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Master of Science in Energy and Nuclear Engineering

Master Thesis

Evaluation and forecast of CO_2 emissions in the electricity sector for European targeted countries

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A questa società maschilista,

che ha difficoltà ad accettare una donna ingegnere

Abstract

Over the last years, the increased sensitivity in environmental issues leads to the development of energy policies to reduce CO_2 emissions. The most polluting sector is electricity generation. For this reason, Life Cycle Assessment has been chosen as tool to evaluate the variation in the production of kg of CO_2 per kWh of electricity produced until 2030. In this work particularly, two target countries were chosen, Germany and Spain due to their willingness to participate in the energy transition objective.

The scenarios of electricity production are based on the National Energy Plan of each country. Each of these plans indicates the energy policies for the implementation of renewable energy sources, and also coal and nuclear power plants decommissioning. Both countries are aiming at a strong implementation of renewables, especially wind and photovoltaic. Moreover, there is a strong development of solar thermal in Spain, and biomass has a relevant role in the German mix. However, while Germany is more focused on the denuclearisation process, Spain gives priority to decarbonization.

Coal plays a minor role in the Spanish electricity mix, therefore this country can become carbon neutral in the power generation sector by 2025. Afterward, the nuclear decommissioning process would begin.

The presence of coal in the electricity mix of German is much stronger, which is the reason why the phase-out process is expected to be longer. Meanwhile, the decommissioning of nuclear power plants should be fast ending in 2022.

These variations in the electricity mix would cause a strong reduction in the value of CO_2 emissions per kWh of electricity produced. Specifically, a reduction of 48 % is expected for Germany and 34 % for Spain to produce 1 kWh of electricity. Thus, in the electricity generation sector, a reduction of 54 % is expected for Germany and 65 % for Spain due to different energy demands.

The second part of the study uses machine learning techniques for time series to analyze the trends of CO_2 emissions in the last 50 years, to forecast the CO_2 emissions for the following 10 years. This allows an evaluation of the energy policies' effectiveness implemented so far and then to modify them in case they are not going in the right direction.

In the case of Spain, it is not possible to proceed with this analysis because the model failed the validation test. For Germany, however, it was possible to continue with the analysis. In this way, it is possible to observe that this country is moving in the right direction for reducing emissions in the electricity generation sector. Besides, comparing this trend with what would be obtained from the projected scenario, the results show that new policies would produce better results than the policies used so far.

Despite the increasing emissions trend of the last years, Spain is deeply reducing the emissions relative to the electricity generation sector. Indeed, the results in terms of CO_2 emitted for kWh of electricity produced are lower than the German case. Although this country presents a decreasing trend and the strong improvements over the last year, big efforts are required to . Although the effectiveness of energy policies and the decreasing trend, Germany has already a high value of emissions due to the presence of coal in the electricity mix.

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1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as a variation of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods [4].
The climate of the Earth changes any time during its life. It is possible to distinguish seven different cycles of glacial advance and retreat since now [5]. The causes of most climate change are related to change in Earth's orbit, which causes a variation of the amount of solar energy received [5]. This brings changes in cloudiness and atmospheric transmission and may substantially affect surface climate, the horological cycle, glaciers, and ecosystems [6]. Only since the nineteenth century there are tools to monitor climate and its changes globally. Thanks to this,since the 1950s it is possible to observe small ups and downs of solar irradiance.
As it is possible to see in Figure 1 there is not a net increase in the value of the irradiance. However at the same time, over the same period corresponds to a deep increase in the average temperature on the Earth.
It could be now interesting to investigate which are the factors that affect on climate change. The Earth's temperature depends primarily on the planet's energy balance. Of all the energy transmitted by the Sun, only a fraction is absorbed by the Earth, being the rest reflected into the Space. The Earth heats up as it absorbs energy, so a change in the absorbed energy causes a change in the energy balance if the Earth absorbs more energy it heats up more. There are many factors, both natural and human,that can affect Earth's energy balance. The most important are:

- Variations in the sun's energy reaching Earth;
- Changes in the reflectivity of Earth's atmosphere and surface;
- Changes in the amount of greenhouse gas released.

As is it possible to observe in Figure 1 there haven't been significant variations on solar irradiance since the 1950s. Moreover, scientists have observed a cooling in the upper layer

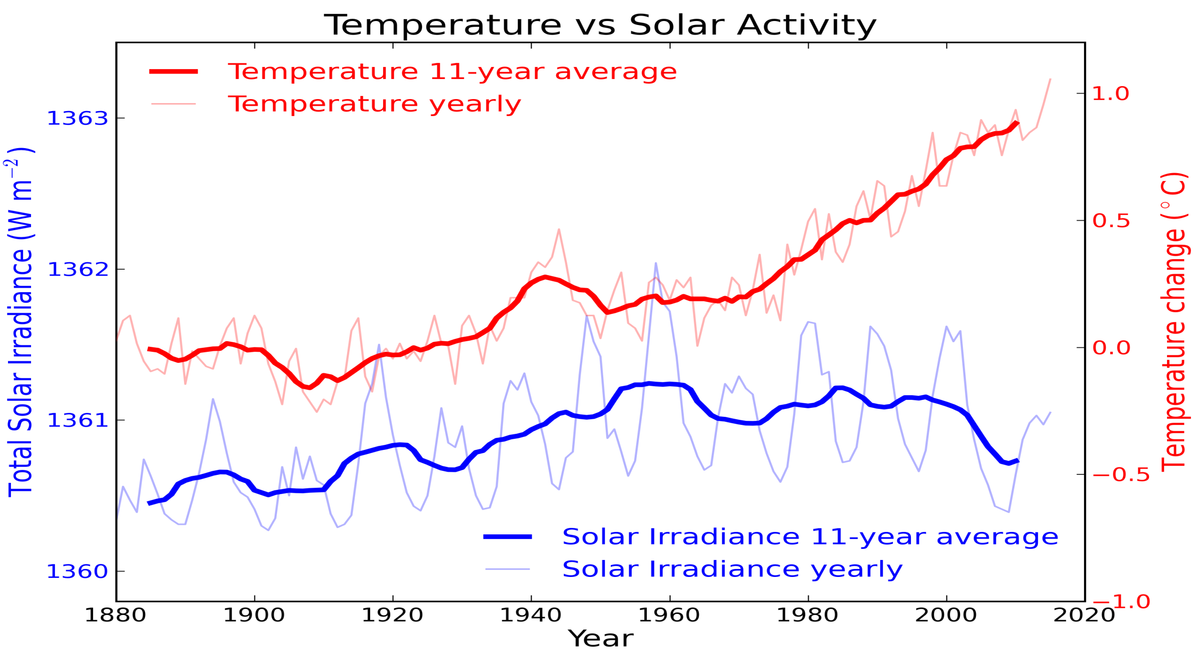

Figure 1: Average solar irradinace

Source NASA [5]

of the atmosphere, and warming on the lower layers [5].

However, this behavior tends to decrease especially in the last years, so the solar irradiance that reaches the Earth is lower than in the past, and this should lead to a decrease of the temperature on the ground while observing the trend of temperature, it shows a tendency to rise. For these reasons, it is not possible to attribute the causes of climate change to the changes of energy coming from the Sun [5].

Sunlight is the primary driver of climate and weather on the Earth. Every day a certain quantity of energy coming from the Sun reaches the Earth. This could be absorbed or reflected. The quantity of energy absorbed depends on the reflexivity of the surface and atmosphere.

The reflexivity of the Earth is measured towards the albedo. The high value of albedo means high reflexivity and so less energy is absorbed by the Earth. Meanwhile, a low value of albedo leads to an increase in the energy absorbed by the Earth. This value changes deeply according to the different zone of the Earth. Albedo is expected to be bigger at the pole, due to the presence of ice, and smaller in the green zone covered by forests [7].

A global reduction on the value of albedo could bring to an increase of the energy absorbed

by the Earth and consequently it could lead to an average increase of temperature [8].
The other important factor which affects the value of the energy remitted by the Earth is the reflexivity of the atmosphere which is related to cloudiness, pollution, and GHGs emissions. These can act like a layer that holds back the re-emitted energy.
GHGs are essential to make the earth liveable: they make the sun's rays pass through, but prevent the refraction of heat. Without them, the temperature on the Earth would be - 18 °C, instead of an average value of 15 °C [9].
These gases allow short-wave solar radiation to travel through the atmosphere. When they come in contact with the Earth they are partly absorbed and then re-emitted in the form of heat. The role of greenhouse gases is to prevent the radiation of long-wave greenhouse gases. These are then absorbed and released in all directions causing the lower layers of the atmosphere and surface of the Earth warming [10].

Greenhouse gases are all the gases that trap heat in the atmosphere. They are produced by natural phenomena like volcano eruption, solar irradiance, etc. , but the major contribution comes from anthropogenic activity. Between them the most important are: carbon dioxide (CO_2), nitrous oxide (NO_2), methane (CH_4) and fluorinated gases [8].
All of them are expressed in terms of CO_2 equivalent, this is a unit of measurement which indicates the amount of a generic greenhouse gas needed to produce the same impact generated by the same amount of CO_2. It can be expressed in grams, kilograms or tons. However, the standard unit for CO_{2eq} is used kilograms (kg).
The total value of CO_2 equivalent depends on the quantity of greenhouses emitted and on the Global Warming Potential GWP of that gas. It is usually used the GWP in 100 years. The value of the GWP for CO_2 is always constant and equal to 1, but it could change a lot depending on the gas and on the time horizon chosen.
Several studies had demonstrated how greenhouse gas emissions are mostly related to human activity as electricity and heat generation, industrial activity, transport, and others [9]. Indeed observing the Figure 2, relating to CO_2 emissions on a global scale, it appears evident that the quantity of greenhouse gases emitted is increased deeply over the years.
It is interesting to note that a comparison with 1990 does not take into account the increase in CO_2 levels that had already occurred. The period between 1600 and 1850 can be de-

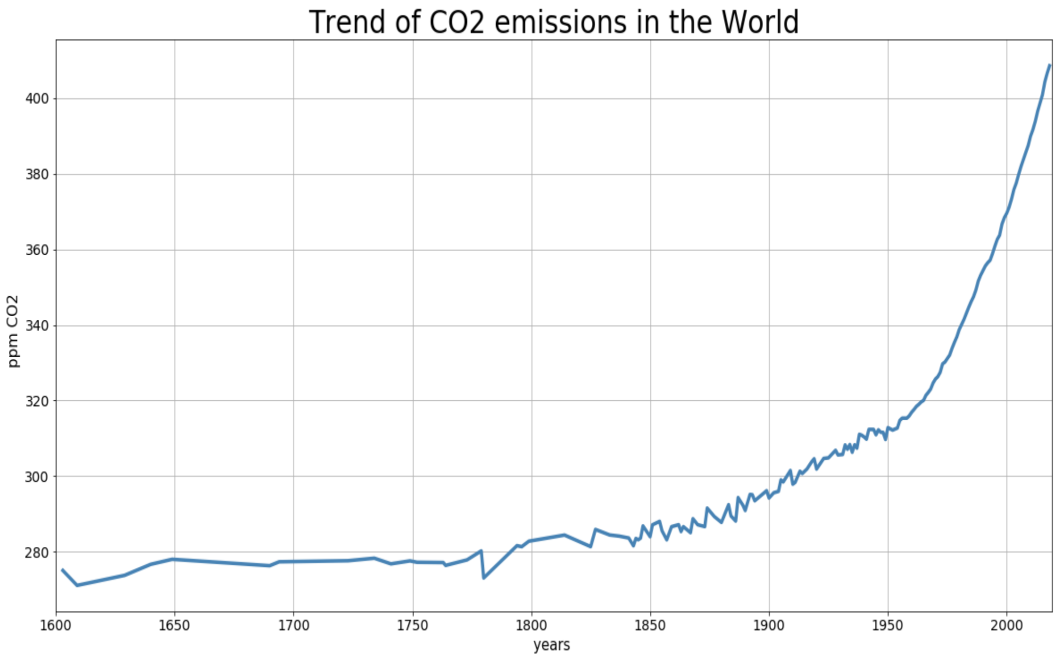

Figure 2: CO_2 emissions world trend. Extracted from [1]

scribed with a flat trend, only the last 50 years starts to show a small change in the trend. In fact, since 1850, with the beginning of the second industrial revolution, can observe an oscillatory trend of growth in emissions, although this value remains below 320 ppm until 1960. With the technical progress, especially in the fields of electronics, information technology and telematics, the increasing diffusion of automobiles ,and the progressive electrification in various sectors such as industrial, residential, etc. ... the value of emissions has undergone an unprecedented growth exceeding 360 ppm already in the late 1990s.
Over the past few years this value has reached and exceeded 400 ppm. The Figure 2 shows that emissions have increased by almost 100 ppm over the last 70 years. In the previous four hundred years from 1600 to 1950 this growth has been much lower, about 30 ppm.
This reckless increase in emissions and so in the amount of CO_2 in the atmosphere has had several effects.
Looking at the Figure 3, it is possible to notice that until 1950 the variation of the annual average temperature recorded a slightly negative trend. This trend appears to be quite similar to the one of solar irradiance. From that year onwards, however, there is a dissoci-

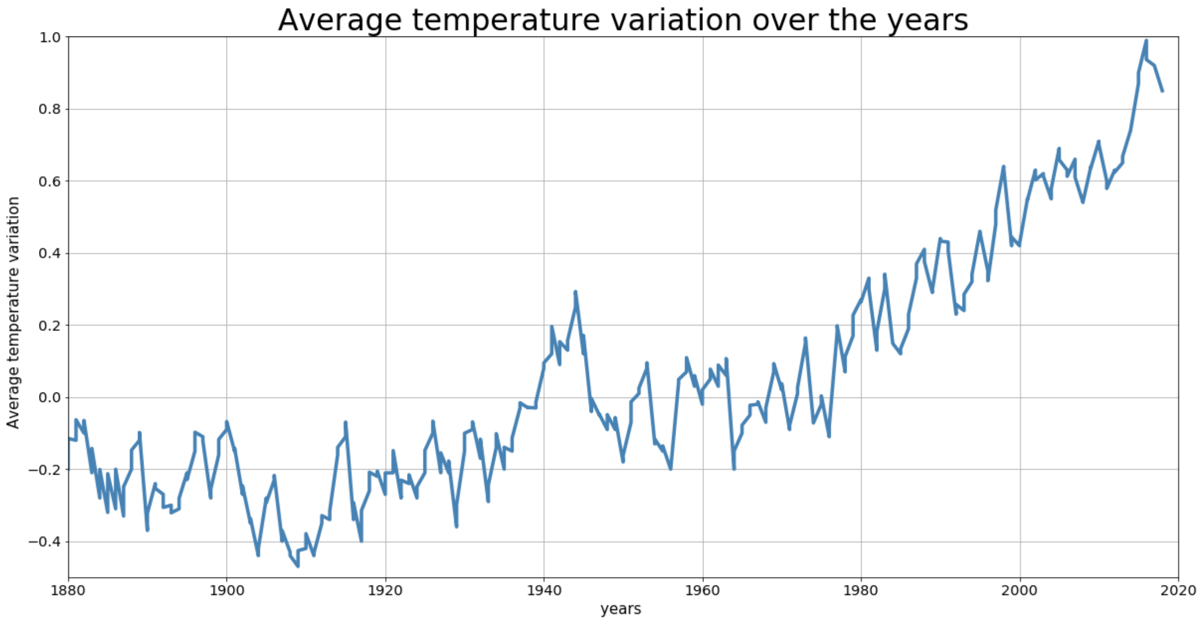

Figure 3: Average temperature variation

Source NASA [5]

ation between the two trends as can be notice in Figure 1. Solar irradiance does not show a change in the trend, while the temperature increases exponentially, reaching an average increase of 0.8 degrees in 2018, as it possbile to observe in Figure 3.

Let's focus now on the last 30 years. The trend in Figure 4 highlights a negative peak in 2009 due to the global financial and economic crisis that started the previous year and dragged emissions down due to the collapse of production in many sectors.

This trend does not bode well, especially since, despite all the efforts done to reduce emissions, they continue to grow. Looking at the different countries separately, it can notice different trends. Indeed, some of them have reduced their emissions, while others show a slight increase in emissions.

This represents a really big problem in terms of an environmental issue because it means that the efforts done to reduce the emissions are not sufficient, and additional ones will be required to reach the targets fixed and to avoid dramatic consequences.

Now it could be interesting to observe Figure 5, where are represented all the sectors that contribute more to the emissions. This makes it easier to understand which sectors contribute more to emissions, and which ones need to be improved first. Of course, this data

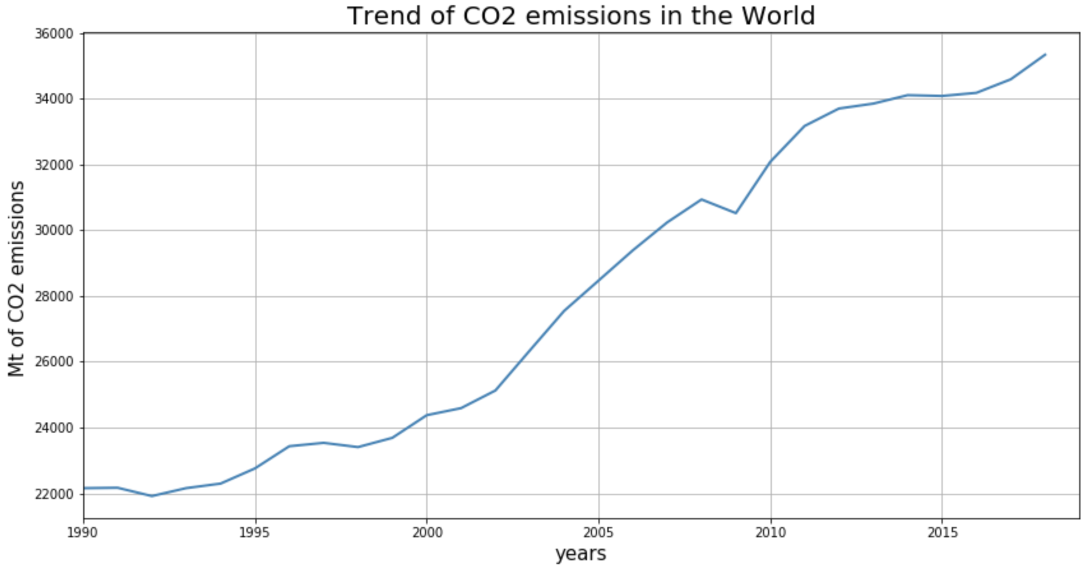

Figure 4: CO_2 emissions 1990-2018

Source IEA [11]

can change a bit country by country, but the general trend is more or less the same.

According to IEA data displayed in the Figure 5, the sectors that contribute more to CO_2 emissions are electricity and heat producers, transport and industry. Specifically, the electricity and heat producer is the most relevant one, so it appears as the best candidate for improvements.

However, also all the other sectors have a really important role in terms of CO_2 reduction. So in order to obtain good results, it is important to consider also them in the energy Nation Plan.

In the Figure 5 it's also possible to see that the electricity and heat production represents alone more than 40 % of the total emissions, so this analysis is focus on this sector.

This high value is related to the deep use of fossil fuel, as hard coal, lignite, and Natural Gas. These sources are largely used all around the world, especially in developed countries as China and India. This is because they are less expensive and also because there are several reserves all over the world. Moreover, producing energy using these sources is not influenced by external factors, such as weather conditions. It isn't possible to say the same

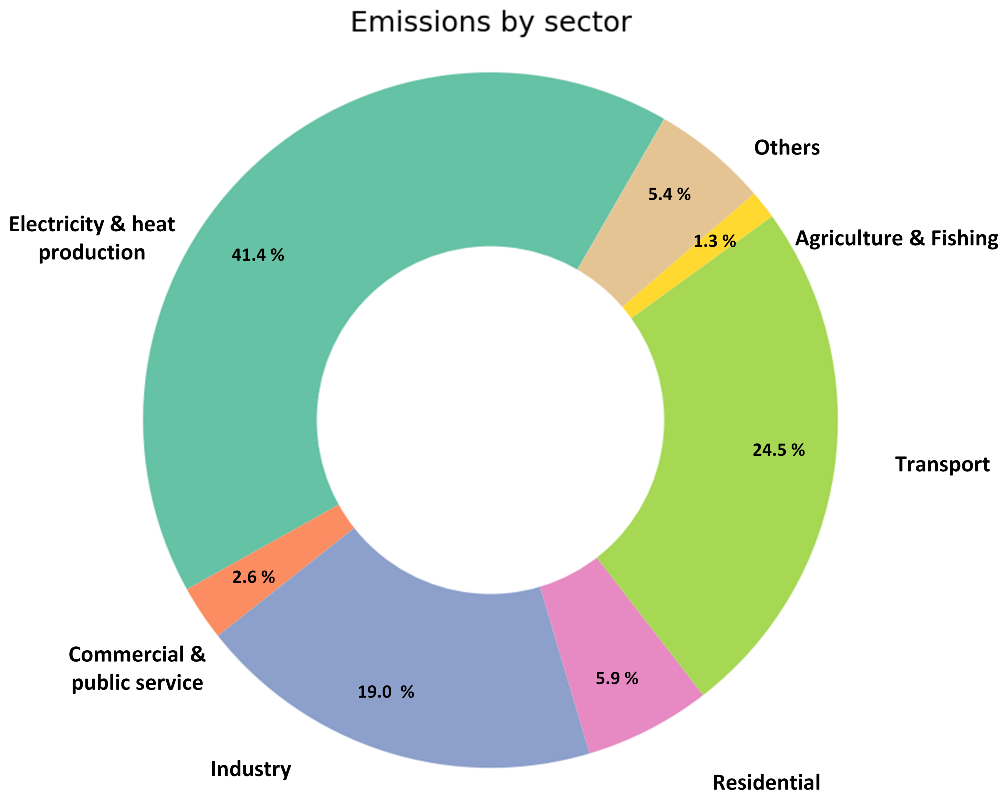

Figure 5: CO_2 emissions by sector

Source IEA [11]

for energy produced using renewable resource. So they appear more reliable in terms of energy security.

Figure 6 shows the most emitted country of 2018. The first rank is gained by China, followed by the United States, India, Russia Federation, and Japan.
These values are not surprising because China and India are developing countries which means that their energy systems are still strictly based on fossil fuels because these sources are more economic and because there are a lot of mines in that areas. China emission's become more and more relevant from 2001, when they start to grow up so far, passing first EU and then the United States of America in 2006, imposing itself as the most emitted country. Of course, this isn't a good point for China. However on the other hand, this country is pushing more and more toward the development of renewable energy power plants. Indeed in 2015 renewable sources represent 22 % of the energy mix and, the goal

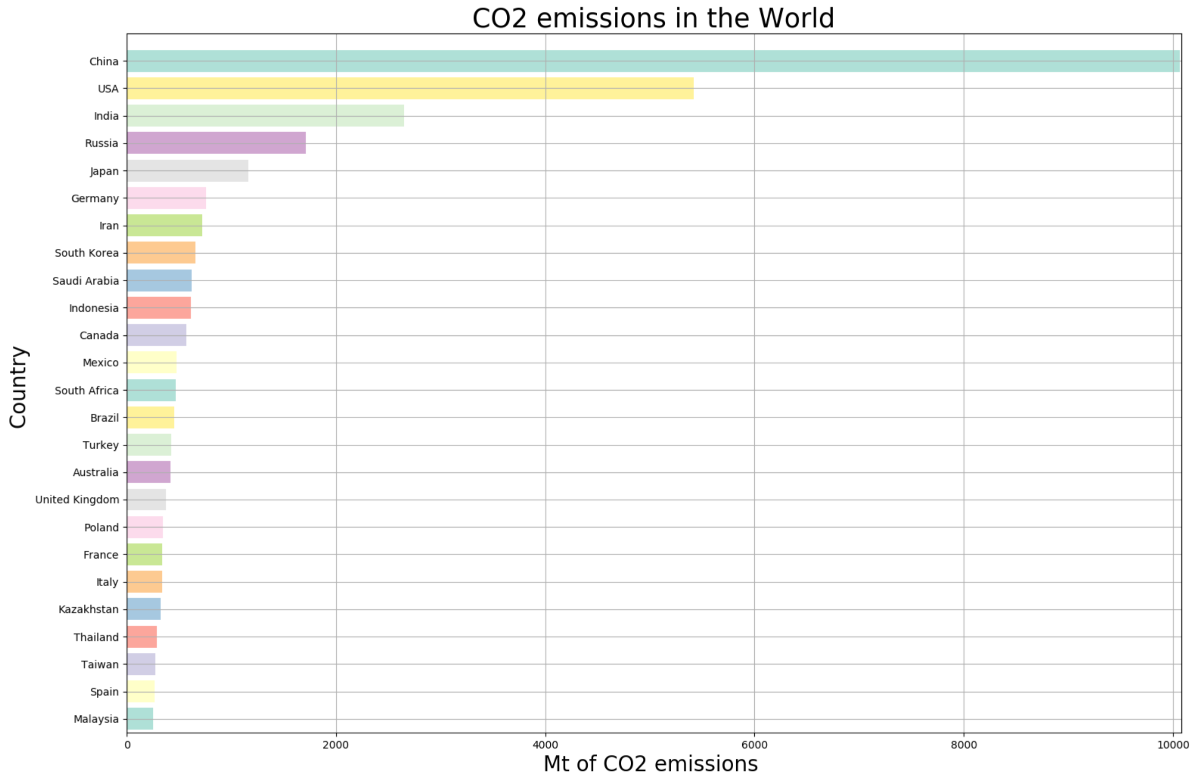

Figure 6: CO_2 emissions by country

Source IEA [11]

is to reach 31 % in 2035 [12]. Here it is possible to find onshore and offshore wind power plants, solar power plants are present all over the country, and it can count on the biggest hydropower potential in the World, which is still under development.

Thanks to its location, China can rely on the abundant quantity of solar energy. For this reason, since 2004 starts a fast growth of photovoltaic power plants, keeping the first place in the world for energy produced by photovoltaic [12].

Due to its agricultural tradition, the cultivation of biomass is widely diffuse around the country in different forms: agricultural residues, forest residues, biomass production on surplus degraded land, organic wastes, and others [12].

China is pushing more and more to increase hydropower and wind power plant firstly, but also solar power plant, which now appears more expensive, biomass, geothermal and energy from oceans [12].

Focusing now on the situation in Europe. It appears in the third position in terms of CO_2 emissions, this is related to the deep presents if coal and oil in the share of energy sources. In Figure 7 the attention is focused on the last 30 years. This makes it possible to assess the effect of green policies in Europe. If the trend of emissions is increasing, it means that energy policies have not been efficient in reducing emissions. In contrast, a decreasing trend is an indication of good results in environmental terms.

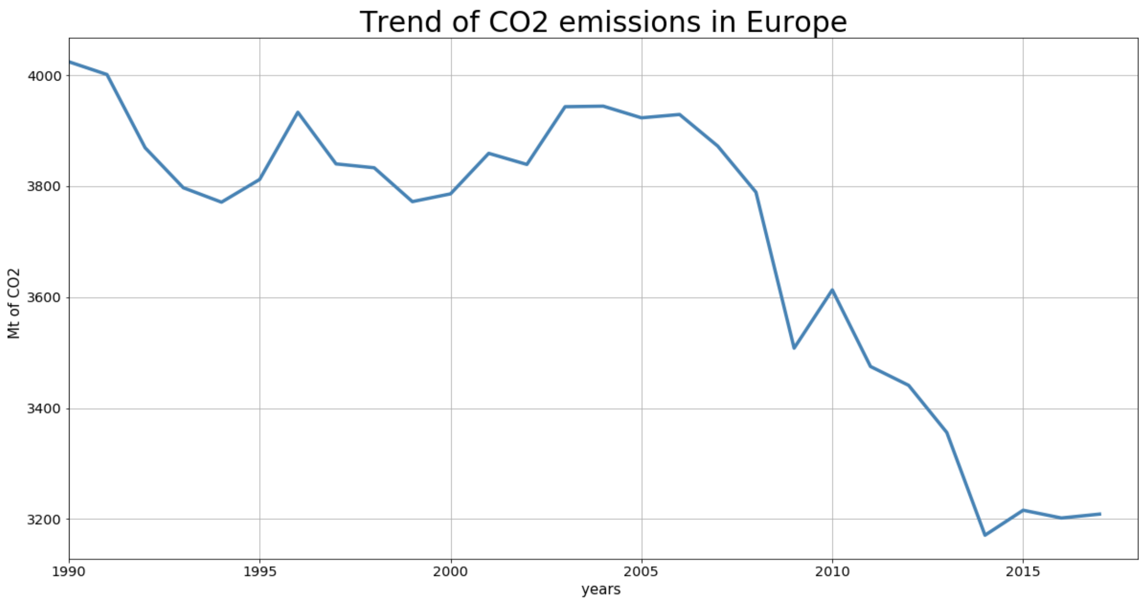

Figure 7: Trend of CO_2 emissions in EU

Source IEA [11]

The overall trend of Figure 7 shows a general reduction of the emissions related to the data of 1990. So, this represents a really good result. However observing better the shape of the curve, it is possible to discover some important hidden information. Indeed, there are two downwards peaks, the first one is in 2009 and the second in 2014 which corresponds to a period of economic crisis. In the early 2010s, the Great Recession affects the most important economy of the world, due to the collapse of the financial sector, this is translate in terms of reduction of production and so also a reduction of the emissions.

This crisis went on, and after 2011 the situation in Europa has worsened due to the sovereign debt crisis. For this reason, and also due to an increase in the share of renewable power plants, it is possible to notice a reduction of emissions. The lowest value reached is in 2014, then the restart of economic growth causes a bit of increase.

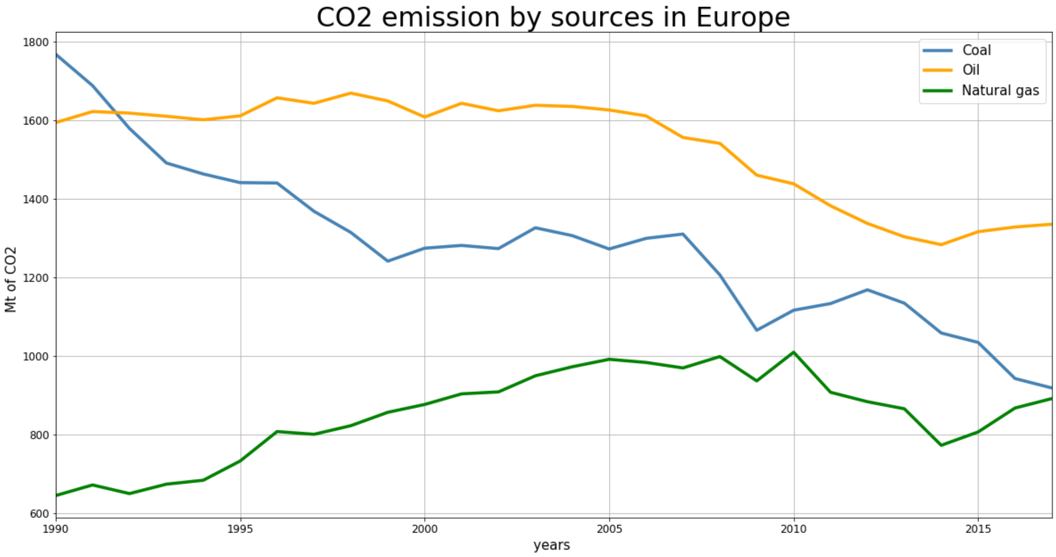

Figure 8: CO_2 emissions by sources in EU

Source IEA [11]

Observing the trends of the different fossil fuels in the EU in Figure 8. It is possible to notice two opposite behavior: Oil and coal reduce deeply their emissions, due to the close of several coal power plants and also due to the increase of the share of renewable energy sources in energy production, while Natural Gas appears has a different behavior,, after the period of crisis keeps on increasing its emissions. As a consequence of the crisis in 2009, the use of coal and so its emissions register a growth until 2014. It is because this source is cheaper than the others, but then it shows again decreasing trends thanks to the greater attention to climate issues.

The emissions due to the use of Oil are the most relevant since 1992 due to the increase of the share of fossil fuel vehicles and the use of oil products. Fortunately, since 2004 the emissions start to be reduced.

On the other hand Natural Gas presents an increasing trend with a downwards peak in the crisis period, but after 2014 it starts to grow again.

Observing the trend of the share of renewable energy sources in Europe in Figure 9, it is possible to notice that hydropower was still developed since 1990, and it keeps its production more or less constant during the years. The down peaks registered in 2011 and 2017 are due to drought, especially in the south.
Wind power plants are increasing deeply their share all over the old continent. Since 2000 the energy produced by this source is growing dizzy. So, it appears as a solid and well-spread technology on the market with competitive prices. It can not be said the same for solar technologies, especially for solar thermal. Which had only been in the share for 10 years and so it is still too expensive and not really used. It reaches almost the energy produced by geothermal power plants. This is also related to the fact that solar thermal technologies require specific working conditions, which are present only in a few zones in Europe. On the other hand, PV panels are growing up so quickly since 2005, especially thanks to government incentives. And it expected to keep on growing thanks to the cost reduction.
Geothermal is not deeply developed in Europe. Although the electricity produced with this source has more than doubled, it still presents a lower share than the other sources.
Tide, wave, ocean technologies are still under development for the EU. They are present in the share but, their trends are flat and present the lowest value.
Bio-fuels are increasing their popularity during the last years, especially solid ones and biogases. The problem is that these technologies are still expensive and with a low value of efficiencies. In Figure 9 the group of biofuel includes primary solid biofuels, biogases, industrial waste, municipal waste, and liquid biofuels.
However, although the share of renewable is increasing widely all around EU, and the world as well, it is not enough to fight climate change. A lot of efforts are still required to avoid the most dramatic consequences. The National Climate Assessment made researches to underline which could be the consequences in terms of human health, energy, transportation, agriculture, forest, water, and ecosystem.
Glaciers and sea-ice are melting more and more quickly causing sea-level rise. This represents a really big problem for some coastal city as Venice, Miami, New York, Bangkok, Maldives, Netherlands, Mumbai, Alexandria, and others, which are in danger of disappearing under the sea [13].

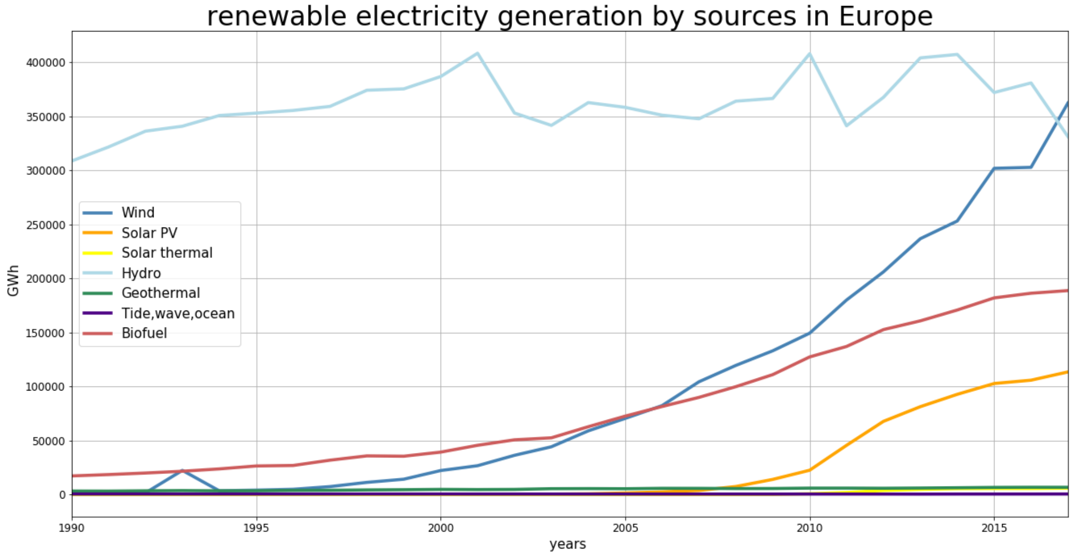

Figure 9: Trend of electricity generation by renewable energy sources

Source IEA [11]

All over the world it is registered a substantial increase in extreme natural events, which has already caused many deaths, and the situation is expected to get worse. The heatwaves in the area in southern Europe have already caused many deaths, especially among elderly people. In the Eurozone only in 2003, heatwaves caused 70000 deaths.It is expected that this number could only increase year by year due to temperature rise. Another serious factor which is causing damage to human health is pollution. This can cause cardiovascular disease and respiratory problems, especially in weaker groups such as the elderly and children. Floods and tornadoes are occurring more and more frequently, bringing with them numerous deaths [14].

Another very relevant factor is the temperature increase which favors forest fires. Every year millions of hectares go up in smoke. In 2019 alone, 900,000 hectares of Amazonian forest have a burden, more than 10.7 million hectares in Australia and 4.5 hectares in Siberia. The high temperatures have reached even the coldest parts of the planet [15].

Moreover,is observed that in recent years climatic anomalies have led to imbalances within the various ecosystems. Causing the migration of animals to areas where they were not previously present. Together with them, however, also diseases often can travel, as in the

case of mosquitoes. This could lead to new epidemics.
Ocean normally contributes to the reduction of CO_2 presents in the atmosphere, but due to the very high concentration in the atmosphere, it is happening the progressive acidification of the sea. This change in the value of pH has disastrous consequences on both fauna and flora. The coral reef is going to disappear, as well as many other plant and animal species, it confuses fish, disturbing their sense of smell [16]. Indeed the risk of extinction of numerous species is also occurring on land.
The WWF estimates that while remaining below the average temperature increase limit of 2 degrees Celsius, more than 25 % of the species on Earth are risking to disappear [17].
Also, the agricultural sector will suffer greatly as a result of climate change. This represents a really serious issue that could bring to have a lot of problems: changing seasons, rising temperatures, torrential rains, and abnormal events can destroy crops and cause hunger in many parts of the world.
The effects and the consequences of climate change are generating another big issue: climate migrants.
Many cities will be flooded and climate change could make several parts of the planet which are now populated uninhabitable. This would lead to a flood of people looking for a new place to live. Estimate how many of these migrants could be is really complicated, but there are studies made by Professor Myers that estimate that 200 million climate migrants could be reached by 2050 [18].
All of these represent really big problems and so help to understand why it is so important to fight climate change.

1.1 EU context

Europe appears in the third position in terms of CO_2 emissions in the world, but from Figure 7 it is possible to observe that after 2006 the amount of emission is deeply reduced. Indeed, during those years, environmental issues started to be more and more relevant.
For these reasons, the European council of 2007 sets the environmental goals of each state of the EU to reach common goals for having sustainable development. These goals have the first deadline in 2020 and they represent the three main pillars of sustainable development also known as 20-20-20. The name is related to the fact that the main goals are [19]:

- reduction of 20 % of greenhouse gas emissions compared with the pre-industrial levels;
- increase of 20 % of electricity coming from renewable energy sources;
- increase of 20 % in energy efficiency;

These targets were enacted in the European Renewable Energy Directive 2009/28/EC [20]. Where it is specified in which sector and how much the directive has to be applied. All EU countries have to contribute to common European goals in a differentiated way, according to different situations and possibilities of development. For this reason, the efforts required by some states are bigger than others.
Moreover, the Council indicates also a long term target for decarbonization. Indeed a lot of countries are starting a process of decommissioning coal power plants, in order to turn into carbon neutral. The overall aim is to achieve the reduction of GHG emissions of around 80-95 % by 2050.
The importance of 2020 Energy Strategy is not only on environmental terms but also from an economic point of view, the aim is to build a pan-European energy market constructing the necessary transmission lines, pipelines, LNG terminals, and other infrastructure. [21]
The European Commission pushes to find a common strategy to fight climate change and to a transition towards a sustainable economy. In this way, it will also be possible to reduce the dependency on energy imports improving energy security, solidarity, and trust to protect consumer rights. The cooperation between countries and the share of information and

techniques allows accelerating the development and deployment of new technologies. In this way, it will be possible to upgrade the energy efficiency which should lead to moderation on energy demand [22]. Another important common goal is represented by the decarbonization of the economy. To do this it is fundamental to prepare market and grid to an increase of the share of renewable energy, and at the same time it is important to improve the existing renewable technologies and energy storage investing on research for innovation and competitiveness [22].

The adoption of the Paris Agreement in 2015 represents a really important mail stone to face climate change. For the first time, an international agreement places obligations on the signature countries. The aim is to keep the average temperature increase below 2 °C, trying to keep it under 1.5 °C and to reduce as much as possible the greenhouse gas emissions. In order to achieve these goals, it is requested for each country to submit its National Determined Contributions, also known as NDCs.
document contains the country's highest ambition to face climate change. It also depends on the principle of common but differentiates responsibilities and respective capabilities (CBDR & RC). The CBDR is based on the fact that all the countries contributed to climate change but in a different way. Indeed there are some of them which contribute more than others so they have to make a bigger effort to face it.
Another important expected concern the respective capabilities of each country to face climate change. It depends on several factors as economic development, technology, and geography of the Nation.
From this analysis it appears quite clear that the poorest and less developed nations necessitate helps from the developed countries, which present higher technological development and more money. For these reasons they can be differentiate between: developed, developing countries, small islands, and unique reality.
A five-year review checks if each country had respected the goals fixed on its NDCs. Depending on the results obtained it could move to a declaration of non-compliance, but it's quite rare. Often developing countries can not reach their goals, due to a lack of resources and technologies, so they need more help. It is not the same for a developed country. In this case, they could receive a declaration of non-compliance.

Europe is one of the most important countries that join the Paris Agreement fixing a really high ambition target. The keys targets between 2021 and 2030 are [23]:

- reduction of 40 % of greenhouse gas emissions compared with the pre-industrial levels;
- increase of 32 % of final energy consumption from renewable energy sources;
- increase of 32.5 % in energy efficiency.

In order to reach the goals fixed in terms of sustainability, each state had drafted energy planning according to their current situation and also according to their possibility of developing different technologies. The main common goals are:

- reduction of CO_2 emissions;
- increase of the share of energy produced renewable energy sources;
- increase in energy efficiency;

The differences are represented on how each state faces these challenges: some states offer economic incentives to encourage the growth of renewable plants, others impose a tax on CO_2 emissions or tax more on plants that use fossil fuels.
The development of different renewable energy sources is related to several factors, as the sustainable policies adopted and it also the morphological and climatic characteristics of the territory.
According to the goals fixed and with the sustainable policy adopted, it is possible to perform different scenarios to find which is the best solution in environmental terms.

1.2 Purpose of the study

The purpose of this study is to analyze possible paths that can be followed by energy policymakers to achieve the goal fixed in terms of reduction of CO_2 emissions and share of renewable energy in electricity production. These are performed using Consequential Life Cycle Assessment, CLCA, and prospects up to 2030. In particular, the attention of the analysis is focused on Germany and Spain. Both of them show a developed economy and an important role in the EU community, but they had a different development. During the

2000s, Germany and Spain were forerunners of the energy transition in Europe. Together with Denmark, these countries had the fastest development of the renewable energy sector in Europe between 2000 and 2010.
During this decade, the share of renewable in Germany grew by about 10 % and about 17 % in Spain. After the global financial crisis of 2007, the situation changes due to the different economic and policy approaches followed [24].
Starting from an overview of the current situation, possible scenarios are performed in order to reach the targets fixed by each country using a CLCA. In this way, it will be possible to observe the effects of different strategies of implementation of renewable energy sources.
The goal of the study is to use CLCA to evaluate the kg CO_2/kWh with the actual share of sources and compare these results with a possible future share of resources, which depend on the environmental policies of the country. Particularly, the analysis is focused on the increment of the sharing of renewable energy sources, and on how the decarbonization process could affect energy production in terms of emissions. The National Climate Action Plan is used to prescribe future scenarios. In this way, it would be possible to asses if the targets imposed by the European Union are satisfied or not. These targets are in terms of reduction of GHGs emissions, increase the share of RES and efficiency increase.

The second part of the study uses the tools of machine learning in order to track the possible trends of CO_2 emissions for Spain and Germany.
The emissions trends from 1970 to today are used as a model to forecast emissions up to 2030. In this case, the input data is the time-series of the Millions of tons of CO_2 emitted in each country
The data comes from the 2018 report on the global CO_2 emissions "Fossil CO_2 emissions of all world countries" [25]. To build and validate the model was used Python programming language. Once the model is validated, proceed with the prediction of the emissions trend. The use of forecasting models for future trends is very useful as it allows you to see if you are heading in the right direction or if a change is necessary.
In conclusion, it was decided to compare the emission trend obtained with python with the one obtained from the electricity production scenarios in accordance with the National

Plans of the countries. The aim is to see if the new environmental policies are more or less efficient than those used so far in terms of emission reductions. This makes it even more evident that the application of different environmental policies generates responses in terms of emissions variation and investment in renewable energy. These analyses can also help in the field of policy-making when energy policies need to be implemented. Energy plans must take into account the needs of the country and its peculiarities while trying to find the most effective way to achieve the objectives set.

2 State of the Art of Energy Polices in Targeted Countries

This section performs an overview of the countries that will be analyzed. The aim is to observe the geographic and economic characteristics and to have a look at the goals fixed for 2030 and which are the policies that will be adopted to reach them. Having a clear idea of the initial situation in each country and its peculiarity is important to understand the possibilities of development. Because, according to its characteristics, it should be better to improve a certain source or policy to another.

2.1 Germany

Germany is located in Western-center Europe. It is the seventh-largest in area, and it borders with several European countries: Poland, Czech Republic, Austria, Liechtenstein, Switzerland, France, Luxembourg, Belgium, Netherlands, and Denmark. Moreover, the north of the country lying between the Nordic and Baltic seas. The Alps represent a natural border in the south.
The major rivers are Danube, Rhine, and Elbe, which contribute to the hydropower production of the country. The wind can reach high speed, especially close to the coast, in the north and also in the center. For this reason, the major wind farms are located in those zones, or also in the north-east. Only a few are located in the south due to the low speed of the wind in that area.
Due to its latitude the value of solar irradiance is quite low if compared with other European countries. However there is an internal difference. Indeed, the value of irradiance is weaker in the north, and it increases a bit in the south. So, for this reason, the majority of the solar power plants are located in that zone. According to its characteristics, it is possible to identify two different zones: the north characterizes by wind power production and the south with more solar power plants than the wind one.
Germany is rich in mineral resources, especially coal. In the past, this has profoundly influenced the development of the industry sector and energy production. Although now most of the mines have been closed, coal still plays a major role in the production of electricity. There are several regions whose economy is still based on coal mining and are the

following: Ruhr, Lower Lusatia, and Central Germany.

2.1.1 Population

Germany is the second European country for the population, with more than 81 million people , the first one is Russia [26]. The population density is around 238 people/km^2 deeply higher than the average value of the EU [27]. The level of urbanization is high, with 76 % of the population leaves in the city [28].
German is the official and most popular language, but there are several variations of dialects. This country appears as one of the favorite destinations for international immigrants, indeed a wide range of residents are immigrants or partially immigrant or immigrant descent. The ethnics most present are Turkish, European citizens and Yugoslav

2.1.2 Economy

Germany has emerged as the largest and most powerful economy in Europe. At the world level, it ranks fourth for the nominal GDP, and fifth for the per PPP, purchasing power capita. It is the third world's largest explore of goods.
The most important and developed sector is tertiary, especially it presents the most innovative and modern industry for the modern car. Moreover, it is important to mention also others sector as machinery, chemical goods, electronic products, electrical equipment, pharmaceuticals, transport equipment, basic metals, food products, and rubber and plastics [29].
The energy industry contributes to the economy of the country. Indeed, there are several factories whose production is related to renewable power plants. The most important in the production of wind turbines are Enercon, Norden, Senvion [30]. There are also a lot of photovoltaic producer as Bosh, Conergy, Solar World, and others [31].
Germany is also an ambitious destination for travelers. Indeed tourism contributes 4.5 % of national GDP. Beyond beautiful cities, as well as Berlin, this country offers a multitude of roads such as the one of Wines or Castles one or the Romantic one or the Avenue one.

2.1.3 Current Installed capacity

The overall installed capacity of Germany in 2018 is equal to 208 GW, and Table5 shows in detail the installed capacity per production type. While 10 shows the share of the electricity produced by the country. All this data comes from ENTSO-E TP.

Table 1: Installed capacity of Germany in 2018

Source ENTSO-E TP

Sources	2018 Installed capacity [GW]
Hard Coal	25.0
Lignite	21.0
Nuclear	9.5
Natural Gas	31.0
Wind onshore	51.8
Wind offshore	5.0
PV	42.8
Hydro	14.0
Biomass	7.4
Geothermal	0.038
Fossil Oil	4.3

As it is possible to observe in Table 5 and Figure 10, wind power plants with 57 GW (5 GW off-shore 52 GW onshore), is the most installed capacity of the country. It contributes to around 20 % of the yearly electricity. Coal with 46 GW installed, divided between Lignite 21 GW, and Hard Coal 25 GW, produce around 37 % of the electricity.
Despite Natural Gas has an installed capacity equal to 31 GW, but its capacity factor is low. Indeed in 2018, it produces only 6.4 % of the electricity. This means that it is possible to increase production without increasing the installed capacity.
In accordance with the decision of progressively phase-out from nuclear, the installed capacity and energy produced are decreasing with now less than 10 GW.
Hydro-power production takes into account hydro-pumped storage, run-of-river and poundage, and hydro water reservoir. It has around 14 GW of installed capacity and participates with

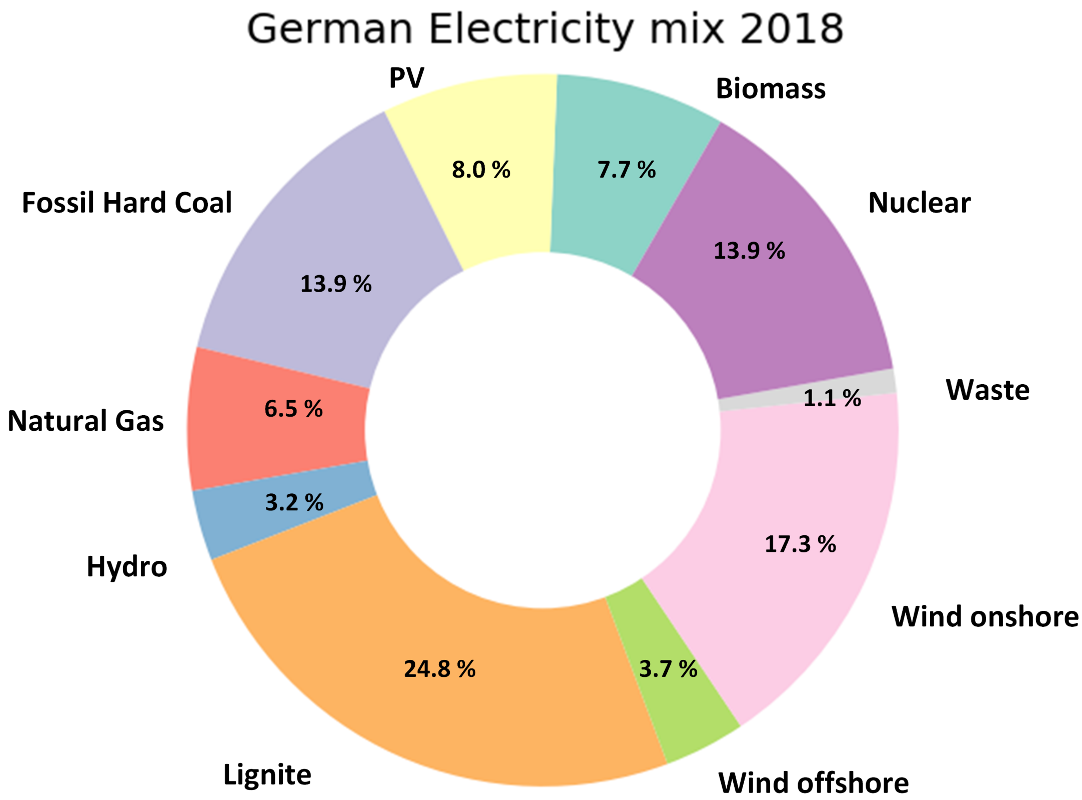

Figure 10: Electricity mix of Germany in 2018
Source ENTSO-E TP

3 % to the share. The solar power plants are deeply present in the country with almost 43 GW. Due to the low irradiance of this country, its contribution to electricity production accounts for around 8 %. .

The biomass contributes to a similar percentage, but its installed capacity is lower, equal to 7.4 GW. So, this source presents a good opportunity for development in the future.

The electricity produced by geothermal, others, other renewable and fossil oil accounts for less the 1 % each. So they can be considered negligible.

2.1.4 Goals & Policy

Germany plays an important role in the European community. It is a driving force and an example in several areas, including the environment. It was one of the first nations to move green initiatives, to drive other European nations. For this reason and for being one of the most economically developed nations, it has set itself more ambitious goals for reducing

GHG emissions than many other nations. For example, Table 2 shows the 20-20-20 targets of the Nation. Germany had set itself the target of reducing emissions by 40 % compared to 1990 levels, twice as much as the common target. However it does not do the same with regard to increasing the share of renewable in final consumption, which is about 2 % lower than the target of 20 %, nor about increasing energy efficiency, whose target is half that of the European one.

Table 2: 20-20-20 Germany Targets

Source European Commission

Indicator	**Target**
% of reduction of GHG emissions	40 %
% increase of energy efficiency	10 %
% renewable energy sources share increase	18 %
% renewable energy share of gross electricity consumption	35 %

The Climate Action plan of Germany for 2050 explaining in a detailed way which are the goals of the nation and which are the strategy to reach them in the period between 2021 and 2050.

The final goal for 2050 is to turn definitively into a greenhouse gas neutral country. Which appears like an ambitious goal, but it is not possible to postpone it anymore.

This analysis takes into account the period until 2030 because it represents a medium-term step. The guiding principles are set in 2050, but the measures and milestones stop in 2030. Therefore, it is considered more appropriate to focus the analysis on this time range, to assess whether the plans and measures adopted can lead to the desired results, or if it is necessary to change them.

The goals change sector by sector and include different fields. The targets for 2030 are the following one:

- reduce of 55 % CO_2 emissions compare with 1990;
- 30 % of electricity produced by renewable energy sources;
- increase of efficiency of 30 %;

- 50 % of renewable energy share in gross electricity consumption;

To do this it is really important to consider all the sectors involved: energy, building, industrial and transport.
The energy sector is the root cause of CO_2 emissions, having a percentage of 42 %, as shown in Figure 11. To improve this value satisfying the demand, it is required to increase the use of renewable energy sources like wind, sun, hydro and biomass. The final aim is to reduce emissions by 62 %, ensuring a secure and affordable energy supply and providing a high-quality job.
Combined heat and power production, mostly based on Natural Gas, will continue to play an important role. However becoming increasingly flexible, to reduce emissions and incorporate renewable heat production [32].
Moreover the use of renewable energy sources will be applied also for transport and building sector. The aim is to reduce emissions in the building sector around 66% and around 40 % in the transport one.
To do this in the building sector, it's really important to consider not only the emissions related to heating and cooling systems but also all the others related to the construction materials. Because of greenhouse gases emitted when these materials are manufactured, used and removed during demolition. So the importance of the choice of construction material is becoming more and more relevant. In this sector, energy efficiency and use of renewable energy sources act together to the final goal.

The goals for the transport sector are the most ambitious one: be virtually decarbonized by 2050. Which means to not depends on fossil fuel containing carbon anymore. However at the same time, it had to be able to ensure the movement of people and goods without affecting economic growth.
The aims are a deep increase in the share of electric vehicles and to feed them with electricity produced by renewable energy sources or with bio-fuel. At the same time, the automotive industry pushes to improve car efficiency to reduce emissions. They believe it is possible to reduce around 30 % of GHG emissions for vehicles kilometer.
In addition to reducing the traffic on wheels, the Government wants to shift the road traffic

of passengers and goods onto railways.
The Climate Action Plan 2050 outlines a gradual transformation in technology, industry, society, and culture [32]. This transformation will be achieved through a learning process involving the scientific community and accompanied by a public dialogue process [32].
German population considers climate action and environmental protection essential for competitiveness, prosperity, and solving problems. For this reason, this document has such an important role. It includes fundamental criteria as social justice, affordability and economic efficiency, participation, and a vibrant democracy [32], trying to obtain social support and participation.
The Climate Action Plan guides all areas of action in the process to achieve climate targets in line with the Paris Agreement. These areas are energy, buildings, transport, trade and industry, agriculture, and forestry [32]. It helps to identify which should be the changes and policies that have to be implemented to achieve these objectives. The plan also includes strategic measures for each action area. It is a long term guideline to achieve the gas neutrality in 2050, fixing milestones and targets up to 2030.
Regarding the reduction of GHG emissions, it's important to understand which are the sectors that contribute more to the emissions to identify which are the ones that require greater improvements.

Looking at Figure 11, it is clear, again, that the most responsible sector for emissions is the electricity generation one. Therefore, it is the sector on which most action is needed to pursue the desired results.
It is really important to push quickly towards renewable energy sources to satisfy the energy demand, especially according to processes of decarbonization and denuclearisation.
The German population has always expressed its disagreement with numerous protests for the construction of nuclear reactors. The Fukushima accident rekindled the protests that led to the referendum in 2015. The result showed that the majority of the population was still strongly opposed to the use of this source. This has accelerated the process of denuclearisation of the country [33]. The decommissioning process should end in 2022.
Now there are 6 active reactors: 1 BWR, water boiling reactor, and 5 PWR, pressurized water reactor. The last reactor was closed in 2019. Then in 2021 and 2022 will be closed

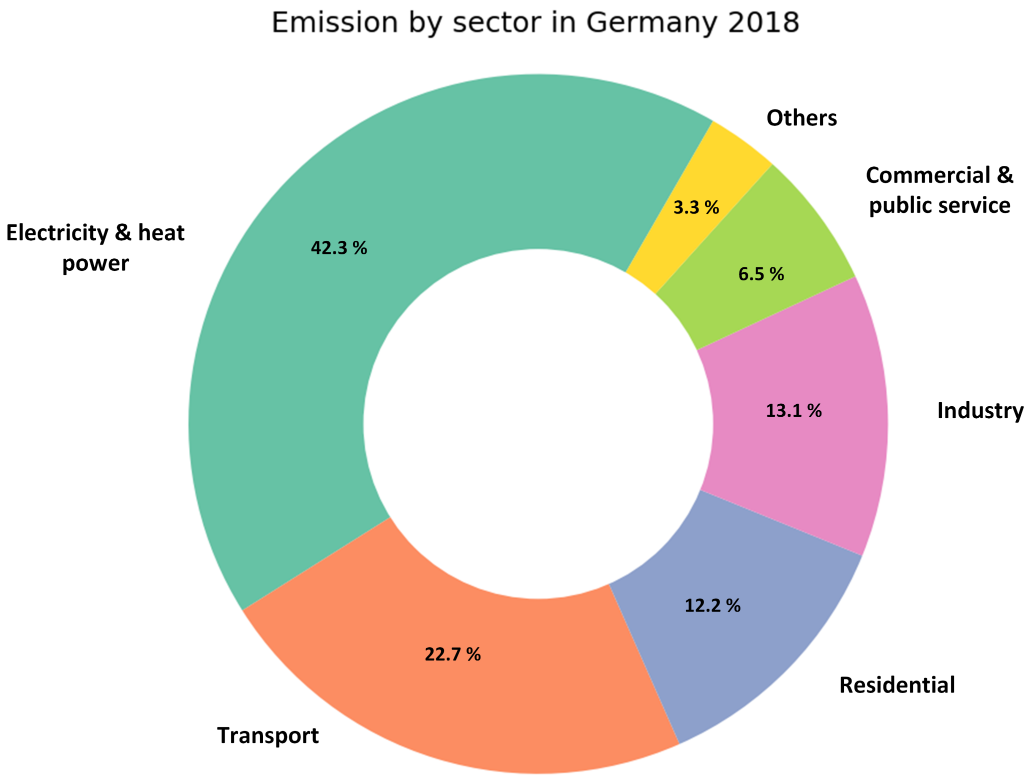

Figure 11: CO_2 emissions by sector in Germany
Source IEA [11]

others 3 reactors each year.

The decarbonization process is long and demanding. The Federal Government appointed the Commission on Growth, Structural Change, and Employment (GSCE) to elaborate it. The difficulties lie in the fact that the economies of some German areas are strongly focused on coal mining and processing. It is, therefore, necessary to ensure a plan of reprimand for all involved workers and economic development for the area. Also, a clean-up process is needed for the mines, which would otherwise continue to be a source of environmental pollution [34].

The final report of Germany coal exit commission sets 2038 as the deadline for the decarbonization.

The decommissioning path foresees a reduction to 15 GW before 2022. Specifically, a re-

duction of 3 GW of lignite and 4 GW of hard coal is planned for 2020. Then it is expected a progressive phase-out of the coal power plant to reach a maximum of 9 GW for Lignite and 8 GW for Hard Coal in 2030 [34].
The GSCE includes also the creation of compensatory measures for the increase of electricity price that could occur due to the accelerated close of the coal power plant. This subsidy is fixed at the National level in the federal budget, to guarantee the energy access to everybody. Moreover, the plan considers also alternative career prospects for the employees of the mines [34]. This aspect is really important for the social acceptability of the people involved. Because they can be skeptical to accept this transition as they would risk losing their jobs.

To ensure secure and affordable electricity supply wind and solar installed capacity had to grow up significantly, according to the energetic plan.
It is planned an increase of 750 MW/year for wind offshore power plant, to reach 15 GW of installed capacity in 2030. The installed capacity of onshore wind is equal to 50 GW and it will count on the additional capacity of 2.5 GW/year. This increase appears to be significantly lower than that which has existed up to now, due to changes in government incentives. Now, due to legislative problems, the construction of new wind farms seems to be more complicated, so the growth rate is expected to be lower.
The goal for the PV panels is to reach an installed capacity of 98 GW in 2030. To do this it is required an increase of an average of 5 GW/year.
Biomass will play an increasingly important role in the coming years as it has different fields of application: electricity generation, heat, and biofuel production. The objective is to have an installed capacity of 8.4 GW in 2030 [35].

2.2 Spain

Spain is the second-largest country in the European Union. It is located in southwestern Europe on the Iberian Peninsula and is bordered by the Mediterranean Sea, the Atlantic Ocean, France, and Portugal. It is separated from France by the Pyrenees and from Africa by Strait of Gibraltar. The Spanish territory also enclaves two cities located beyond the Strait of Gibraltar in the African continent: Ceuta y Melilla. Moreover, its territory also includes two archipelagos: the Canary Islands off the coast of Africa, and the Balearic Islands in the Mediterranean Sea.
Thanks to its particular geographical characteristics Spain presents a high and different energy potential. In particular, it is worth mentioning the existence of the Tabernas desert, in the province of Almeria. It is a dry garrigue site protected as a nature reserve and covers an area of 280 km^2. Its properties make it a particularly attractive place for the construction of solar concentration systems, CSP. The country has an abundance of rivers, widely used for the production of hydroelectric power, irrigation of land and the fishing industry. Among the river, it is important to mention the Taco, the Ebro, the Douro, and the Guadiana.
It is interesting to note that, thanks to its morphological characteristics, Spain is a particularly windy country, with speed peaks that can reach 160 km/h. This makes the country extremely favorable for the use of wind turbines to produce energy, especially on the northern coasts and near the Strait of Gibraltar. Finally, the mineral richness of the region is significant. The presence of numerous coal mines in the Castilla la Mancia mining park and near Aragon had deeply influenced the energy production in the past.

2.2.1 Population

By population, Spain is the sixth-largest in Europe, it has passed 46 million inhabitants in 2018 having a relevant increase since the beginning of the century [26]. The population density is quite low compared with other EU state,and it's equal to of 92 inhabitants/km^2 [27]. The distribution of population across the country appears unequal. The coastal regions and the region of Madrid have a much higher density of population than the inland areas. At the same time, the density in the big city is very different from that in the rural area. In fact, a process of rural migration is currently underway. That partially explains

also the difference between the internal zone and the coastal, where people move looking for a better job opportunity or to study.
The official language is Spanish, but there are other official languages such as Catalan, Galician and Basque.

2.2.2 Economy

The Spanish economy is considered to be one of the most advanced economies in the eurozone. Due to the fascist dictatorship, Spain has lived a period of political and economic isolation until 1975. Then Spain experienced a period of strong development that lasted until the financial crisis and the banking system of 2008, from which it has not fully recovered. Despite the crisis, it has a prominent position in several areas of innovation such as renewable energy, pharmaceuticals, biotechnology, transport and small and medium high-tech industries, which are consolidated strengths to start a recovery and change the basis of the economic model. It is worth to mention the energy industries. This field is particularly developed in Spain, counting on several factories that produce wind turbines or photovoltaic panels. The most important factory are Tamesol, BP-solar, and Isofon for PV panels [31], for wind turbines the most important is Siemens Gamesa [30].

The development of the secondary sector is linked to the mineral resources of Spain. There are four areas of strong industrial activity: Asturias and Basque Country with Bilbao (naval, rail, mechanical and steel), Madrid (chemical, petrochemical, electronic), Barcelona (food, textile, electronic), Valencia and Cartagena (refineries, aerospace) . The textile and footwear sector, which is currently being modernized, is also important.

Spain is one of the most visited countries in the world thanks to the traditional cuisine and the lively nightlife and geographical diversity and the monumental and artistic richness and of course the mild climate. Million and million tourists come each year to visit Spain, so it is not surprising that the most developed sector is tourism, which accounts for about 5 % of the country's GDP.

2.2.3 Current Installed capacity

Thanks to its geographical characteristics Spain has several possibilities to satisfy the energy demand. According to the increasing awareness of climate issues, in recent years Spain has pushed more and more towards the production of energy through renewable sources. In Figure 12 it's represented the electricity mix, despite renewable energy sources are widely present, Spain still has a strong dependence on Natural Gas and lignite and nuclear power. This also implies a strong dependence on imports of fossil sources, as the reserves of Spain are not sufficient. According to data from the ENTSO-E TP, which are collected in Table 3, in 2018 the biggest installed capacity is Natural Gas with 30.7 GW. In

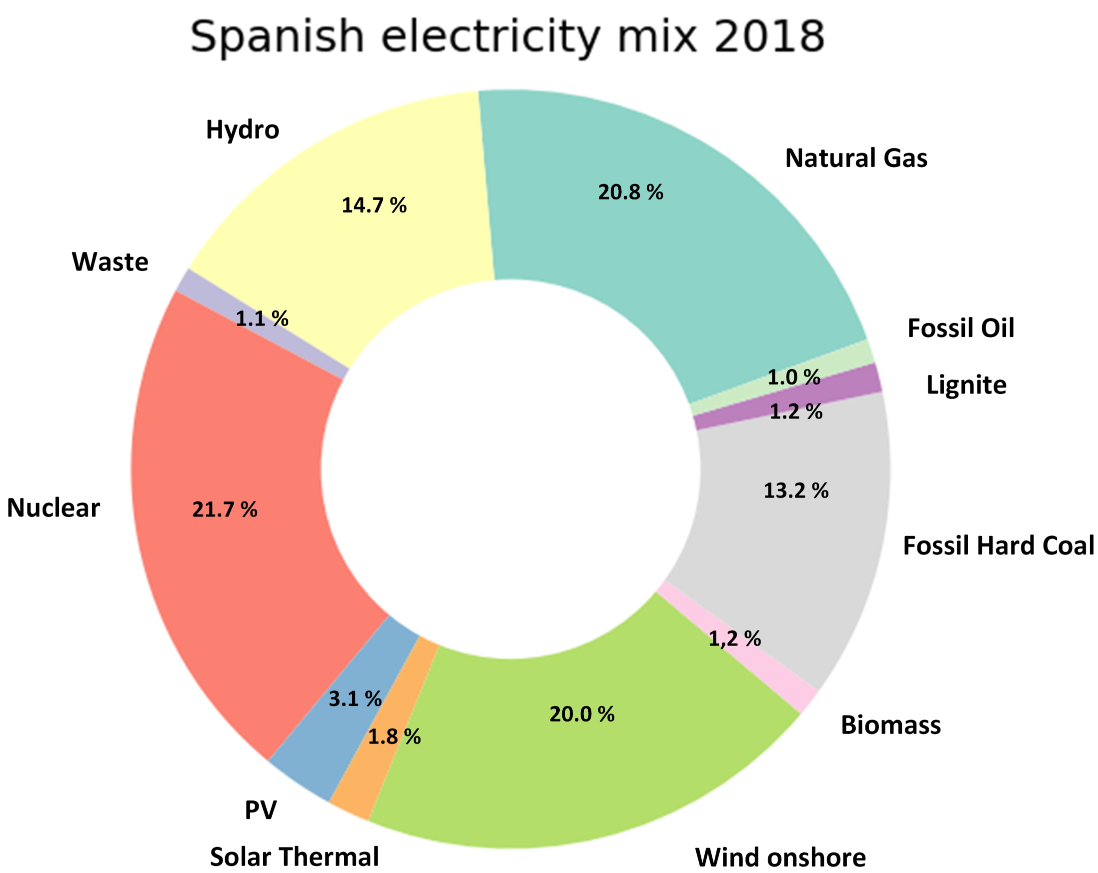

Figure 12: Electricity mix of Spain in 2018. Source ENTSO-E TP

the second place, there is a renewable energy source: wind. Wind power plants are located all around Spain, and it counts of around 23 GW of installed capacity. However there aren't still off-shore power plant. Each of these sources contributes to $1/5$ of the yearly electricity

production. The hydropower plants which take into account hydro pumped storage, hydro run-of-river and poundage, and hydro water reservoir have reached the maximum of its installable capacity 20 GW.
Nuclear power plant with only 7 GW of installed capacity is the most productive source, it contributes to around 21.6 % of electricity production.
In Spain the energy from the Sun is used to produce electricity in two different ways: photovoltaic and solar thermal. Solar power plants can count on 6.7 GW of installed capacity: 5.4 of photovoltaic and 1.3 of solar thermal. The biggest solar thermal power plant is located in Andalucia and Extremadura.
Photovoltaic is much more present in Spain due to the high irradiance present all around the country, while solar thermal is present only on the south because it requires special conditions, really high irradiance, and is still very expensive.
Coal is still presented in electricity production, while Lignite is almost disappeared, it only accounts for 55 MW of installed capacity, while hard coal is still relevant with 9.5 GW.
There are also present other sources, with the corresponding power plant as Biomass with 52 MW, Fossil Oil with 715 MW and waste with 544 MW, but due to their small installed capacity and very low production, around 1 % they are not relevant in energy production.

2.2.4 Goals & Policy

Ending Franco dictatorship, Spain has started a period of growth, especially between 1995 and 2007 it experience an economic boom, which affects the increase of GDP but also the increase in electricity demand. The demand rise by about 5 % per year. This brings the necessity to increase the installed capacity of the nation. The government pushes toward wind power and Natural Gas power plants. However then in the period between 2008 and 2015, there was a decrease of 5 % of electricity demand due to crisis. Since the beginning, the government pushes toward renewable energy sources to satisfy the energy demand of the nation. This is related to the increase of importance of the environmental issue and also due to lack of resources of Spain, indeed it had to import almost all fossil fuel necessary, while this country presents suitable presents the optimal conditions for exploiting

Table 3: Installed capacity of Spain in 2018. Source ENTSO-E TP

Sources	**2018 Installed capacity [GW]**
Hard Coal	9.5
Lignite	0.55
Nuclear	7.12
Natural Gas	30.0
Wind onshore	23.0
Solar thermal	1.3
PV	5.4
Hydro	20.0
Biomass	0.52
Waste	0.54
Fossil Oil	0.715

renewable resources, especially solar and wind energy.
Spain is continuing to pursue this energy transition policy by actively participating in European energy targets. By 202020, Spain had committed itself to the targets collected in Table 4, to contribute to the battle against climate change.

Table 4: 20-20-20 Spain Targets. Source European Commission

Indicator	**Target**
% of reduction of GHG emissions	10 %
% increase of energy efficiency	-
% renewable energy sources share increase	20%

Moreover, Spain is one of the signatory nations of the Paris Agreement. Which presents a longer time step, this implies bigger efforts to fight climate change. The targets set seem quite challenging but underline the nation's determination to make a significant contribution to global warming. By 2030, the country undertakes to :

- 40 % reduction in greenhouse gas (GHG) emissions compared to 1990;
- 32 % renewables over total final energy consumption, for the EU as a whole;
- 32.5 % improvement in energy efficiency;
- 74 % of electricity produced by renewable energy sources

As long term targets Spain is committed to becoming a carbon-neutral nation in 2050.
To do this its fundamental to substitute the fossil power plants with renewable energy sources. The total installed capacity of Spain in 2030 is estimated to be 157 GW, where 120 GW of installed capacity from renewable energy sources. The increment of the power plant will follow the "Borrador del plan Nacional integrado de energía y clima 2021-2030". There are also indicates the decommissioning process for nuclear and coal power plants. The final objective is to obtain at least 1.3 GW of the coal power plant and 3.18 GW of the nuclear power plant in 2030.

The analysis is performed until 2030 because it is an intermediate step towards the final goal in 2050. Where Spain wants to achieve total independence from fossil fuels with electricity production from 100 % renewable sources.
The transport sector will be deeply modified because it appears really impacting in terms of CO_2 emissions.
The goal is to have 5 million electric vehicles and to substitute traditional fuels with biofuels in 2030. In addition, the aim is to replace commercial vehicles with 0 emission ones by 2040.
In the building sector, the energy transition is dealing according to the EU Directive2018/844/UE, which involves the transformation and development of energy-efficient and decarbonized buildings before 2050.
The objectives for 2030 in the private sector are essential to improve the energy efficiency of around 300,000 homes per year in terms of heating improvements. And improvement of the thermal envelope of 1,200,000 homes in 10 years. As far as public buildings are concerned, the European Directive provides for the annual renewal of 3 % of the built area so that buildings can meet minimum energy performance requirements.
Spanish energy policy is deeply influenced by the European Union and Paris Agreement.

The Integrated National Energy Planning of Energy and Climate(PNIEC) consists of the analysis of possible emission scenarios in the different sectors to be able to compare the values obtained with those fixed. If the expected values cannot be met, changes to the policies chosen will be necessary.
The plan provides for the economic modernization of Spain also. The driving forces behind this process are the development of renewable energy sources, the development of rural areas, the improvement of human health, the environment and the increasing affirmation of social justice [36].
It deals with different issues related to five energy fields: decarbonization pathway, energy efficiency, energy security, energy market, investigation innovation and competition in the energy sector.
The plan is made up of two parts: the first one concerns the process required to reach the objectives fixed, while the second one is an economic analysis in terms of employments and health benefits .
The final aim of the plan is also to make the Spanish energy production system increasingly self-sufficient [36]. Spain is currently heavily dependent on the import of raw materials such as Coal, Natural Gas, and Uranium. These dependencies are considered to be a negative factor for the country's economy, so it is appropriate to aim for an improvement in this condition [36].
It is highlighted that the electricity generation and transport sectors are the main cause of CO_2 emissions. For this reason, the National Plan proposes 20 different measures to initiate the process of decarbonization. Half of these measures regard the increment of renewable energy sources, but also the transport sector has a really relevant role.
The decarbonization path is expected to end in 2030 when all the coal power plants will be definitively closed. The closure of these plants must be accompanied by the construction of new ones to meet the country's electricity demand. The new power plants will use mostly renewable energy sources, according to the emission reduction targets. Specifically, the plan provides to build additional capacity of 57 GW of renewable energy sources. The most important driving sources will be wind and solar.
Wind power plants should double their installed capacity, reaching 50 GW, becoming the most important energy sources for electricity production.

For solar power plants it is important to distinguish between thermal and photo-voltaic. Both of them will increase a lot, about 7 times their actual installed capacity. Photo-voltaic power plants will reach about 37 GW while solar thermal around 7 GW. Thanks to the high irradiance of the country, this will provide an important contribution to electricity production. Finally, a measure on the implementation of emissions trading and another on taxation to push the reduction of GHGs emissions.
Moreover, the Spanish government planned to shut down all seven nuclear power plant presents all around the country before 2035. Four of them will be closed between 2027 and 2030, therefore, in the expected scenario, uranium will still be present among the resources, although to a limited extent [37].

The European Commission has allocated funds to finance the process of converting the energy system to encourage this process [36]
The PNIEC also provides for the development of two new sources: geothermal and marine. In fact, from 2025 onwards, it is planned to start exploiting these two resources, although the process will be very slow. In fact, 15 MW of Geothermal will be installed by 2025 and will be doubled by 2030. While as far as marine energy is concerned, 25 MW are expected in 2025 and double the capacity in 2030.
However in the analysis these two sources are not taken into account because they are not relevant compared with the other.

3 Methodology for Holistic Environmental Impact Assessment

3.1 LCA

Product life cycle assessment, internationally known as LCA , Life Cycle Assessment, is the basis for conscious sustainable development. LCA is an environmental assessment method that includes all the environmental impacts associated with the product's entire life, that is, raw material extraction to waste materials deposition after its life expiration.

The ISO standard ISO 14040 and ISO 14044 are used as guide for the basic framework of LCA, but do not provide guidelines on how, in particular, GHG emission estimates of electricity consumption should be determined. The estimates used in LCA of various products may vary significantly, with no clear reasoning behind the assumptions used. The uncertainty in LCA is due to methodological choices, parameters, and models [38].

It is a really useful tool for comparing different generation technologies and moreover to its nature it can be also used for evaluating the emissions related to renewable energy sources. It is a comprehensive methods which considers the different stages associated with electricity generation. The difficulties can be on data sourcing because they can produce uncertain [39].

3.1.1 State of the Art of Enviromental Assessment Techniques

It is possible to account for GHG emissions in electricity production following several approaches. The most famous are: LCA, absolute emission approach, pinch analysis, marginal emission approach, index decomposition analysis, and time-varying carbon intensity approach.

For electricity production is important to consider both direct and indirect emissions, direct emissions are the one related to the extraction of the raw material, transportation and

generation, while the indirect emission concerns the one related to transmission, distribution, and consumption of electricity. For this reason, time-varying carbon intensity and marginal emission approach don't appear suitable, because they only take care of temporal variation of GHG emissions. The first one due to a varying on the fuel mix, while the second one due to an additional unit of generation. These methods appear useful to analyze the variation of energy demand in a certain time frame.
On the other hand the pinch analysis is excluded since its graphical approach does not provide any temporal information about emissions.
As suggested by the name the index decomposition analysis, decompose the emissions in three effects: fuel intensity effect, generation mix effect, and fuel quality effect. The difficulty is to deal with variations over time because it wants to take into account change in carbon intensity, fuel intensity, generation mix, fuel quality. The absolute emission approach wants to quantify the total amount in tones of CO_2 emitted on a certain period. It is mostly used in national and international studies for tracking emission changes, comparing scenarios and assessing GHG emissions abatement options. This approach seems less effective when emissions are compared over time and when the comparison is done between two countries with distinct sizes and economic conditions.
In this context, it is quite clear why LCA is the most used and effective method for analyzing emissions from electricity production [39]. Hence it appears as the most suitable option to perform this study. The Figure 13 shows the most important step to proceed with the analysis in accordance with the ISO 14040 and ISO 14044.

3.1.2 Attributional and Consequential LCA

The Life Cycle Assessment can be performed following two different approaches: attributional (ALCA)or consequential (CLCA) LCA. Both of them are used to quantify GHG emissions, but they are used differently according to the aim of the study. Basically are used to perform analysis with different scope, since each method responds to a specific question. For this reason, ALCA is used to describe the emission of average consumption at a given point in time, without taking into account the indirect effect. It generally provides information on the average unit of product and is useful for consumption-based

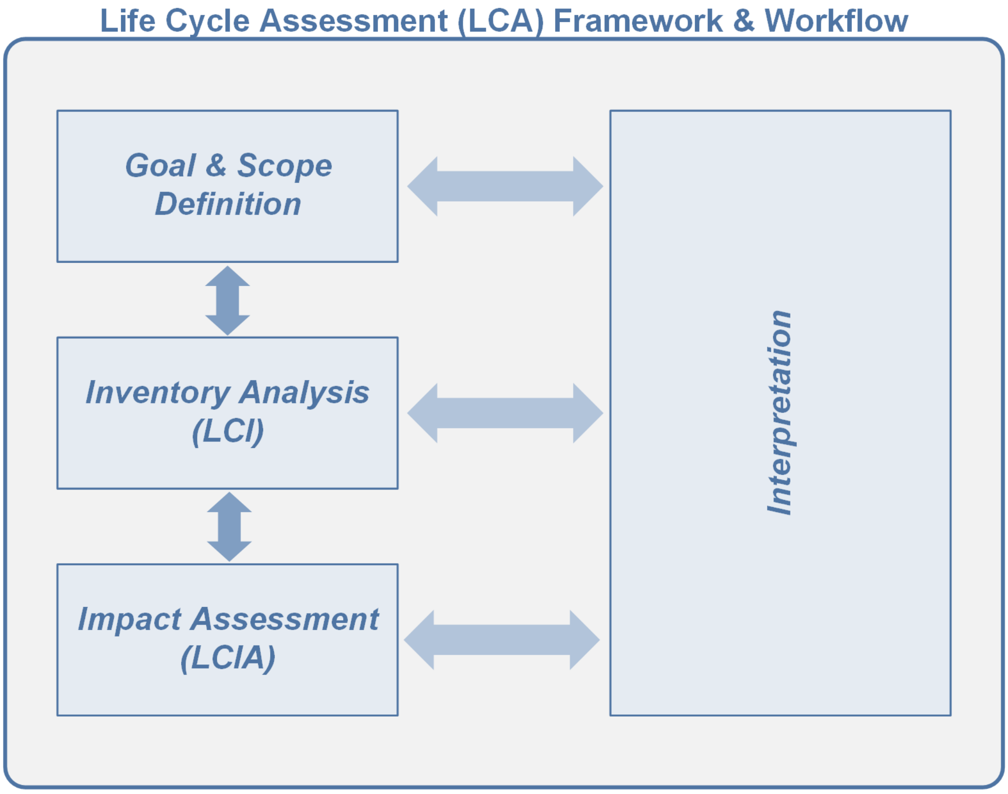

Figure 13: Step of LCA analysis

carbon accounting. It answers the following question : What are the total emissions from the processes and material flows directly used in the life cycle of a product? [40]

On the other hand, CLCA is used to provide information about the consequences of changes in the level of output of a product, including effects both direct and direct effects on the life cycle of the product. It answers the following question : What is the change in total emissions as a result of a marginal change in the production of a product? [40]

The Attributional analysis is performed to compare direct emissions during the lifetime of a product. It can be used also for consumption-based emissions, but it can't be used to quantify the total change of emissions. In ALCA, the system boundary for one product can't overlap the emissions of the other products and services. So theoretically, it is possible to quantify the overall emissions multiplying the quantity of each product produced for each emission. This approach is characterized by a low level of uncertainty because it generally used stoichiometric relations between input and output.

The Consequential Life Cycle Assessment presents a totally different approach to respect the previous one because it wants to quantify the total emission variation as a result of a change in the level of production. For this reason, it takes into account direct and indirect effects. Indeed it is influenced by policy decisions and market effects. This is because a change in market price could influence the level of output and vice-versa. So it can cause an increase or a decrease in the value of the emissions. For CLCA, the boundaries considered appear bigger than the ALCA approach, but it does not mean a greater emissions value. It tries to avoid allocation by using system expansion. To not being meaningless, the method requires that changes are defined in terms of time-scale, promoted methods, the magnitude of the change [40].
All the reasons above explain why the CLCA is most suitable for this anlysis. Hence, it suits the exigence of the study.

3.1.3 LCA steps

Goal & Scope

This is the first step in Life Cycle Assessment. The aim is to provides a clear description of the production system in terms of the system boundaries and a functional unit [41]. The functional unit represents the basis of the analysis because it gives the possibility to compare different alternatives in terms of goods and services. Indeed, it is necessary to make a comparison of the same quantity.

Goal

To define the goal of the analysis it is necessary to take into account different points:

- *Intended applications*: in which sector the analysis is performed (marketing, product evaluation, strategic planning, etc.);
- *Purpose of the study*: the purpose of the study affects the type of writing, the amount

of technical detail and the comprehensive. This is related to the final use of the study because it can be published or can be used for internal analysis. This is because the study can be performed to be published or for internal analysis;

- *Intended audience*: who is the receiver of the analysis? There are several possibilities, it can be a stakeholder of the projects, customers, politicians, public administration, etc;
- *Comparative analysis*: At the beginning of the report it is really important to clarify which are the alternative that will be compared;

Scope

This step is fundamental in order to proceed with the LCA analysis. In this phase, the system to be analyzed is identified and defined in terms of hypotheses made and the methodology used. This allows the reader to have a clear comprehension of which are the relevant points and how the study is performed.

- *Function of the product*: how the product or system works;
- *Functional unit*: It is one of the most important definitions. It is used to perform a comparative analysis on the basis of the equivalent function. The unit represents a qualitative or quantitative measure of the product or system to be analyzed. The evaluation of the functional unit could be really difficult due to the fact that it isn't easy to describe or isolate the performances of the product;
- *Reference Flow*: it is defined in the functional unit and it is the measurement of product materials and components needed to fulfill the function. The data used to perform the analysis had to referee to this flow;
- *Description of the system*: the description of the system helps the reader to better understand the specifics;
- *System Boundaries*: boundaries are required in order to simplify the analysis and this allows us to increase the level of specificity. The system boundaries can be set up in different ways: cradle to grave, cradle to gate, gate to grave, gate to gate. The best

option is represented by the Cradle to Grave model which includes all the steps between the extraction of raw materials and the disposal of the product. Cradle to gate takes into consideration just the use process of the product. Gate to Grave includes all the steps from the factory gate and the disposal of the product. The Gate to Gate takes into considerations all the steps from the raw materials unit to the factory gate;

- *Allocation Procedures*: it could be difficult, so it is preferable to avoid it if possible, dividing the unit precess. It consists of the portioning of the input or output flows of a product or a process between the product system under study. It is used in case of co-products and reuse/recycling;
- *Impact categories and Impact assessment method*: this method is used in order to express the result of the LCA analysis to help the inventory results. It takes into account different environmental impacts related to climate change. Each impact category has its emission-specific characterization factor to express the potential environmental impact;
  - *Atmosphere* : climate change, ozone depletion, smog formation;
  - *Hydrosphere* : eutrophication, acidification;
  - *Biosphere*: soil depletion, deforestation;
- *Data requirement*: it is necessary to properly document all the data and to evaluate their quality in this way it will be possible to use it for future analysis;

3.1.4 Life Cycle Inventory (LCI)

This phase concerns the inventory of energy, material input, environmental output during the whole lifetime referring to the goal and scope phase.
The collection of data requires a lot of time because it describes in detail the process including the inside system boundaries, but it is necessary because it represents the basis of the Inventory analysis. The steps required to analyze this phase are still indicated by the references ISO 14040 and 14044.

- *Data quality*: data should be able to satisfy stated requirements;

- *Data acquisition*: measured, calculated or estimated? Primary data (measured) or secondary data (calculated, taken out from literature and database)?
- *Time-reference*: when was the data obtained and until when it is supposed to be valid?
- *Geographical reference*: from where the data was obtained (Country or Region)?
- *Technology coverage*: define specific single technology or technologies mix;
- *Uncertainty of the information*: define assumptions and limitations of the model;

3.1.5 Life Cycle Inventory Analysis (LCIA)

The aim of this phase is to translate emissions, used raw material and energy demand quantified in the previous phase into the related environmental impact. To perform LCIA the following step had to be followed: Selection of impact categories, Classification, and Characterization.

- *Impact category*: the ISO 14044 indicates the class which represents the environmental issues of the analysis;
- *Classification of the model*: During this phase, the model calculates which are the environmental impacts using the relationship between the LCI and category indicators. For the same system, it is possible to use several characterization models that are able to assess all the potential environmental impacts. The most complete methodology is the CML Impact Method, a problem-oriented LCA method developed by the Institute of Environmental Sciences of the University of Leiden;
- *Characterization of the model*: this phase wants to analyze the interpretation of the results it is the last one and the most interesting step of the whole Life Cycle Assessment. It is needed to assess the real and effective environmental impact of the product or project that has been studied. Then, the results can be compared with the existing literature, to observe if they are aligned with the goal and scope of the project. At this stage it is possible to understand if the right data and assumptions were taken into consideration, realizing which are the weaknesses and the limitations of the assessment;

3.2 Scenarios

3.2.1 Introduction to Scenario

A scenario is defined as the description and reproduction of a possible future. It would be wrong to consider it as a forecast, as each scenario depends on the assumptions and constraints considered [42]. Therefore it is more appropriate to define it as the description of the possible evolution of the chosen system concerning the constraints and assumptions considered [42].

An energy scenario allows observing the possible evolution of a sector in terms of demand and supply of resources. In order to make a good analysis, it is important to assess which drivers influence electricity demand and production [42].

A scenario presents some uncertainties, because as there is a lack of reliable information that will write qualitatively and quantitatively about the system and its characteristics in the future [43]. Uncertainties can be divided into internal and external. Internal uncertainties are those related to the structure of the problem and the analysis. Therefore they can be avoided or at least limited as they depend on the stakeholder. External uncertainties, on the contrary, cannot be controlled because they depend on the surrounding environment, so it not possible to avoid them [43].

In this case the system analyzed is that of the electricity production of a given nation. The constraints and assumptions are made concerning the Paris Agreement and therefore to the NPDC of the nation, where the objectives to be pursued are indicated.

Scenarios are playing an increasingly important role in policymaking decisions. They represent a very useful tool to analyze possible energy policies and to choose the one that leads to the desired results.

The prediction of a scenario can be very useful as it allows to have probable information on the possible evolution of the system studied concerning the chosen constraints. In this way, it is possible to observe whether or not the set objectives are reached. If these are not, it's required to make changes to the chose a better strategy [43].

Especially this period, which is characterized by energy transition, shifting from fossil fuel and nuclear power towards renewable energy sources, so predict a scenario plays a key role [43].

3.2.2 Scenarios definition for energy transition

According with the aim of the analysis there are several ways to perform a scenario, and it could be done using different time scale and different geographic scale. The chose of one model respect to another depends on the scope and type of the analysis.
In particular it is possible to distinguish three different geographic scales: micro, meso, macro. Micro-scale refers to a single house or several houses, meso-scale analyzes a city, while macro-scale can refer either to entire nations or to the whole world.
As far as the chosen time horizon is concerned, it's important to take care choosing an appropriate period of analysis. Hence, it can be much more complicated to make long-term analyses that are reliable. In fact, making analyses over too long periods of time can make the scenario less reliable because it is more difficult to make hypothesis about possible changes. For this reason, in this case it is choose to analyse the system until 2030 instead of 2050.
In addition, the choice of the model depends on the kind of analysis that had to performed. In this case a bottom-up model is chosen, that starting from the current situation goes through possible alternatives in order to evaluate which one of these leads to the best result, according to the targets fixe. It is an engineering model that works in an aggregated level and uses aggregated data. This type of models, unlike the top-down, is particularly rich in details at a technological level.
The main object of the scenario is to analyse the change in CO_2 emissions according to a variation in the share of electricity production from renewable energy sources. Particularly, the aim is to see whether or not increasing energy from renewable sources will actually lead to an improvement in terms of emissions.

Firstly, to perform the scenarios is necessary to define a baseline for each country. According to the data of the ENTSO-E Transparency Platform about electricity generation in 2018, and the installed capacity of the different technologies, it is possible to define the baseline.

The EU regulation No. 543/2013 establish this platform. It is an online platform, and the aim is to provide detailed data about the European electricity system [44]. It represents a big challenge because it requires a big amount of data with a high level of detail. The difficulties lie down also in the fact that, in many countries, this information is not available to the public [44]. The article [44] provides important clarifications on the data quality, and it justifies its reliability. Nevertheless, significant efforts are made to improve the platform and data quality.

Different nations show different values of installed capacity and of energy production, which depends on the demand of the nation and the resources present on the territory.

This analysis takes the data from the section 'Electricity generation-Country'. This is because Germany presents a common power price-bidding zone with Luxembourg and Austria. So, it is not possible to use the 'Bidding-zone' section, because electricity production would appear bigger than reality, especially in the case of hydropower production [45]. In the case of Spain, the data of two sections coincide, so it is possible to use both of them indistinctly.

Moreover, for Germany's hydropower production from pumped storage, is calculated as the difference between the actual aggregated and actual consumption value. Because the actual consumption represents the energy necessary to pump water.

For Spain, the electricity produced by hydro-pumped storage isn't used during the analysis due to a lack of data. The ENTSO-E TP only has the Actual Consumption value, so it isn't reasonable to use it as electricity production value.

Not all the sources contribute significantly to the electricity production. For this reason, all the sources that contributes for less the 1 % to the electricity share are neglected.

Once it is known which is the energy production in GWh, it's possible to predict the evolution of electricity demand during the years ahead. The changes in electricity demand are described in the technical note of the European Commission EUCO3232 [20]. Since the document uses the year 2007 as its baseline, the data provided are not used. However is calculated the percentage change every 5 years from 2015 to 2030. And this variation is used to calculate the evolution of electricity demand, but starting from ENTSO-E TP data. In this way it possible to predict which the possible variation in electricity demand, and

then it is chosen as a possible way to satisfy it.
In both cases the behavior of the demand appears oscillatory,so it could be interesting to analyze which could be the possible causes. This kind of analysis will be performed in a different section.
Performing this analysis, it could be useful to understand how much each source contributes to electricity production. For this reason, the calculation of the capacity factor is important.
The capacity factor (CF) is a dimensionless factor defined as the actual electricity production, divided by the maximum possible electricity output of a power plant, over a period which in this case is equal to 1 year, so 8760 hours [46]. The CF depends on several factors like resource availability, the time required for maintenance, the time necessary for cleaning the machinery, etc. Due to this, it's necessary to calculate the capacity of each technology and to compare them with the theoretical values. The Figure 14 shows the steps followed to calculate the CF to perform this study. Starting from ENTSO-E TP data of the section 'Installed capacity' and the 'Actual generation' is possible to calculate the CF. This factor is equal to the ratio between the yearly value of the actual generation in GWh, and the product of installed capacity of the same sources in GW, and the number of hours in a year. Once the value is obtained it is possible to proceed with the comparison. The theoretical value can be found in "Project Cost of Electricity " [47].

This book examines the levelised cost of electricity generation for different technologies and several countries. To the aim of this study, the attention is focused on the section of the capacity factor. The book contains a table for each technology, where it is indicated for each country the net installed capacity and the capacity factor. As it is possible to observe, the theoretical value of the same technology can change deeply between countries due to distinct geographical, morphological, and atmospherical characteristics. This is particularly true for renewable energy sources, because the value of irradiance, speed of the wind, and regiments of the river could vary a lot. For example, countries closer to the equator present a higher level of irradiance then countries closer to the pole. At the same time, several factors can influence wind speed. While all fossil fuels present a capacity factor of 85 %, because it does not depend on the external factor, but only on maintenance and cleaning. Hence, for fossil fuel, if the value of CF calculated is smaller than the theoretical

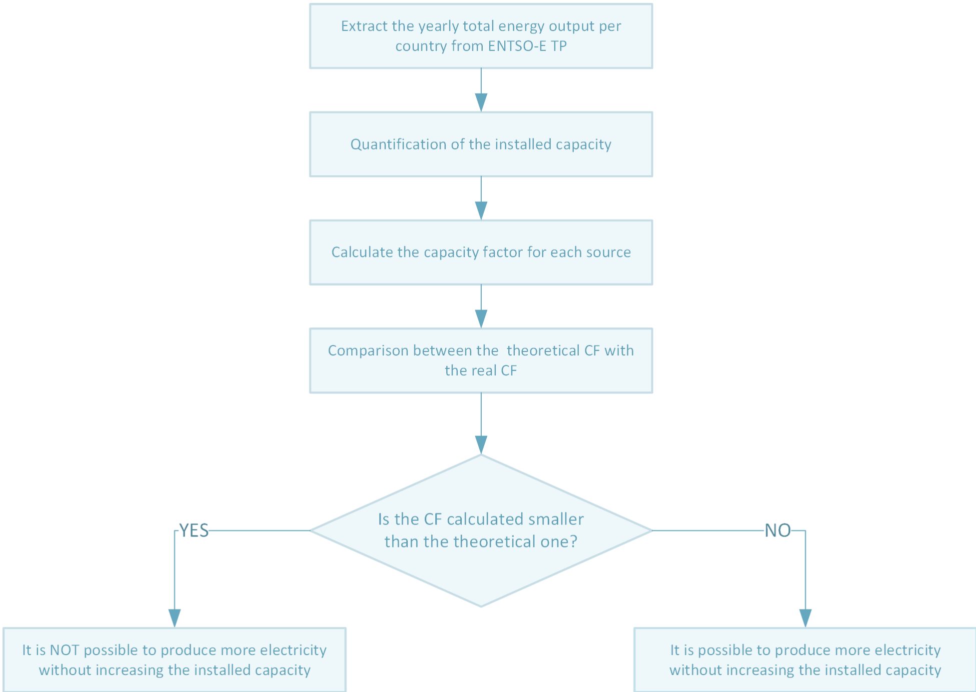

Figure 14: Calculation of the Capacity factor

one, it is possible to increase it without increasing the installed capacity, just increasing the quantity of primary sources used. The same procedure can not be used for renewables because it is not possible to increase the quantity of the input source manually.

The importance of CF lies down also in the possible influence on energy policy. It gives important information about which are the most productive sources in a determinate country. Hence, energy policy should push towards the development of the most productive source.

Increasing or decreasing the electricity production by source respect to another affects the quantity of CO_2 emitted. Moreover, in some cases for the fossil plant is not used to the fullest of its potential, so increasing the capacity factor brings to an increment in production without the need to add to installed capacity.

For this reason, the installed capacity in the scenarios performed for fossil sources does not increase. Because if it is required an increase in the share of the sources, it is possible to modify the capacity factor, if the value calculated is smaller than the theoretical one.

Hence, the installed capacity for fossil fuel is only reduced according to the programs of decommissioning of the sources for the different countries.

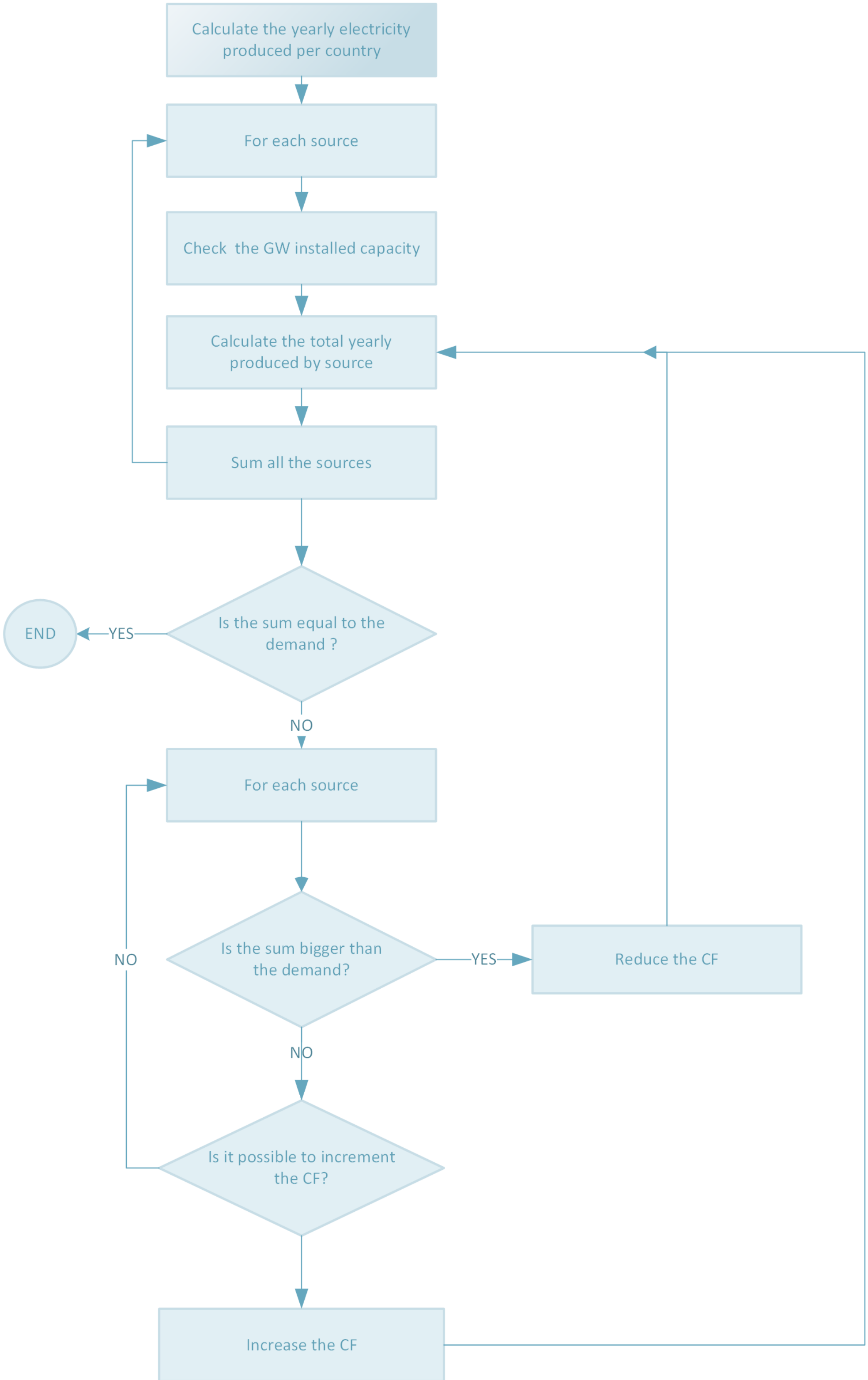

Figure 15: Step to obtain the electricity production

However, renewable energy sources have a large increase in the installed capacity since it is not possible to modify the capacity factor arbitrarily, because the quantity of fuel can not be modified manually. At least it is possible a small CF decrease during the years due to the efficiency losses. For this reason, the only way to increment the electricity produced by renewable energy is to increase the installed capacity or to improve the efficiency of the technology.

The first scenarios are performed for 2020 and then using a time step of 5 years until 2030. The change of the installed capacity is made following the Energy National Plan, while the capacity factor is modified arbitrarily to meet the predicted demand, always trying to prefer the use of renewable sources rather than fossil sources.Once it is known the GWh produced, the following step is the calculation of the emission factor in kg CO_2/kWh.
To do this the amount of electricity produced is escalated to 1 kWh and then it is used the software GaBi to calculate the emission factor. Multiplying this value for the total energy produced, and convert it, the result obtained is the tons of CO_2 emitted in a year by the electricity sector. In this way, it will be possible to calculate the emissions trend.
Figure 15 represents a flow chart with the steps followed to define the electricity scenarios from 2020. Knowing the electricity demand and the installed capacity on a year, the share of each source is defined as the product of the installed capacity and the CF. Where the CF value can be modified to satisfy the demand. The result is the GWh of electricity produced by each source. Then, the total electricity generated is equal to the sum of all the contributions. If this value is equal to the electricity demand, the calculation ends here. However, if it is not, an additional modifications of CF are required. Depending if the electricity demand is bigger or small than the one generated, it would be necessary to decrease or increase the electricity produced,so the capacity factor.
The overall rule to perform the study is to try to reduce the use of fossil fuel, increasing renewable energy. That explain why it is always preferred the use of renewable instead of fossil fuel.

3.2.3 Modeling

GaBi is product system modeling and assessment software by PE INTERNATIONAL used to proceed with the LCA analysis, it first appears on the market in 1992, and it presents several updates [48]. Thanks to its easy structure and its huge and detailed database able to details the costs, energy and environmental impact of sourcing and refining every raw material or processed component of a manufactured item, it is one of the most used software for LCA analysis.

In addition, it looks at the impact on the environment presenting alternative options for manufacturing, distribution, recyclability, pollution, and sustainability. So it can be used in different sectors and with different scopes.

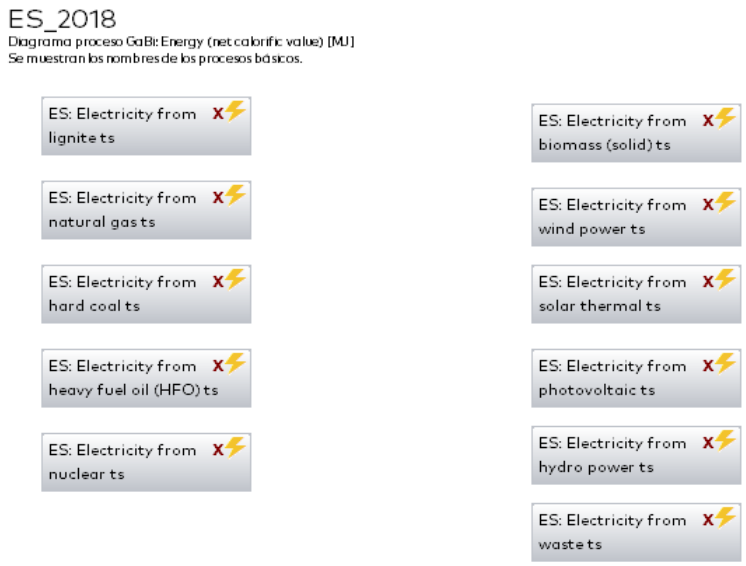

Figure 16: GaBi layout

source GaBi

The Figure 16 shows the layout of the program. In this case, it is represented the electricity production of Spain in 2018. Each box contains the information in terms of CO_2 emissions relative to the electricity production of a certain source. Indeed it is associated with the corresponding percentage of electricity produced by that source. The sum of all the electricity produced is equal to 1 kWh. This means that the outputs obtained are the total quantity of kg of CO_2 produced using that share, and the kg of CO_2 emitted by each source. Hence, because the total electricity produced is equal to 1 kWh, the result is the amount of kg of

CO_2 / kWh of electricity produced.

Each box contains all the information related to electricity production, since the raw material extraction, until the use of the source. It uses the system boundaries cradle to gate, so without taking into account the material disposal. The CO_2 values of each box depend on the sources considered, and also on the country. Especially for fossil fuel, the values can change from country to country.

3.3 Assumptions

All the sources with a share lower than 1 % can be considered negligible. Because the simulations show that they don't affect the final result. Especially all the sources called "others" and "others renewables" are not considered because there isn't information relative to these sources. Also, all the new sources implemented in the next years are not taken into account due to the lack of data about productivity. All energy imports and exports of the nation are not included. Because of the change in characteristics of the electricity produced and also the transport losses. The data necessary to make such an analysis appropriately are not available, so it was decided not to include them.

It is assumed that all renewable and Natural Gas power plants in the case of decommissioning shall be replaced by equal installations. Therefore, they are not considered within the national strategies for the implementation of renewable. The same is not true for coal-fired and nuclear power plants, as both these technologies will undergo a phase-out process.

The variation in CF depends on personal decisions in line with environmental policies aimed at promoting the use of renewable sources compared to fossil fuels, and the deterioration of plants in operation for a long time, which brings to a decrease in efficiency and so productivity. Generally, efforts are made to reduce the CF of fossil fuels. Due to the phase-out of nuclear and coal and the change in electricity demand, it has not been possible. On the contrary, it has been necessary to increase the CF.

All the data related to the installed capacity and the share of electricity production used as baseline referred to 2018 because the analysis was performed before at the end of 2019, so not all data were available for that year.

The variation in installed capacity depends on the nation's environmental policies which are expressed in the national energy plans, so the objectives set by the Paris Agreement can be achieved. As regards the variation in electricity demand, the European Union document EUCO3232 [20], which takes into account several factors such as population change, GDP, efficiency improvement and the introduction of the electric vehicles has been used.

3.4 Germany

From the German Action Plan for 2050, it is possible to predict the following share in three different time frames: 2020(Figure 17), 2025 (Figure 18)and 2030(Figure 19).
The variation in installed capacity depends on the nation's environmental policies, which are expressed in the national plan, to achieve the objectives set by the Paris Agreement. As regards the variation in electricity demand, the European Union document EUCO3232 [20], which takes into account several factors such as population change, GDP, efficiency improvement and the introduction of the electric vehicles has been used.

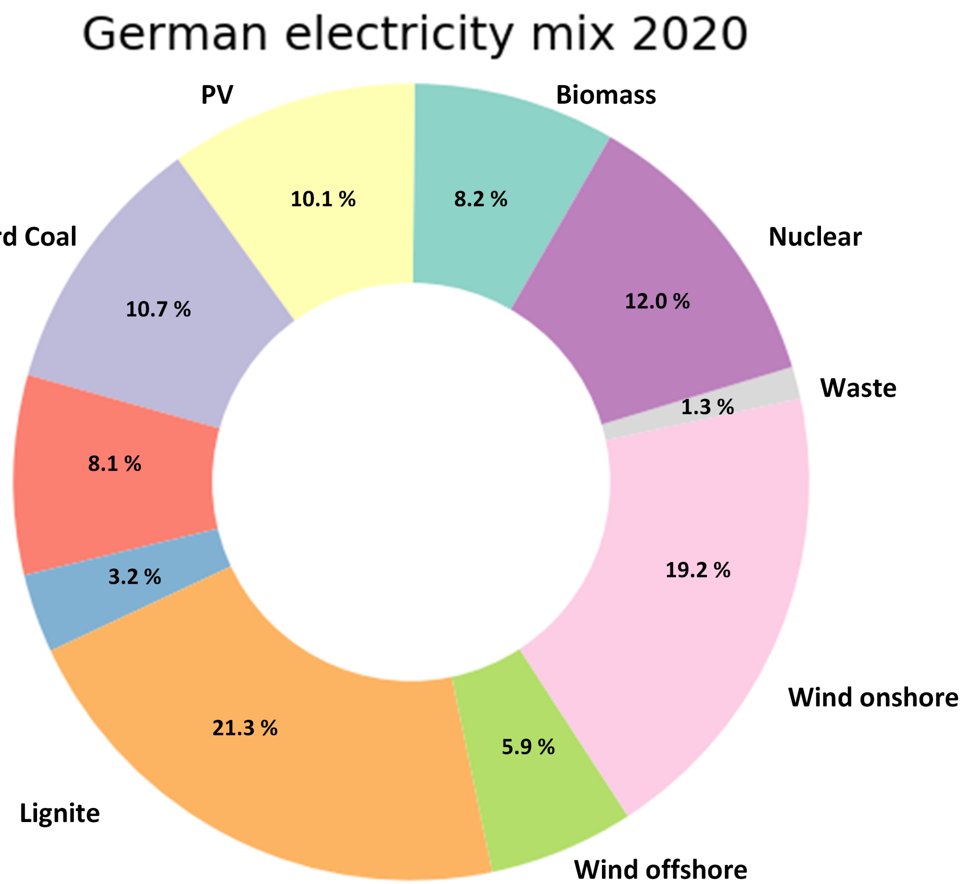

Figure 17: Electricity mix of Germany in 2020

As can expect, the variations between the base year and the first time frame, that of 2020, are not particularly relevant. That is due to the short time between the two scenarios. The most relevant variations concern the closure of some hard coal plants for a reduction of 4.5 GW and 3 GW for lignite. An increase of 5 GW should be observed for both wind onshore and photovoltaic plants. The share of Natural Gas in the electricity production is expected to increase to, but without additional capacity installed as it possible to see in Figure 17. These small changes in the share shown in Figure 17 have already led to a slight reduction in the value of emissions to 0.411 CO_2/kWh.

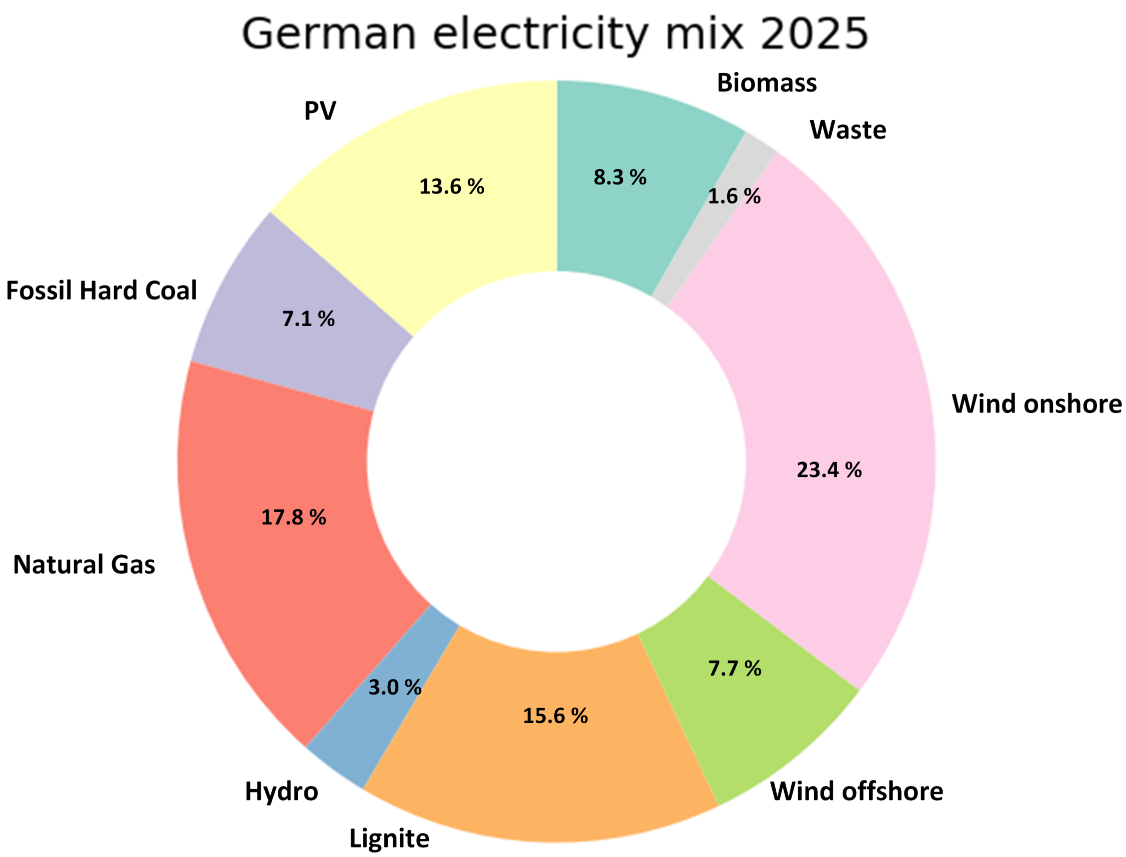

Figure 18: Electricity mix of Germany in 2025

The next time step between 2020 and 2025 shows big differences as the total disappearance of nuclear power plants because the decommissioning process is expected to finish in 2022, which disappears from the share in Figure 18. Wind power plants are increasing their presence, becoming the most important sources of the country with around 11 GW offshore and 67.4 GW onshore installed capacity, increasing their share from 25 % in 2020 to more than 30 % in 2025.

Althought solar panels reach almost 76 GW, their presence on the electricity share is still less than 1/7 of the total production.

The share of Natural Gas in figure 18 appears doubled in order to satisfy the electricity demand.
Biomass should grow of 0.7 GW, without a significant increase on the share.
This changes made possible to have a further reduce the value of emissions to 0.371 since 0.411 CO_2/kWh.

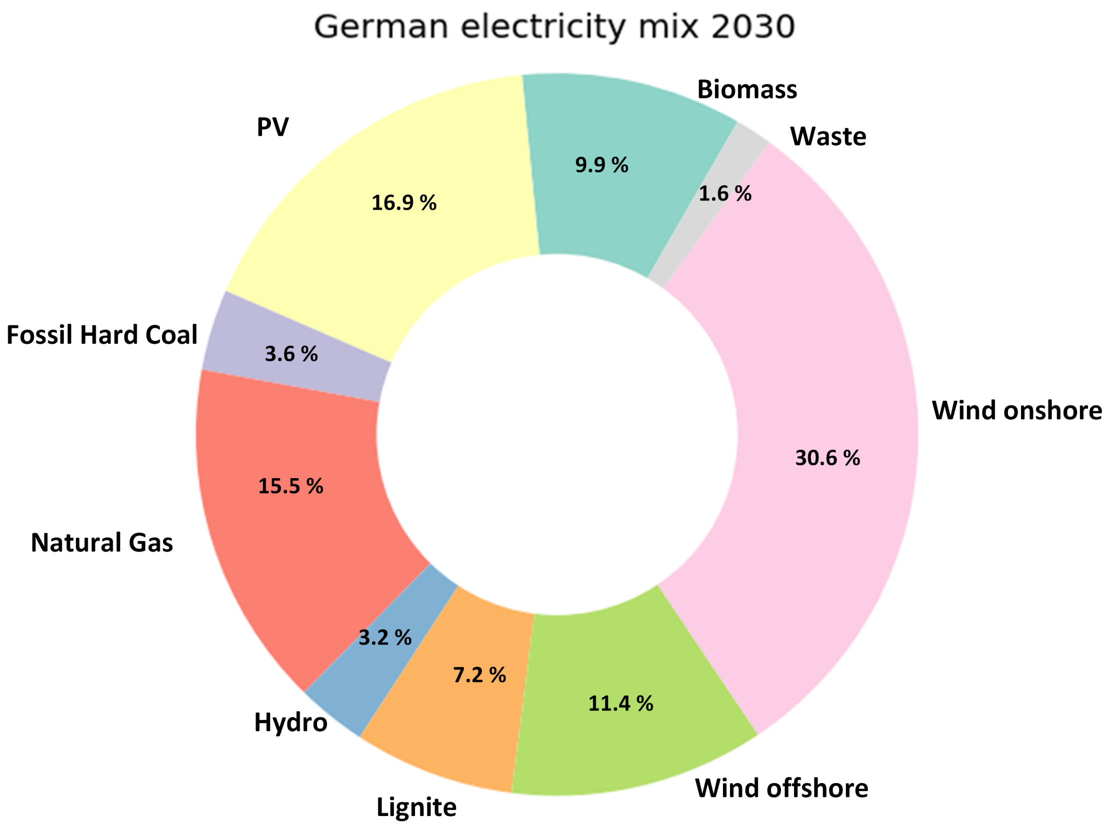

Figure 19: Electricity mix of Germany in 2030

The last time-step is characterized by 214 GW of installed capacity of renewable resources, out of a total of 260 GW, Figure 19 represents the share. RES represents more than 80 %. Wind power plants will reach a capacity of 92 GW, with 15 GW of wind offshore, imposing itself as the most productive source, with more than 40 % of the share. Although the estimation is that in 2030 Germany will reach 98 GW of solar panels, turning to be the first resource for installed capacity, the contribution in energy production does not even reach wind one. Coal has substantially reduced from the initial 24 % of Lignite to 7 %. Hard Coal from 14 % is now at 3.6 % as shown in Figure 19. Hence, the country appears on a good way to the decarbonization of its electricity system. Indeed the LCA analysis registers a value of 0.229 CO_2/kWh. The Table 5 resume the change of the installed capacity during the years.

Table 5: Installed Capacity of Germany. Extracted from [2]

Sources	**Installd capacity [GW]**			
	2018	**2020**	**2025**	**2030**
Hard Coal	25	20.5	13	7
Lignite	21	18	14	8
Nuclear	9.5	8.1	-	-
Natural Gas	31	31	31	31
Wind onshore	51.8	55.8	67.4	77
Wind offshore	5	7.7	10.7	15
PV	42.8	52.8	75.8	98
Hydro	14	14	14	14
Biomass	7.4	7.55	8.2	9.2
Geothermal	0.0038	0.0038	0.0038	0.0038
Fossil Oil	4.27	-	-	-

The resource that has increased most in terms of installed GW is the photovoltaics, which has more than doubled its presence. However it has not the same variation for the share of electricity production. As can be seen by comparing the values in the Figure 10 and Figure 19. From the same Figure, it's possible to notice the source who reduced more its share is by far nuclear, which passes from the 13.6 % in Figure 10 to 0 % already in Figure 18. Also, Coal power plants show a reduction both on the installed capacity 5 and in the share.
It's surprising the behavior of Natural Gas. Looking at Table 5, it is possible to notice that despite there isn't a change in the installed capacity, the share has increased about three times. That is because the source wasn't fully used since 2018, for this reason its capacity factor was quite low, respect to the theoretical value. Then, due to a decrease in coal and nuclear power plants, the use of these sources becomes more and more necessary to satisfy

the demand. Increasing the CF is possible to increase also the use of these sources without the need to build other power plants.
The last time-step is characterized by 214 GW of installed capacity of renewable resources, out of a total of 260 GW, Figure 19 represents the share. That represents more than 80 %. Wind power plants will reach a capacity of 92 GW, with 15 GW of wind offshore, imposing itself as the most productive source, with more than 40 % of the share. Although the estimation is that in 2030 Germany will reach 98 GW of solar panels, turning to be the first resource for installed capacity, the contribution in energy production cannot even reach the goal of wind power production. Coal has substantially reduced from the initial 24 % of lignite to 7 %. Hard coal from 14 % is now at 3.6 % as shown in Figure 19. Hence, the country appears on a good way to the decarbonization of its electricity system. Since the LCA analysis registers a value of 0.229 CO_2/kWh.

3.5 Spain

The draft national integrated plan for Spain for 2021 - 2030, begins its analysis in 1990 and observes the variations in electricity demand in the various sectors and the change in installed capacity. In Table 6 are resumed the change foresee from 2018 to 2030.

Table 6: Installed Capacity of Spain. Extracted from [3]

Sources	**Installd capacity [GW]**			
	2018	**2020**	**2025**	**2030**
Hard Coal	9.5	8.5	4.5	-
Lignite	0.55	0.5	-	-
Nuclear	7.12	7.12	7.12	3
Natural Gas	30	30	30	30
Wind onshore	23	28	40	50
Solar thermal	1,3	2.3	4.8	7
PV	5.4	8.5	23	37
Hydro	20	20	20	20
Biomass	0.52	0.87	1.07	1.67
Waste	0.54	0.54	0.54	0.54
Fossil Oil	0.715	-	-	-

Also in this case, the scenario analyzes 3 time-steps, which are: 2020, 2025 and 2030.
In Spain, the electricity demand shows a very strong reduction in 2018 but then recovers immediately increasing the trend. That can be linked to the nation's growth forecasts in terms of GDP, to the introduction of electric vehicles, and a general increase in electrification in the country.
The decommissioning process of nuclear power plants starts only after 2025. Despite the installed capacity is kept constant until this period, but the share of electricity produced, decrease a bit over the years. Waste and hydropower plants are supposed to not change their installed capacity over the years. It is assumed that the hydroelectric power is already used to its full potential.

Natural Gas installed capacity is kept constant along all the period, but its share changes. Its capacity factor is deeply lower than the theoretical value, which means that it can be modify . Hence, if necessary, it will be possible to change its share just varying the CF. For example, in 2020 is expected an increase in the use of NG to satisfy the increase in electricity demand.

It is assumed, all the fossil oil power plants are decommissioned in 2020. Moreover, the decarbonization process started in 2018 keep on with the closure of power plants. This brings to the necessity of an increase in renewable power plants, especially wind, solar photo-voltaic, and solar thermal, whose growth is hampered by the high price of this technology.

Figure 20 shows the electricity mix of the country. Despite the strong contribution of wind to the total share, this mix still based on Natural Gas and Nuclear.

From the LCA analysis comes out that, with this share, the grams of CO_2 emitted per kWh produced are equal to 0.241.

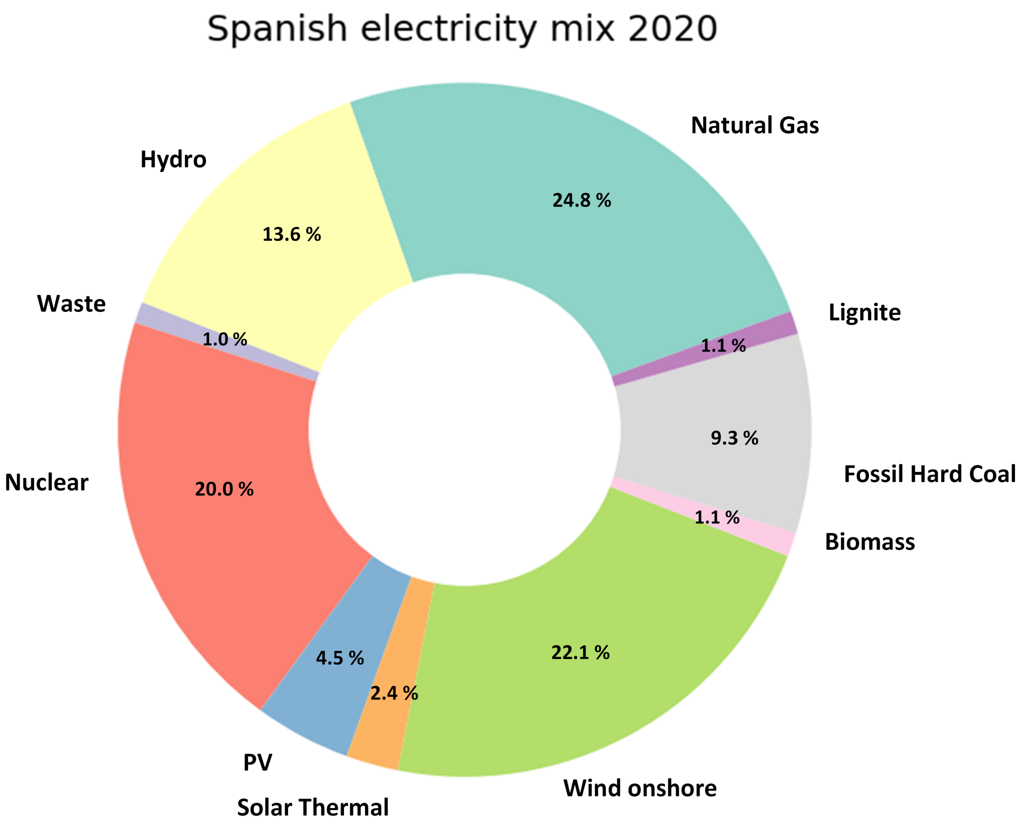

Figure 20: Electricity mix of Spain in 2020

Since 2025, Wind it is expected to turn into the most important sources of the country, with more than 30 % of the share in electricity production as shown in Figure 21. That also thanks to the increased installed capacity, which reaches 40 GW.

Phtovoltaic power plants have almost tripled its GWs reaching 23 GW and with more the 11 % of the share. Solar thermal is supposed to double its presence on the territory and consequently to increase its share.

That increase in renewables energy sources, therefore, makes it possible to continue the decarbonization process. Closing the last power plants powered by Lignite and reducing to 4.5 GW those powered by Hard Coal. Moreover, it is also possible to decrease the electricity produced by Natural Gas and Nuclear power plants, pushing more towards green electricity production.

That changes in the electricity mix lead to a deep reduction of the emission factor which is equal to 0.133 CO_2/kWh.

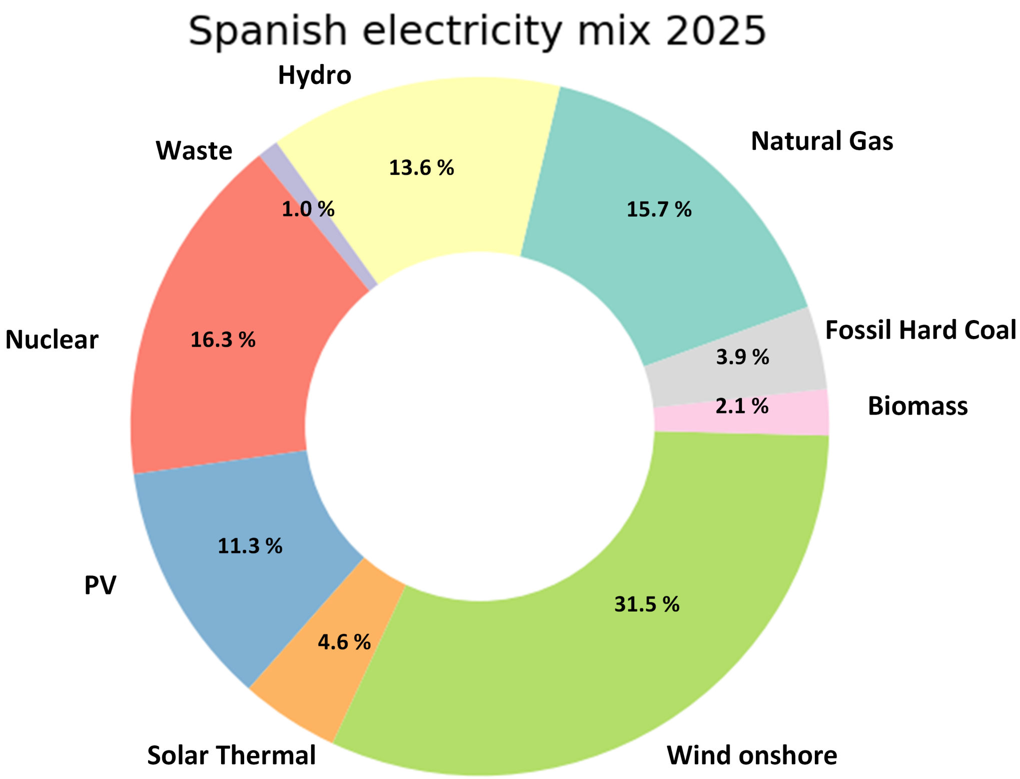

Figure 21: Electricity mix of Spain in 2025

In 2030, the electricity sector should become carbon-free. All the coal power plants are supposed to be closed, and the nuclear ones reach at least 3 GW having a share of less than 5 % according to Table 6 and to Figure 22 .

Consequently, it is necessary for an increase in renewable power plants to satisfy the demand, although it's decreased respect 2025. For this reason, wind power plants will add 10 GW of installed capacity, while solar power is supposed to reach 44 GW: 37 GW of photovoltaic and 7 GW of solar thermal. In this way, it becomes the second source of the country. Nuclear power plants are still contributing to electricity production, but it decreases the share. Biomass has 1.67 GW, and it almost reaches 4 % of the share, becoming quite relevant for electricity production.

In this way, emissions for electricity production have further reduced to 0.0927 CO_2/kWh.

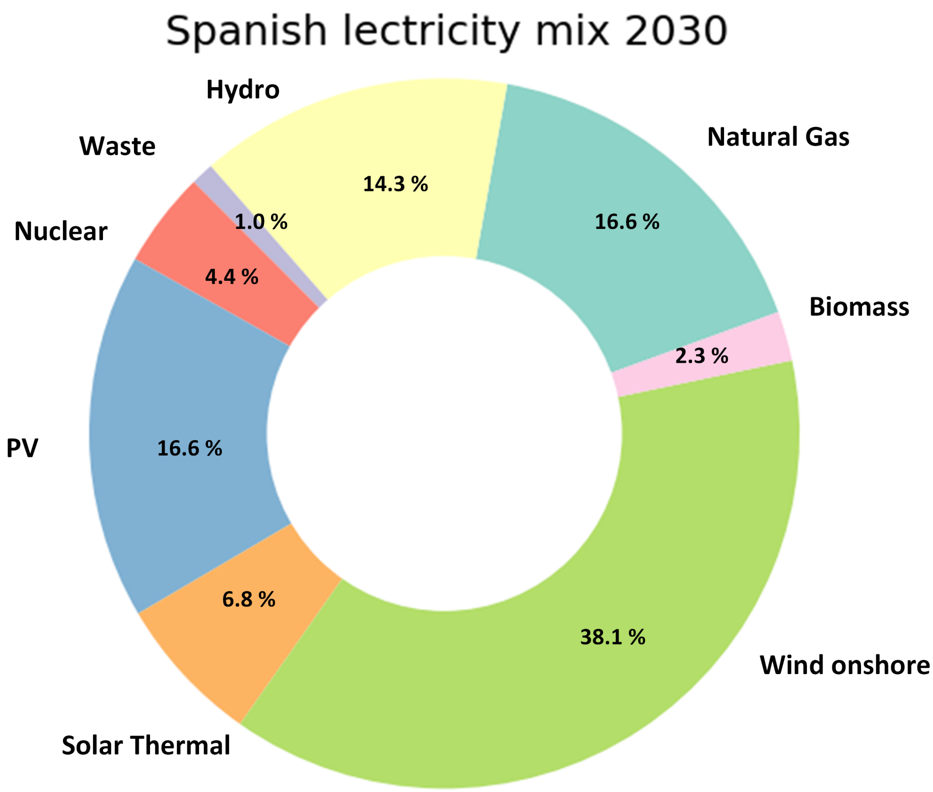

Figure 22: Electricity mix of Spain in 2030

Comparing Figure 12 and Figure 22 it is possible to appreciate a reduction of the share for Coal, Nuclear and Natural Gas and a strong increase for Wind and Solar. That is due to the huge implementation of renewable energy sources and decommissioning policies. Thanks to its characteristic, the electricity production towards renewables allow reducing the share of Natural Gas. This result is significant for the country because it permits a further reduction in the use of fossil fuel, improving emissions.

4 Machine Learning Model for CO_2 Forecast

This section aims to predict the emissions trend using machine learning (ML). To do this it is necessary to construct and validate the model to use. To perform the analysis, it's required to use a proper programming language. The choice is between C, C++, Ruby, Pearl, and Python.

In this case, Python is chosen as a programming language to the ML model, thanks to its very flexible, simple, and specific programming language [49]. It uses an interpreted language, which means that the code is executed immediately in the console, and it is not required the compilation step to machine language.

Python can use several libraries depending on the kind of analysis performed. In this case, the libraries used are *numpy*, *panda*, *prophet*, and *matlplotlib*.

The first one it's necessary to perform numeric and scientific computation, the second one is used to read the file in different formats [49]. Panda's mains object is the Data Frame, which is rectangular data, like a spreadsheet, that represents the basic data structure used for statistical and machine learning models. It is a table, or two-dimensional array-like structure, in which each column contains measurements on one variable, and each row contains one case [50]. *Matpolotlib* is a library necessary to plot the figures, which gives different possibilities to plot the data, and to arrange different layout [49].

The *Prophet* library is a Facebook's' open source time series used for prediction. It decomposes time series into trend, seasonality, and holiday..

Machine learning is quite a new technique that is spreading and improving so fast. The challenge is now express through data new aspect of the world which aren't yet quantified. In this case, this methodology is used to predict future events, as the CO_2 emission, using a robust model able to predict future data samples. Obviously, it is quite impossible to predict a future which suits all the situations and which take into account unpredictable events [49]. However it could be useful to identify which could be the unpredictable events that could affect the analysis.

Prophet uses an additive model based on non-linear trends on yearly, weekly, daily sea-

sonality, and holiday effects. In this case, since the values used are yearly average data, the model only takes into account the yearly value. Due to the lack of information, other trends can not be performed.
This model appears to be very robust to missing data and shifts in trend, and it can handles well with the outliers [51]. Prophet model is based on equation (1) [52] to build the trend:

$$[\, y(t) = g(t) + s(t) + h(t) + \epsilon \,] \tag{1}$$

It's important to know which is the meaning to each term in order to better understand better the model. According to [52]

- g(t) models trend, which describes long-term behaviour of the data. It is made up of two models, a saturating growth model and a piecewise linear model.
- s(t) models describe the seasonality using a Fourier series. It includes the seasonality factor.
- h(t) models takes into account about the effect of holidays or large events which impact the series.
- ϵ represents the irreducible error.

Due to the fact the the data used are average yearly value the terms s(t) and h(t) are not considered by the model.
The dataset is really important in this kind of analysis, it represents and extension of the Data Frame. To obtain a good result it is important to have a robust and large and trustworthy data set. Moreover, it's also important to have enough data to track a reliable trend to make a good and accurate prediction. As shown in Figure 23 the dataset is divided into two parts. The training data are used to build the model, while the test data to validate it.

All the data relative to the value of CO_2 come from "Fossil CO2 and GHG emissions of all world countries" [1]. That is a report which collects all the emissions values from 1970 to 2018. It allows observing the changing trend of the different countries, and the different sectors over the last 30 years, to understand the behavior changes.

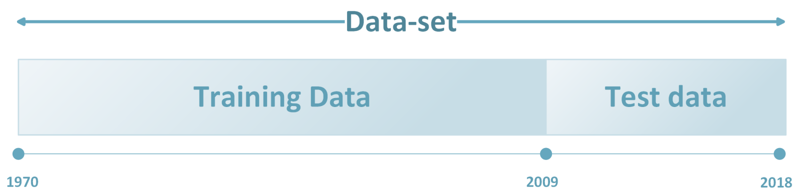

Figure 23: Data-set

After collecting the CO_2 emissions data for the studied country, for electricity generation, the first step done is the performance evaluation of the model. That consists of dividing the data into training and test data. The split of the data can be done differently, but always keeping the amount of training data bigger than the test. In this case, the choice is to consider 80 % of the data as training and the last 20 % as the test. As shown in Figure 23, the data between 1970 and 2009 represent training data, while others represent the data test. So using the Prophet library, basing on the training data it is possible to track the foresee of future values, which correspond to the period of the data test. Then, comparing the values obtained with one of the data tests it is possible to verify if the model suits the reality or not.

The model produces as output the above trend and the confidence interval. This represents the validation range of the model, which allows the model to take into account possible variations, deviations or unexpected events. The longer is the forecast, the wider the confidence interval becomes. If the test values fall within the bands means that the model represents the forecast with a certain value of accurately. The closer the values are to the trend, the more accurate they are.

Obviously, it's necessary a high level of accuracy to use the model for forecasts, it should be around 90 % and 95 % .

There are several metrics for time series model evaluation using regression metrics: mean absolute error, mean square error, R^2.

The Mean Absolute Error (MEA) gives an idea of how much the predictions are wrongs. The smaller is the value, the more accurate the forecast is. It is equal to the sum of the differences in absolute value between real value and predictions [46].

The Mean Squared Error (MSE) provides the gross idea of magnitude error. It is similar to the mean absolute error [46]. Also in this case, a low value indicates a good fit quite well.

The mean absolute percentage error (MAPE), also known as mean absolute percentage deviation (MAPD), is another method of the accuracy in prediction of forecasting, it is quite similar to the mean absolute error. It is calculated as the sum of the difference in absolute between the actual value and the forecast one, all divided for the actual value. In the end, the value obtained is multiplied by 100 [53].
The R^2 o R squared acts on the opposite side. It aims to indicate the goodness of the predictions. Its value changes between 0 and 1, So as close as the value to 1, better is the fit [46]. In this case it is chosen to use the MAPE to measure the accuracy. This choice is justified thanks to its easy interpretation, its popularity, and because it is scale-independent [54]. To make a very good analysis, which also means a good forecast, the value of MAPE should be less than 10 % [55].

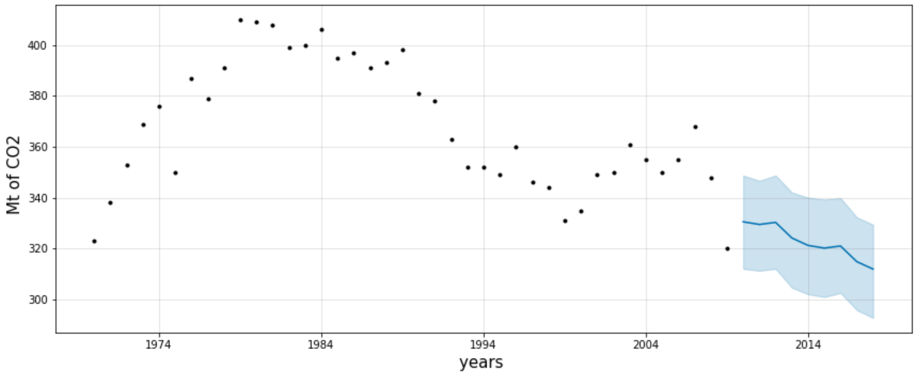

Figure 24: German training trend of CO_2 emissions

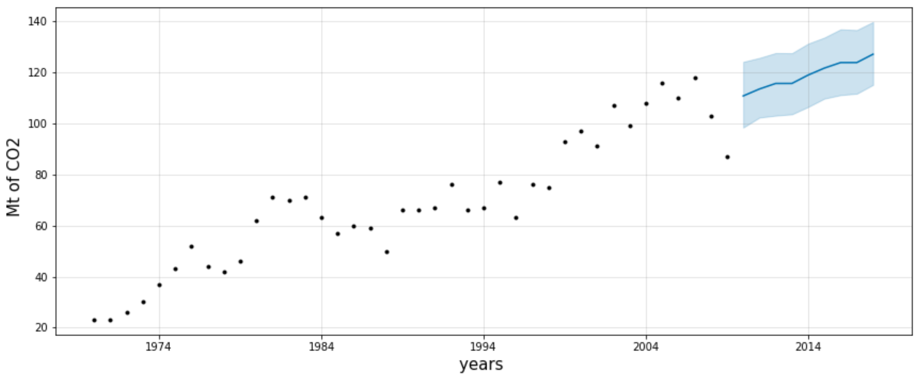

Figure 25: Spain training trend of CO_2 emissions

Figures 24 and 25 show the trend of the emissions of Spain and Germany.
The black dots are the real value of the emissions from 1970 to 2009 and represent the training data. The blue line represents the forecast trend based on the training data. The light-blue shaded regions are the confidence intervals, this takes into account possible small variation that could occur. They present and affordability of 90%
Despite the increase in the first two decades, Germany presents an overall decreasing trend since the nineties. The lowest value is reached in 2009, which coincides with the last value of the data set. So it is expected a further reduction of emissions as shown by the forecast trend. The Spanish trend, in Figure 25, shows the opposite behavior. It keeps on increasing its value until 2007. Hence, despite the strong emissions reduction in 2009, the overall trend of this country is increasing. For this reason, as shown by the blue line in Figure 25, it is expected that emissions keep on growing.

The next step is the model validation. To do it is necessary a comparison between the real value of emissions from 2009 to 2018 and the trend foresee. Then according to the value of the MAPE is be possible to decide if the model can be validated,or not. Only after the validation is possible to use it for the prediction.

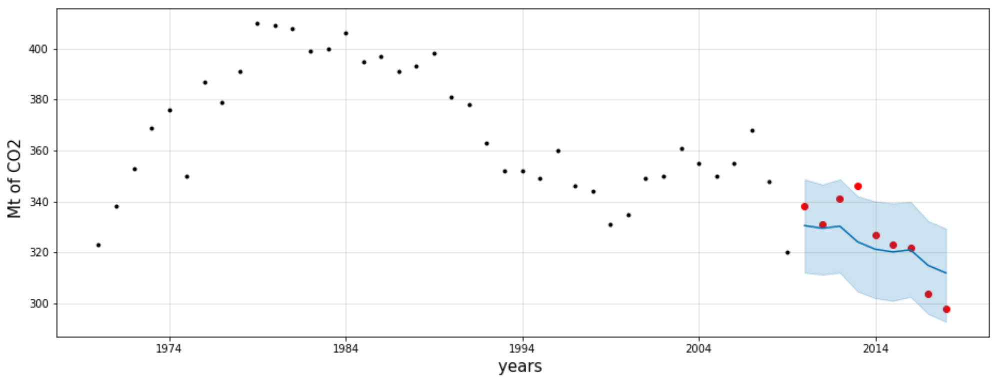

Figure 26: German test trend of emissions

The red dots represent the values of the data test, which are the real emissions value . In the case of Germany shown in Figure 26, almost all the red dots are close to the line of the forecast trend or in the interval of uncertain.
While as it is possible to observe in Figure 27, it is not the same for the Spanish trend.

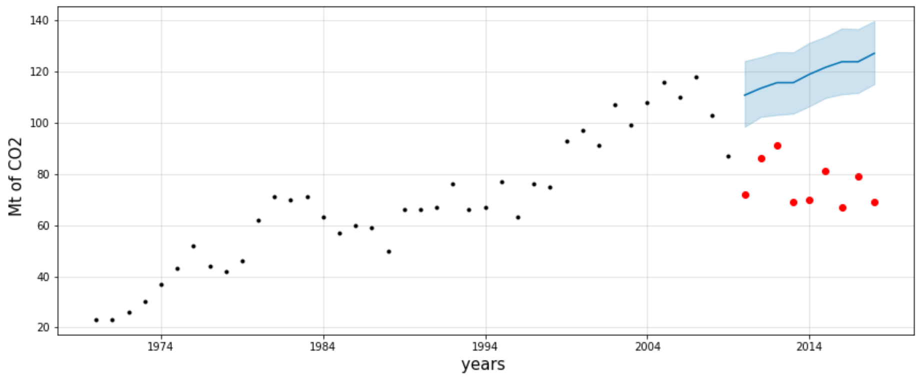

Figure 27: Spain test trend of emissions

Especially, in this case, no one of the red dots is along with the trend or in the interval of uncertainty. Hence it appears clear how this model can not be used to predict the emissions trend until 2030.

The value of MAPE has been calculated in Python using the *sklearn.metrics* library.

For the German trend, this value is equal to 2.58 %, while for Spain it is 58.5 %. According to what said before, to have a good and reliable forecast, and to use this model to foresee the trend, the value of MAPE has to be under 10 %.

It is clear that the forecast model of Spain can not be used because of the MAPE high value. , observing Figure 27, no one of the predicted values falls within the uncertainty band. Instead, the German model appears reliable, so it is possible to proceed with the analysis. Figure 26 shows that almost all the red dots are inside the uncertain band, and a lot of them are close or along the trend line. That explains the low MAPE value.

Once the model is validated, the next step is to build a new model using the whole data set from 1970 to 2018. Then using this new model, it is possible to make CO_2 foresees until 2030. The trend obtained is shown in Figure 28.

As it possible to observe in Figure 28, the emissions trend keep on decreasing its value, but the forecast is expected to grow up a bit respect to the data of 2017 and 2018. The trend shows a further reduction of the emission in these two years which is not taken into account by the forecasting trend. Since it is not known the reason for this further reduction, it is not possible to know if it is an accident or if there has been a change to the model. It would be necessary to continue monitoring the trend.

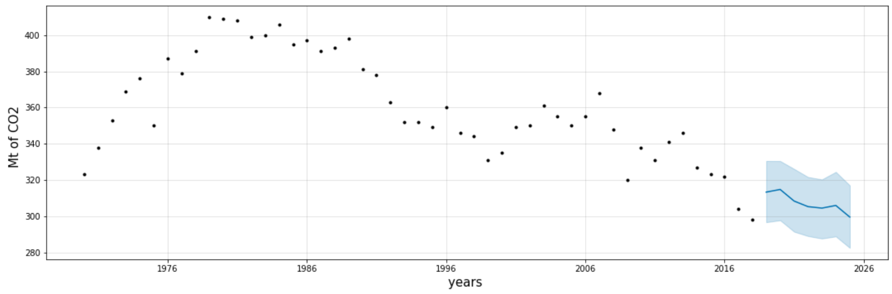

Figure 28: German forecast trend of emissions

It is important to notice that the emissions deeply reduce since the maximum value reached during the 1980s, the forecast indicates that the value will continue to go down.
This model does not take into account the new energy policy. It only considers the past behavior. For this reason, this trend can be considered reliable only if the energy policy keeps on with the same strategy. In this case, due to the changes, like the strong decarbonization and denuclearization, it would be possible a further modification on its performance.

Performing this analysis, it is important to understand which are the causes that don't allow to validate the model of Spain. This could be related to the fact that with the end of the Franco dictatorship in 1975, Spain began a process of economic and industrial growth. As a matter of fact, from this year onwards, a continuous upward trend in emissions can be observed, which follows the trend of GDP. The first strong reversal occurred in 2008 due to the economic crisis that affected the whole of Europe. That year, it is possible to observe a peak downwards in both GDP and emissions. From this moment, both trends show an oscillating trend, but with a tendency to decrease. Therefore 2008 marks a variation concerning the model used. From that year, it is necessary to use another trend to make the forecasts. That is not possible because the data are not enough to build a new robust and reliable model.
A new model should be implemented, taking into account other factors that should be used to make the forecast such as GDP, electricity demand changes, energy efficiency, the spread of electric cars, and new energy policies for the implementation of renewable and the closure of fossil power plants.

The last step of the analysis wants to compare the forecasted trend using machine learning with the emission trend of the scenario performed. The last one is traced as the product of the kg of CO_2/kWh of electricity produced in the different time-step and the electricity demand forecast.

The black dots in Figure 29 are the past emissions value, while the blue line represents the forecast value, using the same model of Figure 28. The light-blue shaded regions are the confidence intervals. The green dots represent the emissions value of the scenarios.

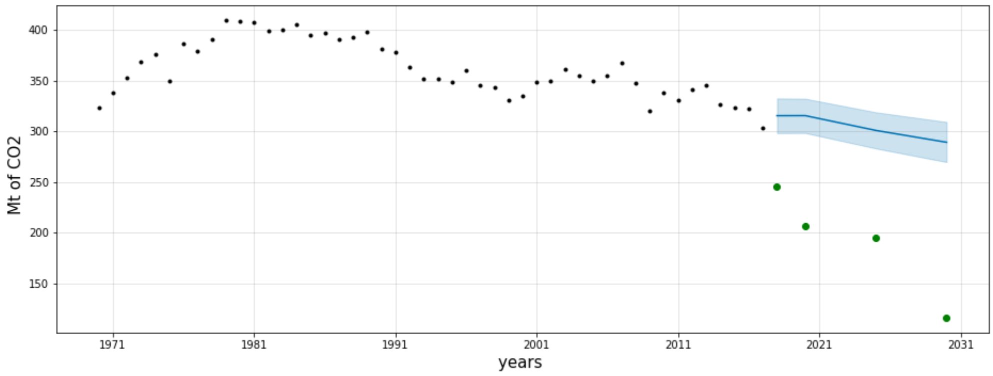

Figure 29: Trend vs Forecast

It is interesting to notice the totally different behavior of the two trends. This is because the blue one follows the model based on the past data, and according to the current energy policy. The green one considers the value obtained by the simulation of the scenarios, according to the new energy policies. These new policies aim is to proceed with the decommissioning of nuclear and coal power plants, which represents an important change. Comparing the two trends appears clear that the new policy scenario brings an additional reduction in emissions, so it appears as a further improvement.

In conclusion, the new energy policies appear better than the old one. Hence, Germany's emission trend is expected to reduce much more than it had done until now.

It is also important to remember that, the electricity demand considered in the two trends is different. Indeed, for the scenario, it depends on EUCO3232 [20], following the procedure described previously, while the blue line depends only on the past emissions value., it isn't affected directly by a change in the demand.

5 Results Analysis and Comparison

In this section, the results obtained are observed and commented to understand if the scenarios performed to respect the targets fixed. In this way, it will be possible to modify or change the plans to reach the goals of the country. Then the two scenarios are compared to better understand the different environmental policies.

5.1 Germany vs Spain

Spain and Germany have established themselves as forerunners of the energy transition in Europe. This two nations, together with Denmark had experienced the fastest development of their renewable energy sector in Europe,by significantly increasing their share of renewable. Both countries have shown a certain sensitivity towards environmental issues, but have followed different energy policies, which are also influenced by different models of economic development. For this reason the energy transition process in these countries is very different.

The figures 30 and 31 show the emission trends of the two countries, already here there are numerous differences. Germany has a peak emission trend in the decade between the end of the 1970s and the 1980s. To which corresponds in fact a period of strong economic and industrial development, until the fall of the Berlin Wall in 1989. The reunification led to an economic collapse which resulted in emissions continuing to fall until 1999.

The financial crisis of 2009 causes a new negative peak in emissions. Despite a small increase, starting in 2012, the year in which the Paris Accord was signed, the trend of emissions shows an increasingly strong negative trend.

As far as Spain is concerned, on the other hand, the trend in emissions is increasing until 2008 as shown in Figure 31 . In fact, with the end of the Franco dictatorship, the country has seen a period of strong economic growth, also thanks to the liberalization of the market. It should be noted that in the case of Spain GDP and emissions show a similar trend. This is a growing trend with a peak in 2009, and a collapse the following year due to the economic crisis.

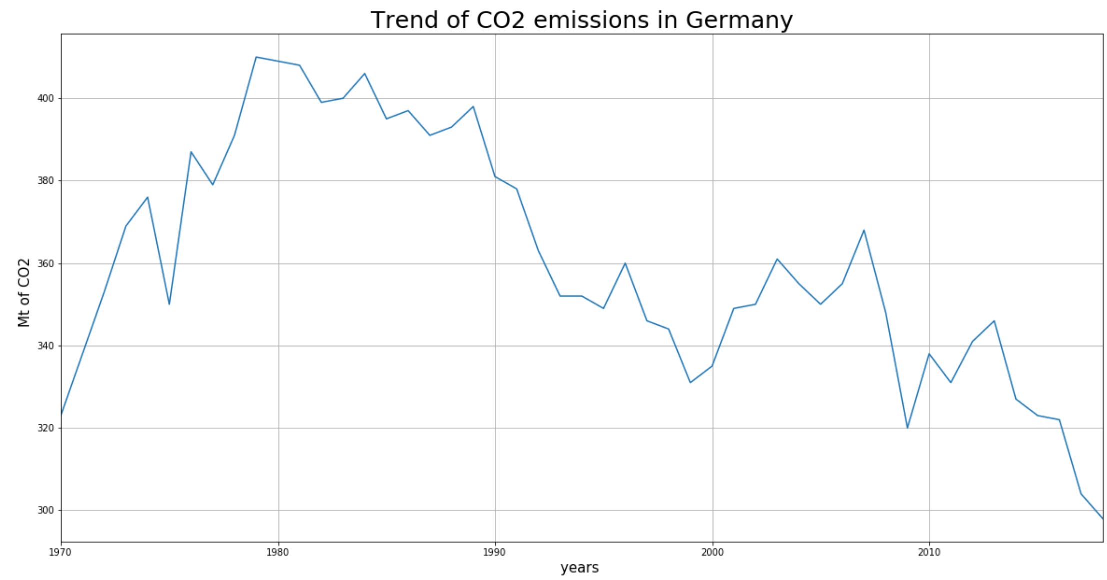

Figure 30: Emission trend Germany

Extracted from [1]

Thereafter, the trends is oscillating, but emissions decreased significantly compared to the value reached in 2009. The emissions trend in Spain therefore shows two very different trends.

In both cases, emission trends were affected by the economic crisis, which led to a collapse of production.

It is also interesting to note that despite the downward trend in Germany, it has a CO_2 value emitted that is four times higher than in Spain. In fact, in 2018 Germany's emissions amounted to 299 Mt and those of Spain at 68 Mt. It is therefore clear that Germany must make a much greater effort than the country on the Iberian Peninsula.

In fact, as can be seen in Figure 6 Germany occupies sixth place globally, while Spain is in 24th position. There are several reasons for this discrepancy. The demand for electricity in Germany is much higher than in Spain. Moreover, because of its different geographical position, Germany does not enjoy the same irradiance as Spain. That explain why , although the GWs of photovoltaic plants are much larger in Germany, the share of solar energy is lower. Furthermore, looking at the electricity mix of the two countries, it can be seen that coal is strongly linked to electricity generation in Germany.

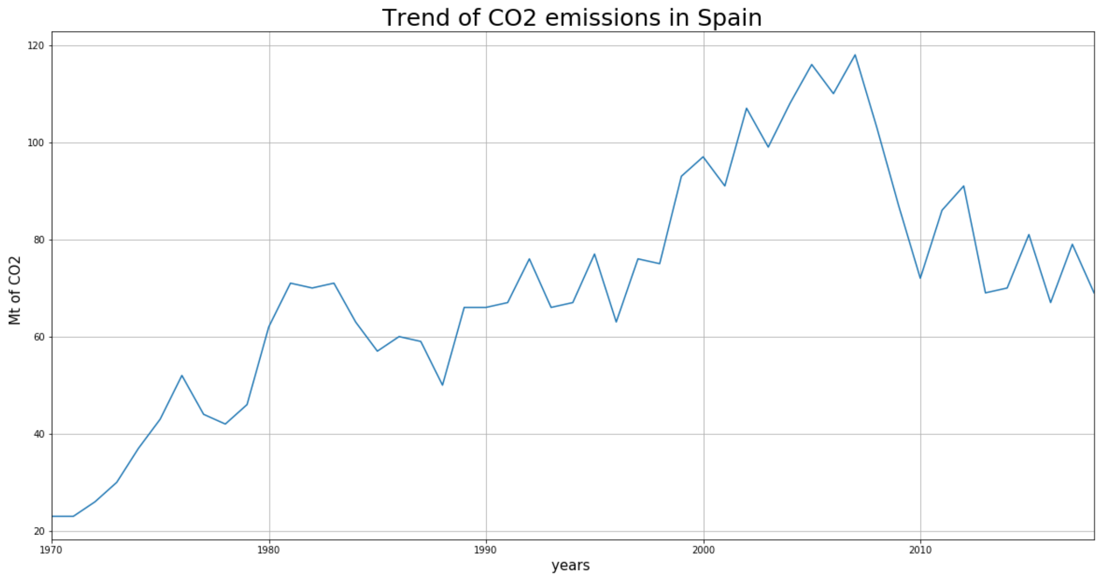

Figure 31: Emission trend Spain

Extracted from [1]

This is partly due to the structure of the electricity system, which is in both cases the sector most responsible for emissions. In fact, looking at the Tables 1 and 3 relating to the installed capacity of the two countries or the share of electricity production in Figure 10 and 12. It can be seen that in Germany electricity production is still strongly linked to fossil fuels, mainly Lignite and Hard Coal, which are highly emitting. These two resources alone produce almost 40 % of annual electricity production. While in Spain this value does not even reach 15 %. On the contrary, it's possible to find greater exploitation of Natural Gas and Uranium, which are less polluting than coal.

Looking at the installed capacity in the Tables 1 and 3, it can be noted that Germany has many more GW of renewable than Spain. However despite this, the percentage of electricity produced by these sources is slightly higher in Spain.

5.2 Germany

Germany will have a big increase in the share of renewable energy sources. In 2018, it represents only 41 %, reaching 74 % in 2030. The trend of the share is displaced in the 32, the difference between 2018 and 2020 is not particularly relevant due to the small period, while it starts to become more significant compared with the other time-step. Closing all nuclear power plants before 2025 and the decarbonization process, bring to an increase of almost 12 % in the share of electricity produced by renewable energy sources.

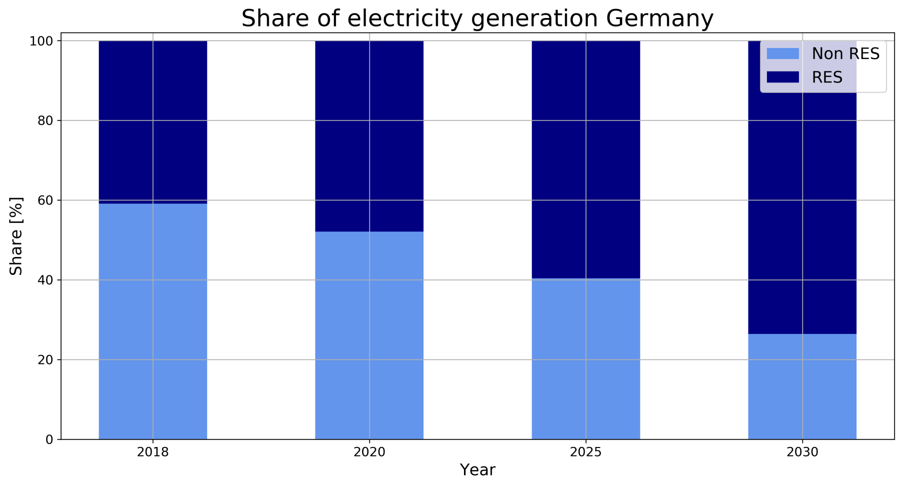

Figure 32: Share of GE

The last time-step is characterized by a further increase in the share of green electricity. From the 60 % in 2025, it reaches 73 % in 2030. This is possible because several coal power plants will be definitively closed, and thanks to the additional 22 GW of photovoltaic power plants, and the 14 GW of wind power plants. In this way it is possible to use less Natural Gas, obtaining a further reduction in the value of emissions per kWh.
The value of kg of CO_2 per kWh emitted for electricity production is halved. This represents a really important result in terms of environmental issue, because the electricity sector is the most emitting one.
The target set by Germany for energy production from renewable sources is equal to 30 % by 2030. This scenario achieved and doubled this target. However from this analysis, it is not possible to say if the other targets set are also met. Despite can be observed a reduction in emissions in the electricity sector, nothing can be said about other ones. As far as the improvement in electricity efficiency is concerned, there is also supposed to be a reduction in energy demand, but no analysis has been made of this.
Figure 33 shows the different values of kg of CO_2 per kWh of electricity produced in the

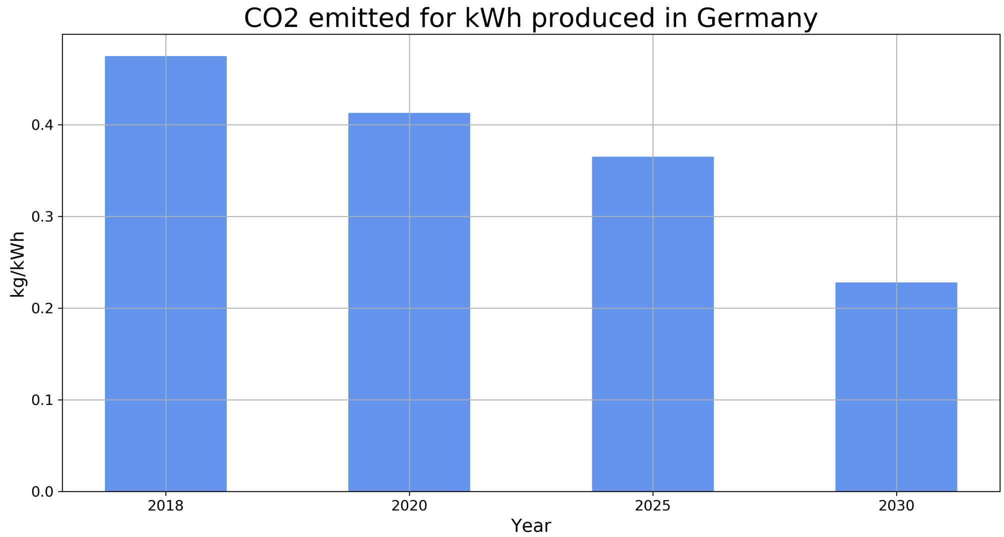

Figure 33: CO_2 emitted per kWh of electricity produced in Germany

different scenarios. The decreasing trend presents an overall reduction equal to 48 %. This represents a really good result for Germany because it allows a reduction of 54 % in the sector of electricity generation. The closure of many coal-fired power plants between 2025 and 2030 brings the most significant reduction in the kg of CO_2/kWh.

5.3 Spain

Already in 2018, the share of electricity production in Spain, is characterized by a low presence of fossil fuels, as can be seen in the Figure 12.

In fact, therefore, the value of CO_2 emissions per kWh of energy produced is quite low and is equal to 0.276 kg/kWh. Thanks to the decommissioning of coal, which disappears

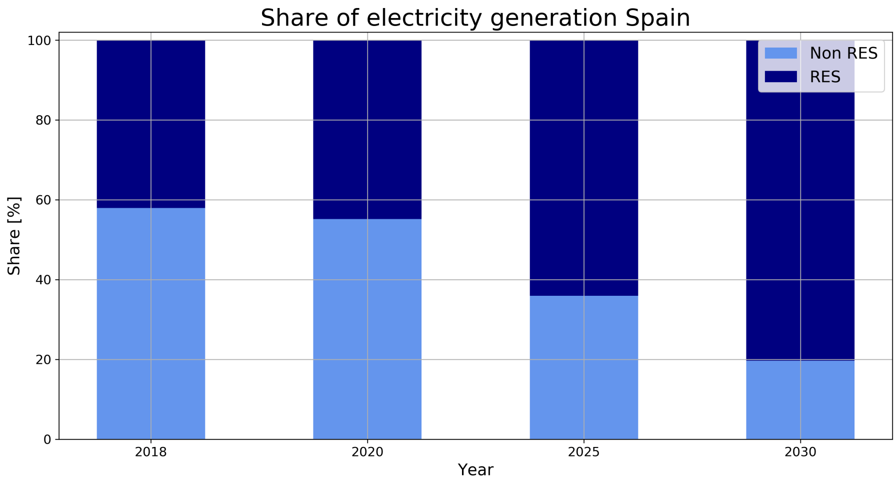

Figure 34: Share of Spain

definitively by 2030, and the progressive phase-out of nuclear plants, which significantly reduces its installed capacity, the Spanish share is becoming more and more green. All these plants are being replaced by plants powered by renewable sources.

The 34 shows the share of Spain's electricity production in different periods. There it is possible to observe a growing trend in the share of electricity produced by renewables energy sources, from 42 % to 80 % in 2030.

The most significant increase is between 2020 and 2025, with a 20 % increase in the share of renewable.

During this period the installed capacity of hard coal is halved, and that of lignite disappears. At the same time, 12 GW of wind power are installed. Solar thermal power doubles its installed capacity, and photovoltaics almost triples it.

The next time-step shows an equal increase in photovoltaics, which adds another 14 GW to the 23 GW already present. While for solar thermal and wind power the increase is slightly

smaller. The last one reaches 50 GW of installed capacity, and solar thermal reaches 7 GW. Indeed, in Spain in 2030 out of 149 GW installed 116 GW are renewable power plants.
The target fixed was to reach the 74 % of share of renewable energy sources, instead with this scenario it exceeds the target by reaching 80 %. Which represents a really important result for the country. In this way, Spain has managed to further reduce the value of CO_2 emissions per kWh of energy produced. In 2030 the kg of CO_2 emitted per kWh of energy produced is expected to be 1/3 of the 2018 value. In fact, from 0.276 kg /kWh, in 2030 should be obtained 0.092 kg/kWh. This represent a really good result for the reduction of GHGs emissions. However due to the fact the transport sector affects a lot the overall emission, so despite improvements in the electricity sector, it is not possible to evaluate if the target fixed for the reduction of GHGs are satisfy or not.

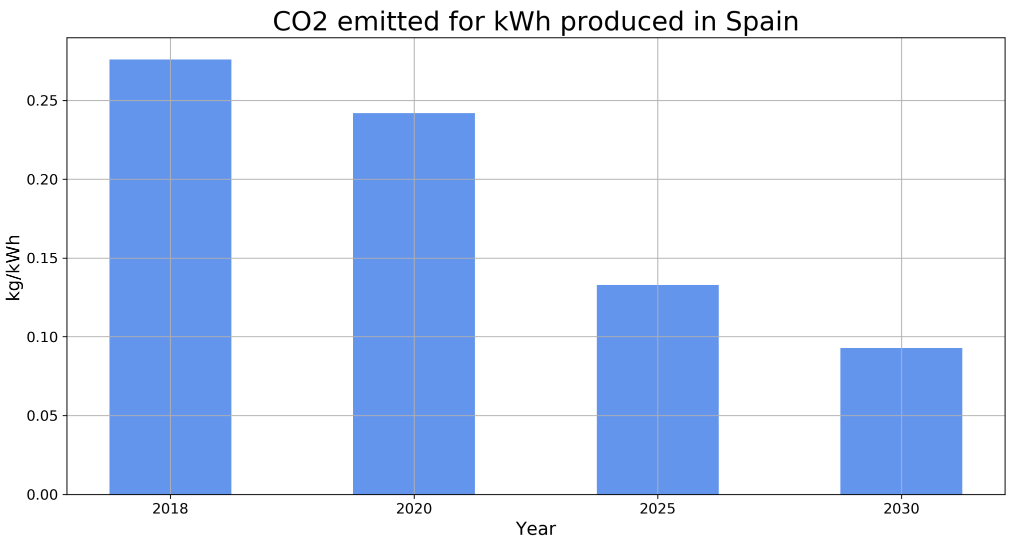

Figure 35: CO_2 emitted per kWh of electricity produced in Spain

Figure 35 collects the values of kg of CO_2 emitted for kWh of electricity produced with a certain mix obtained by GaBi simulations. These show a decreasing trend whit a reduction of 38 % respect to 2018. Moreover, they are lower than in the German case. Hence in 2030, it should be equal to 0.0927 kg of CO_2/kWh for Spain, while the same year it should be 0.228 kg of CO_2/kWh for Germany.
The overall reduction of emissions in the sector of electricity generation is equal to 65 %. Which is a really big result for Spain.

6 Conclusions

This study is divided into two-part, and it analyzes two European targeted countries: Germany and Spain.
The first part is focused on the prediction of energy scenarios for the next ten years. The aim is to analyze the changes in terms of kg of CO_2 emitted per kWh of electricity produced. While the second part, starting from past behavior, wants to foresee the CO_2 emissions trends.
The scenarios are performed according to the National Energy Plan of each country [2] [3]. In both cases, there is an increasing share of renewable energy sources, but following different decommissioning policies. During this process of decommissioning, the increase of renewables power plants has a relevant role. In this way, it will still be possible to satisfy the electricity demand, but in a greener way. Despite that, in the baseline, both countries show a deep dependence from fossil fuel, the situation changes in 2030. Indeed, in 2018, Germany is strongly dependent on coal, while Spain depends on nuclear and Natural Gas.

Germany gives priority to the decommissioning of nuclear power plants because of the strongly adverse public opinion. In this way, it turns to be nuclear-free in 2022. The analysis in GaBi showed that this change does not bring significant changes in emissions, as can be observed in Figure 33. That is because the simulations show that the CO_2 emissions produced by this source are negligible. Indeed, considering other indicators this source considerate polluting. For this reason, the most significant variation is during the last time-step due to the strong reduction in coal use, while the reduction during the first time-step is due to the increase of renewable. During this first step, the increment of renewable is equal to 7 %, from 40.9 % to 47.9 %, while the other steps have a stronger increase in RES. In 2030 the 73 % of electricity is produced by renewable energy sources. This makes possible a reduction of fossil fuel consumption and so cuts emissions by 54 % in the electricity sector.
This result is good, but the country has to keep on making efforts to reduce emissions. Because, despite Germany shows a decreasing emissions trend since 1990, it is still one of

the most emitting countries in terms of CO_2 emissions.
This is possible also thanks to the increasing importance of environmental issues and the strong agreement of public opinion. Hence, the Government can push on strong environmental policies. Public opinion has an important role in the energy transition process, as it appears to be a support and a stimulus. It makes it possible to give greater importance to these issues without any obstacles. One example is the case of nuclear energy. Public dislike has accelerated the process of decommissioning nuclear power plants rather than coal-fired plants, even though the latter ones are much more polluting.

Spain presents a different baseline situation. Despite its increasing economic growth, the values of emissions in the electricity sector are deeply lower than the German case. That is because of the low presence of coal in the electrical share. For this reason, Spain decides to push on the decarbonization of the electricity sector. The aim is to reach carbon neutrality before 2030. The National Energy Plan provides the steps for the decommissioning of the fossil fuel power plants and also for the growth of renewable power ones. The aim is to reach in 2030 116 GW of renewable over 149 GW of installed capacity. In this way, the electricity production of RES accounts for more than 80 % of the total share.
However, it is interesting to notice the correspondence between the phase-out of coal power plants and the decrease in the kg of CO_2 for kWh of electricity produced. Since the first time-step is characterized by a small reduction in the GW of fossil fuel, there is also a small reduction in the emissions per kWh.
The strongest reduction of the kg of CO_2 for kWh occurs between 2020 and 2025, due to the disappearing of Lignite power plants, to the strong closure of Hard Coal power plants, and also to the deep reduction on the use of Natural Gas. The last scenario presents a lower value of the emissions per kWh thanks to the quit of all coal plants, but this reduction is not as significant as the previous one because of Natural Gas slightly increase.
However, until 2009 the overall emission trend of this country was increasing, then after the economic crisis, the trend appears oscillatory. Despite of emission of this country are deeply lower than others, the increasing trend does not represent a positive issue. For this reason, it is necessary an overall change in the trend.
According to the measure of the National Energy Plan, it is possible to change it. The path

towards decarbonization could be long and complicated, but with an adequate increase in renewable energy sources, it will be possible to invert the emission trend. Following the indications of the National Plan, it could be achievable to halve the emissions per kWh of energy produced. This represents a good step towards emissions reduction. Despite this, other factors have to be considered. For example, a notable increase in electricity demand could lead to an increase in emissions, although the decrease of kg CO_2 per kWh. For this reason, more efforts are required.

Comparing the different decommissioning strategies of the countries appears clear that both obtain better results in terms of GHGs reduction, during the decommissioning of coal power plants, respect to the nuclear one. This result appears quite obvious because, performing GaBi simulation, it was evident that coal pollutes much more than nuclear in terms of CO_2 emissions. Comparing the two values of kg of CO_2/kWh, the result is that nuclear value is negligible. Hence, Spain starts with the decarbonization path, expects a better outcome, this is true, concerning the low installed capacity of coal in this country. In reality, in Germany, the overall closure of coal power plants amount to 23 GW, while in Spain, it is equal to 10 GW. These data mean that to obtain good results, Germany has to make more significant efforts.
The denuclearization process does not concern emission reduction but other environmental issues and the adversity of public opinion, especially in Germany. So, its decommissioning does not bring an improvement in terms of CO_2 reduction.
Both countries have invested a lot in the implementation of renewables. Despite the geographical and morphological differences, the primary source for both countries is wind. The diversity lies in the fact that Spain has only onshore power plants, while Germany pushes a lot on the implementation of offshore power plants. It is possible thanks to the favorable features of the country, and it is a good investment because of the higher capacity factor. For this reason, this source has an exponential increase.
In Spain, wind doubles its installed capacity, while in Germany, the offshore capacity triplicates its value, and the onshore one grows significantly. Hydropower does not change its installed capacity, because it is assumed that it had already reached its maximum.
Solar power is the source with the highest increase. Hence, this source has a high potential

for development and production, particularly in Spain, because of the higher CF. For this reason, thanks to the high value of irradiance that characterizes the country, it is possible to install also solar thermal power plants. This technology presents a high potential, but it requires specific working conditions.
Germany has lower values of irradiance, but despite this, it is investing a lot in the development of this source, reaching 98 GW in 2030. Even though it becomes the most installed capacity in the country, its contribution to the total electrical share is not relevant.
Only in Germany biomass makes a significant contribution to the share, even though the installed capacity is not much. The CF of this resource is quite high, so it has a good chance of development. In Spain, on the contrary, this resource is not yet widespread, it should reaches 1 GW only in 2025.

The second part of the study is focused on the machine learning approach, to forecast the evolution of CO_2 emissions of these targeted country. Python programming language is used to build a model to predict the emission trend to foresee its possible evolution. To proceed with the forecast is fundamental to test and validate the model using the available historical data. During this step, the Spain model does not pass the validation step, so it can't be used for prediction. The reason can be different, first of all, it is possible to observe a change in trend after 2009, which the model fails to take into account due to the limited data available. Moreover, these time-series models don't take into account the influence that can have different parameters. It relies only on the past data to build the model. In the case of Germany, the model is validated, so it is possible to continues the study. The overall trend is decreasing, hence the forecast foresees a further reduction in emissions over the next ten years.
Although this trend brings to positive results, it shows a small increase in respect to the last two values. Also in this case, it is not possible to know if there is a change in behavior or this reduction was an inexplicable event, so further research are required to understand this unexpected reduction. The only option is to keep on monitoring the trend to understand if there was a change in the behavior or not. The use of machine learning to foresee future behaviors could be useful in the energy field. Indeed, it allows analyzing which could be the possible future trend basing on the past data. In this way, it will be possible

to understand if a change necessary or not.

The comparison between the forecast trend and the scenario ones helps to underline the effect of a change in energy policies, and to make the most suitable choice according to the final aim. In this case, the scope is to understand which is the path to bring a further emission reduction. As reported by Figure 29, the change done in environmental policy seems to bring better results than the old one. These tools could be really effective to the implementation of new energy policies, because it gives an idea of the possible results. In this way it should be easier to identify the best option. It's also important to remember the limitation of these methods. Indeed, this big difference can be related tot the fact that, while the time-series trend depends only on the past behavior without considering to any other external variable, the scenarios trends consider not only the new energy policies but also the foresee trend in electricity demand.
Maybe the use of a multilinear model could lead to more accurate results. Indeed this kind of model takes into account several parameters that could influence the trend. In this case, to foresee CO_2 emissions trend, it would worth to consider specific parameter as GDP, electricity demand, weather, energy efficiency, the share of electric veihcles. According to its structure, time-series do not consider other variables, but only the historical data.
For this reason, using a multilinear model, it could be possible to understand how each specific parameter affects the behavior of the model, making an accurate prediction trend. This kind of analysis will require further research.

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