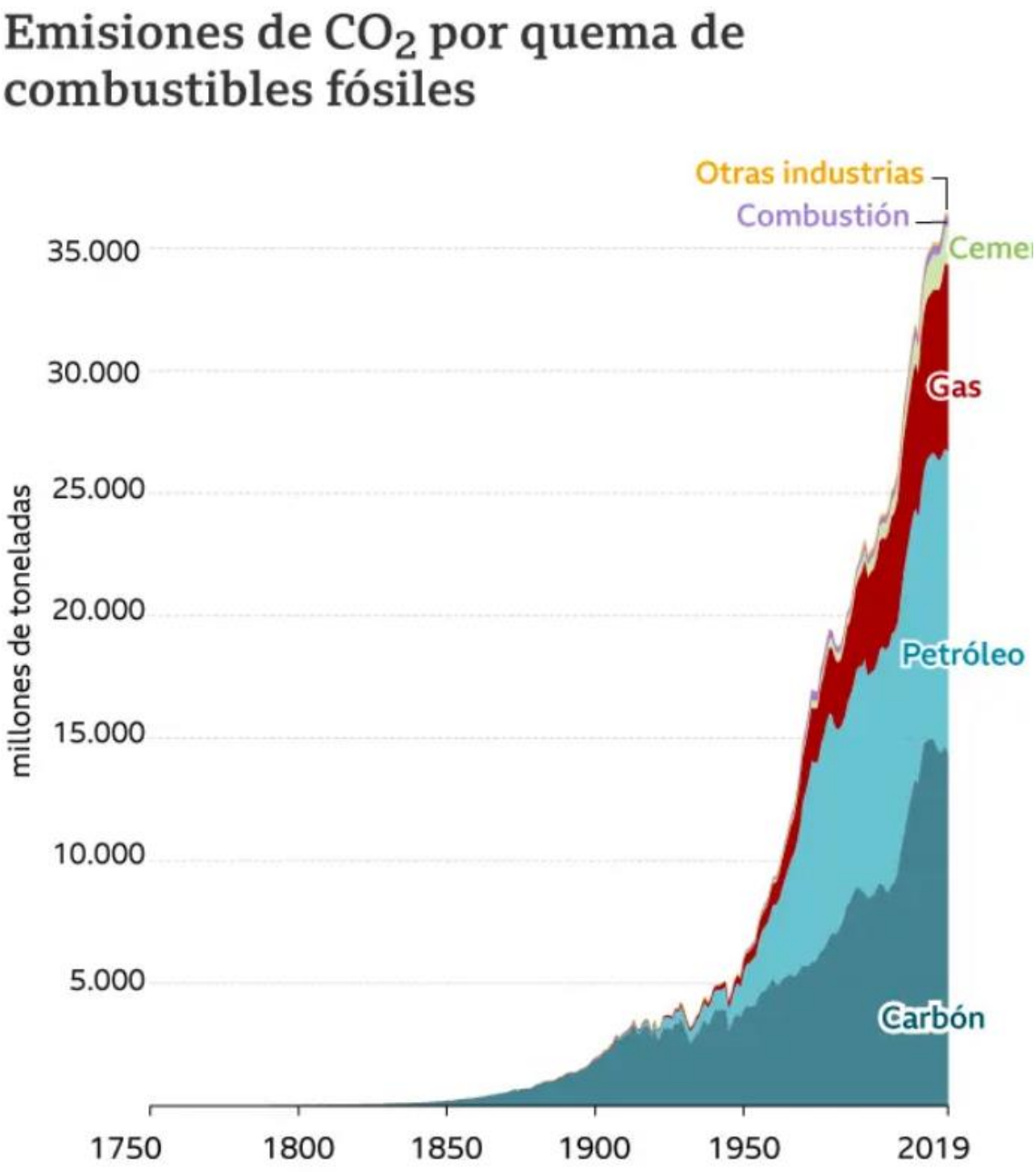


Figure 52. Carbon emissions of fossil fuels [64]

The image shows the carbon emission of fossil fuels. As can be seen in figure 52, coal is the highest one.

Carbon emissions have many negative consequences for the environment and that is why all the governments of the world are trying to reduce them. 26 % of the carbon emissions come from transport and 21 % from energy generation [65].

To reduce the emissions that come from transport, electric vehicles are the solution. Norway is the country that leads the ranking of the highest number of electric vehicles but the other three are also investing in this new technology as it is necessary to achieve the goal of decarbonization.

When it comes to reducing carbon emissions from electricity production, the answer is clear,

renewable energies.

Spain is investing in solar and wind energy. These two technologies have grown a lot in recent years and are becoming more important every day. It is such a growth in solar photovoltaic energy, that at some hours of the day this technology can produce almost all the energy consumed.

Norway is the example of a market which needs very little changes. The trend that will follow is to improve its hydraulic production and keep increasing wind energy. Although solar energy is developing fast, it seems to be an unprofitable technology due to its weather conditions.

In the French case, the reduction of the nuclear plants is essential, but it is such the importance this technology has in the energy system, that is going to be a hard and long task. Onshore wind and solar energy are the alternatives France are investing the most.

Finally, The United Kingdom has become the point of reference worldwide for offshore wind energy. That is the trend that is going to follow in the future, trying to reduce energy imports and being able to have an energy production system big and good enough to supply all the energy consumed in the country.

7. CONCLUSION AND FUTURE WORK

The aim of this work is to provide information about four different ways of exploiting energy resources. During the whole work, it has been established that there is not only one way to proceed and that every country uses different technologies depending on weather conditions and on the most reachable sources.

In Spain, the most used renewable technologies are wind and solar. That is because of the climate conditions this country has. It is always sunny in most of the cities and due to the fact that it is a peninsula, it has many kilometers of coastline where wind plants become very profitable.

In terms of non-renewable energies, coal has always been a crucial source in energy production but because of the aim to achieve in 2050 a global decarbonization, this source is becoming less used every year. Natural gas imported from Russia, is also important for the electricity market. Of course, the idea is to replace these non-renewable sources with green technologies.

Norwegian electricity market is one of the greenest in the world. An average of 98 % of its annual energy production comes from renewable energies. Because of its geographical conditions, hydraulic energy has been developed at a such level that it is possible to cover the energy demand of this country just with this technology.

It is an example of what every country is dreaming about, a renewable source which due to the amount of the source is manageable, and that can also be used to store energy exceeds. But the truth is that only very few countries can hope to achieve such goal because countries with geographical conditions similar to the Nordics ones is odd to find.

On the other hand, France is an example of what every country is trying to avoid, an energy system with a huge reliance on a non-renewable source. France is the country in Europe which uses nuclear energy the most. It has been proved that if this technology stops its production, the electricity market is about to collapse.

That is why this government has been investing a lot of money in recent years to accelerate the development of wind and solar energy. France needs to speed up in the energy transition race because it has been left apart.

Finally, the United Kingdom is a particular case. It is an island so connections with other countries are more difficult. It is more difficult to import energy and sources what makes it different from the other 3. This system has the necessity to take the maximum advantage possible of their sources.

Due to its geographical and weather conditions, the only profitable renewable source is wind. Floating offshore wind technology is one of its biggest producers. This country is moving step by step to achieve its energy transition goals. Every year the percentage of low carbon energy

production increases.

Every government is working on its goals. Sometimes on their own and sometimes together but what all of them have in common is that energy transition is not possible without the help of other countries.

For a country with the geographical and weather conditions of the United Kingdom it would be very hard to be able to cover the demand everyday just with its own renewable plants. That is why interconnections with Norway are being built, because Norway most of the days have an overproduction and instead of wasting it, it seems more logical to sell it. Both take advantage of this agreement, the UK because it is using green energy and Norway because it is selling useless energy.

The objective of every electricity market is to establish a fair energy price. That is the ideal situation, but not every day is possible. Energy price depends on many factors. For example, weather conditions, in the case of Spain energy price is going to be lower if it is sunny because of the high number of solar plants installed in its territory. It also depends on the day of the week; at the weekend energy is cheaper because the demand is lower. If there is a maintenance stop or restrictions in several plants, the price is going to increase. Energy prices are very variable, but the idea is to make it as steady as possible.

In the final summary, the four countries are approving measures to achieve what is called the energy transition. It consists of replacing non-renewable sources with renewable ones. The difficulty of this transition is ensuring that green sources can supply enough energy to cover the demand, even in the days when meteorological conditions are not the most profitable.

It is obvious that it is not a two-day work. Governments have been struggling with this issue for decades. But the current situation the world is facing has accelerated the whole process. Global warming and ozone layer destruction are consequences of pollution and bad human habits. So, every activity that contributes to these effects needs to be reduced, erased or replaced, and energy generation is one of them.

As a future working line, it would be interesting to study energy storage. It is a concept which has grown a lot in recent years. Energy storage systems are a key factor to face climate change and are so useful in energy transition.

According to a study published by the research center TNO (Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek, in English Organization in the Netherlands for Applied Scientific Research), Fraunhofer-Gesellschaft and the consultancy company Trinomics Spain and France are the leaders in the European list of the countries which have more energy stored [66]. Spain has more than 20000 MW stored and is the country with the highest number of energy storage systems in Europe measured by power and the second one with more projects, 128, only Germany has more, 169.

Norway has developed its energy storage systems. This country has more than 1000 energy storage reservoirs of hydraulic energy with a capacity of 865 TWh [14]. The biggest 30 reservoirs supply almost half of the storage capacity.

In the case of France, Harmony Energy announced in 2024 that will build the biggest BESS (Battery Energy Storage System) in France [67]. The name of the project is Cheviré and will become the first battery system designed to operate for two consecutive hours. The idea is that this system will produce enough energy to cover the demand of 170000 houses for two hours.

This project represents exactly the idea of energy transition. It is going to replace the old energy

plant of Nantes which used fossil fuels with a renewable energy installation.

Finally, the UK has been working on energy storage systems for the last years. Currently, the energy storage system market size is estimated to be 10.74 MW in 2024 and hopefully will reach 28.24 MW in 2029.

Energy storage systems are the perfect partners for renewable energies, that is why every government is investing in this technology.

These systems allow renewable plants to produce more than is needed. They can store those energy excesses and then use them whenever it is required.

This new technology is the last piece of the energy puzzle. The issue with renewable energies has always been that they are not manageable, it is impossible to control the wind or the sun. But, if there is a way to use the energy that is wasted because of overproduction and use it when weather conditions are not profitable, green energy systems are a step closer.

The advantages this technology can bring to the electricity system are many [68].

- Energy efficiency
- Flexibility in energy management
- Fast answer to load fluctuations
- Integration with renewable energies
- Carbon emissions reduce
- Energy independence
- Economic savings

This technology seems to be the most logical to implement. Governments know it is going to be a long and hard way until all the energy goals are achieved but the future looks bright with a system that is zero pollution and powerful enough to cover every day the demand.

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