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COMPARISON BETWEEN SPAIN AND SWEDEN FROM THE POINT OF VIEW OF INVESTORS IN RENEWABLE ENERGIES

WITH A SPECIAL FOCUS ON SOLAR PV AND WIND POWER TECHNOLOGIES

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ABSTRACT

This report is composed of two parts. The first part compares different aspects of Swedish and Spanish electricity systems, such as the average price in the spot market, the generation structure, the available support polices for renewable energies and the distribution of the installed power capacity, in addition to wind and solar resource of both countries, to find out what opportunities Sweden and Spain offer to new investments on solar PV and wind power technologies.

Since this complex analysis could lead to a subjective conclusion, the second part of the project simulates the behaviour of a wind power station and a solar PV power station in Sweden and in Spain, with the same characteristics, regardless of the country where they are installed. Moreover, the four power stations have 50 MW of installed power.

The behaviour is simulated in two different situations. The first one ignores the effect of each country's support policies, and the second one includes this effect in the analysis. This way, it is possible to discover if a technnology is profitable by itself in these countries and the effectiveness of such policies gets exposed.

The conclusion of the report is that utility-scale solar PV technology is currently profitable in Spain but not in Sweden, regardless of the support policies' effect. On the other hand, new wind power projects seem to be more profitable in Sweden, although in Spain its feasibility is possible too. In both cases, support policies help to improve profitability, but they are not decisive in the cases presented.

ACKNOLEDGEMENT

I would like to thank three people in particular. Igor Assis Lana e Cruz has been my supervisor in Linköping from the beginning of this project. He freely chose to be my supervisor and agreed on developing my own idea, and I really appreciate that. He has been guiding me through the process when there was a problem I had to face, and there were many of them. Being new in this country, and not speaking Swedish, sometimes it was very difficult for me to get and understand some information that was crucial for the project, and Igor was there when such difficulties appeared.

On the other hand, David Ribó Pérez and Manuel Alcázar Ortega have been my supervisors in Spain. They both made this project possible too. I would like to give special thanks to David, who helped me with the approach of some of the most important parts of the project, improving it with more reliable data and calculations, that finally led to a more solid conclusions.

Actually, the idea came to my mind while I was taking my “Energy Markets” course in Spain, where Manuel and David were my professors. They made that course really interesting for me and inspired me to develop this idea. I have always been interested in environmental issues, so renewable energies have always seemed fascinating for me, but after courses like Energy Markets I understood many other benefits that they have, so I thought it could be stimulating to study a country like Sweden, famous for its environmental awareness.

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1. INTRODUCTION

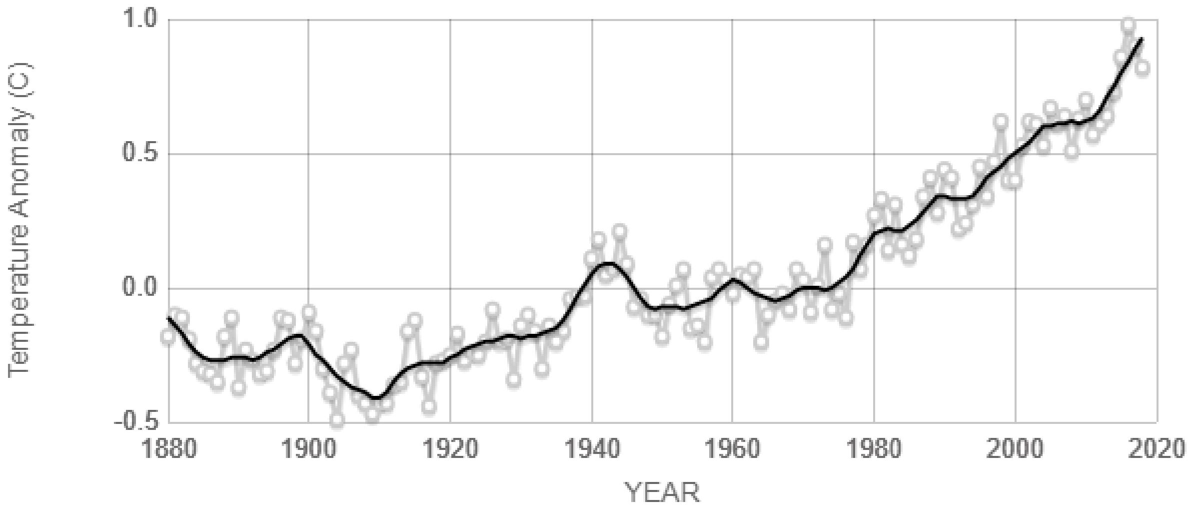
1.1 Background and objective

The aim of this project is to analyze Spanish and Swedish electricity markets to identify what strong points and weaknesses they both have when it comes to building a power station that uses renewable resources and how big their respective rooms for improvement in this field are. Specifically, the analysis will focus on solar PV and wind power stations.

To justify why a government like the Swedish or the Spanish one should be interested in promoting and researching about renewable energies, the following paragraphs offer two strong arguments: one is environmental, and the other is economical.

From the industrial revolution, coal, oil and natural gas have been the motors for economic growth worldwide. Most of the countries which had access to such sources of energy and had the proper technology have become some of the most powerful countries in the world. However, this growth was not free. The combustion of such fuels emits greenhouse gases (carbon dioxide, nitrogen oxides, sulfur oxides, etc.) that seriously damage the environment, especially due to the increasing global warming the earth is experiencing right now, caused by these gases. As it can be observed in *Figure 1.1*, the average global temperature has increased 1ºC from 1960, which, given the Earth's dimensions, is considerably worrying.

FIGURE 1.1: GLOBAL TEMPERATURE ANOMALY FROM 1880 TO 2018

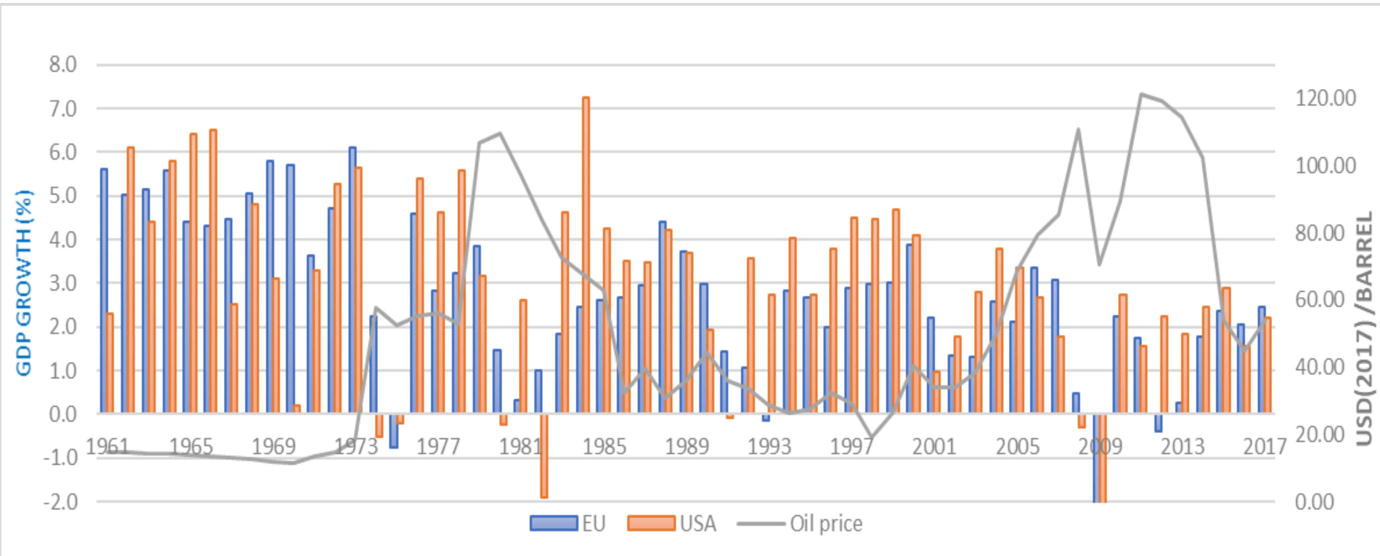


Source: NASA, 2019

But environmental issues are not the only ones that matter when it comes to choosing a source of energy. Any country with great dependence on oil, coal and natural gas, becomes extremely vulnerable to its variation in price.

One way of demonstrating this is to compare the evolution of oil prices with the evolution of some developed countries' GDP. In *Figure 1.2* the evolution of EU's and US' GDPs can be observed, together with the average prices of oil for each year, from 1961 to 2017.

FIGURE 1.2: EVOLUTION OF OIL BARREL PRICE VS US' AND EU' GDP



Source: Own preparation based on data from Quandl and World Development Indicators

In 1973 there was a global oil crisis, caused by a sudden increase of its price. As the image shows, while the oil barrel price was tripled, the GDP's growth of both the US and the EU plummeted.

It is interesting to observe that this relation between GDPs and oil price is reciprocal. Looking at the same image, around 2009, it can be observed how the financial crisis unfolded with the collapse of Lehman Brothers had a considerable impact in oil price, which changed from 110 USD/barrel to 70 USD/barrel in one year. This was due to the demand drop, after the closing of many companies.

Moreover, oil has been pointed out as one of the main reasons for many wars and international tensions, since all countries are aware of how powerful they would become if they could control oil production and distribution.

1.2 Problem formulation

The main obstacles for a fossil fuel-based economy to be transformed into a renewable energies-based economy are the feasibility and profitability of these new sources of energy.

There are different types of renewable energy resources. From the potential energy that water in a reservoir carries, to the kinetic energy of the wind, going through the thermal energy of a fluid heated by the sun, the Earth has plenty of renewable energy resources. However, the technology that takes advantage of such resources has not always reached the necessary level of development to do it in a profitable way. On the contrary, conventional thermal power plants reached great development in the previous decades.

This situation hampers that some renewable energies compete against fossil fuels in equal conditions and, therefore, the investments in this field are not as high as they could be.

Nevertheless, some renewable technologies have evolved faster than expected, and many experts have already stated that they have finally become profitable by themselves, that is, without the necessity of any subsidy or bonus.

Thereby, this report will try to find out if solar PV and wind power technologies have real chances to grow in the Swedish and Spanish electricity markets, in a cost-efficient way.

1.3 Purpose and research questions

Some of the questions that are intended to be answered with this report are:

- How much do Spanish and Swedish economies depend on fossil fuels?
- Is utility scale-solar PV technology profitable in Spain and in Sweden?
- Is wind power technology profitable in Spain and Sweden?
- Do the Swedish and Spanish support policies make a big difference?

1.4 List of variables

In this part, all the variables used in the calculations explained in *2. Methodology* named, together with their respective meanings and units.

Such information is available at Table 1.1.

TABLE 1.1: LIST OF VARIABLES

Symbol	Meaning	Units
K	Scale parameter. It is one of the parameters that define the Weibull distribution.	None
c	Shape parameter. It is the other parameter that defines the Weibull distribution.	m/s
V	Wind speed	m/s
F(V)	Probability of having a wind speed lower than "V".	None
c(z)	Value of the Weibull distribution's shape parameter at a height "z"	m/s
c_a	Value of the Weibull distribution's shape parameter at a height "z_a"	m/s
z_a	Height of the wind speed meter	m
α	Quotient used to approximate c(z), given z_a and c_a	None
K_a	Value of the Weibull distribution's scale parameter at a height "z_a"	None
R	Ratio cancelled certificates / issued certificates	None

2. METHODOLOGY

This project has two main parts. First part collects data from very different sources of information to evaluate the current state and the room for improvement in energy matters for Spain and Sweden. This information is presented in *3. State of art* part, and it includes a global energy balance, with a special focus on renewable energies. Then, the following aspects for Spain and Sweden are presented:

- Energy balance
- Distribution of the electricity generation
- Electricity price in the spot market
- Installed power capacity
- Time with a shared price with neighbor countries
- Support policies
- How Mibel and Nord Pool work
- Solar resource
- Wind resource
- Costs for wind and solar PV technology

The collection of all this data provides a broad perspective to analyze both energy systems, which is done in *5. Discussion* part. However, this analysis could be claimed to be too subjective, and that is what the second part of the project is for.

The second part uses more specific data about resources in a concrete location, in addition to the findings about spot market price, costs and support policies to simulate the behavior of 4 different power stations:

- 1 solar PV power station of 50 MW in Norrköping, Sweden

- 1 solar PV power station of 50 MW in Valencia, Spain
- 1 wind power station of 50 MW in Malmslätt, Sweden
- 1 wind power station of 50 MW in Valencia, Spain

The power stations of the same kind are configurated with practically all the same specifications and characteristics, regardless the country where they are installed. This way, technical parameters are fixed, and the variables that change the profitability of each power station are only dependent on the country and the location (electricity price, costs, support policies and renewable resource).

Moreover, the results are divided in two different scenarios. In the first one, all support policies are ignored and in the second one they are all included, to find out their effectiveness.

2.1 Theoretical part

Now it follows a list of the different sources of information for every point of the theoretical part of the project. In most of the case, the procedure consisted in reading certain part of some reports, analyzing them and then extracting the most relevant pieces of information. If any point was addressed in a different way, such particular method will be also explained in this list.

a) Global energy balance, renewable energy share of global electricity production and installed renewable capacity. These points were made using information from REN21's report "Renewables 2018 Global Status Report".
b) Spanish energy balance. This part was made using data from IDAE's website.
c) Swedish energy balance and Swedish distribution of the electricity generation. Both parts were made with information from Swedish Energy Agency's report "Energy in Sweden 2017".
d) Spanish distribution of the electricity generation and the time with a similar price than neighbor countries are based on data from OMIE's report "Informe de precios 2018".
e) Electricity price in the Spanish spot market. Made with data from OMIE's website. In this case, average prices from the last 10 years were taken to make a graph when the evolution of price can be observed together with the amount of energy traded.
f) Electricity price in the Swedish spot market and time of shared price with neighbor countries. Made with data from Nord Pool's website. In this case, the average prices in the 4 Swedish zones were taken from 2012 to make a similar graph than in the Spanish case.
g) Spanish installed power capacity is based on the REE's report "Las energías renovables en el Sistema eléctrico español".
h) Swedish installed power capacity is based on the IVA's report "Electricity production in Sweden"

i) Spanish support policies are based on Law 24/2013 of the electricity system and order ETU 315/2017.
j) Swedish support policies are based on the Swedish Energy Agency report The Norwegian-Swedish Electricity Certificate Market, Annual Report 2016".
k) Mibel's working and rules are based on Mercados Energéticos' notes (this a course in the Energy Engineering degree in UPV) as well as on REE's website.
l) Nord Pool's working and rules are made using information from the Ei's report "The Swedish electric and natural gas market 2017".
m) Spanish solar resource part is based on ADRASE's website and REE's report "Las energías renovables en el Sistema eléctrico español". A map with the solar resource was obtained directly.
n) Spanish wind resource part was made using information from the REE's report "Atlas eólico de España". Different maps for different heights and applying different filters are offered in this report. For this project, only the wind speed maps at 80 meters were relevant, because that is the height of the aerogenerator's tower.
o) Swedish solar resource part is based on information from the SMHI's report "Measurements of Solar Radiation in Sweden in 1983-1998". In this case, unlike in the Spanish one, there was no map with the distribution of average radiation. Therefore, the procedure consisted in using data from 10 different cities from the very south to the very north of Sweden, to have an idea of the Swedish solar resource's dependence on the location.
p) Swedish wind resource part is based on Bergström's report "Wind resource mapping of Sweden using the MIUU-model". Maps of wind speed for different heights are available there.
q) Costs part was made using different data from IRENA's reports "Renewable Power Generation Costs in 2017" and "The power to change: solar and wind cost reduction potential to 2025", IDAE's report "Plan de Energías Renovables 2011-2020" and Swedish Energy Agency's report "National Survey Report of PV power applications in Sweden 2014". Data here was addressed very carefully, since given the quick evolution of wind power and solar PV costs, data from 4-5 years ago could be already "too old". Therefore, only the newest and most reliable pieces of information, from these different sources, were taken here.

2.2 Simulation part

On the one hand, for the solar PV power stations, "PVSyst" was the software used. It can make a quick pre-design of the facility and also a much deeper design. For the purpose of this project, the pre-design was enough, although the costs offered by the software were discarded for being ridiculous, if compared with data from *3.7 Costs*. Therefore, only output energy was used from all the results given by PVSyst, while costs were estimated using all theory presented in *3.7 Costs*. It was also considered to use PVGIS to do this pre-design, but the program itself explains that its results are not reliable when simulating the behavior of a utility-scale solar PV power station. Therefore, this option was discarded.

On the other hand, for the wind power stations, Excel was used to make all necessary calculations. The option of using "Wasp" software to do this part was considered, but then it was discarded because learning how to use Wasp was too time-consuming, and the author had already experience in making this kind of wind speed calculations with Excel.

Many assumptions in the different parameters of the simulation had to be made, especially when choosing a price for the electricity sales and when estimating the installed and O&M costs, since such data is normally private and not accessible to the general public. In the case of the price, its current and past value is quite easy to obtain, but its future evolution is subject to a high grade of uncertainty, that is why the considered prices are only based on the most recent historical data (prices in 2018). Nevertheless, since all calculations are programmed in Excel, simply by adding a correction factor based on predictions of the future price, all the results would change automatically.

The aim and limits of this simulations must not be overlooked. A way more detailed analysis on every power station should be done to reach truly reliable results, while these simulations are only looking for giving some illustrative values, so that a final conclusion could be justified and based on them.

The locations selected are not intended to be neither the best nor the worst possible ones in both countries. The criterion was simply to choose locations close to Valencia and Linköping, the cities with the universities where the author has studied his degree, since data from these cities was easier to find.

Now, a detailed description of how every calculation needed for the different simulations was made is presented. First 4 points disregard the effect of the support policies, while the 5^{th} point describes how such effect was later added to the analysis.

2.2.1 Wind power station in Malmslätt (Sweden)

The wind resource for this location was extracted from the Swedish Meteorological and Hydrological Institute's website (SMHI, 2019). Its database has hourly wind speed values for several decades at 10 meters height, from which the last 35 years were considered to build the different wind speed curves. All calculations and graphs were made with Excel, and a summary of them will be shown lately in this point. The procedure was the following one:

A) How the energy generation was obtained:

1) In a first column, every hourly piece of data was classified in different whole wind speed intervals. For example, if Excel detected the value “3.5 m/s” it would add it to the “3≤V<4 m/s” interval.
2) Then, a second column contained such numbers divided by the total amount of hours of the sample, and a third one contained the accumulated values of the series.
3) Finally, one last column shows the amount of hours per year for every speed interval. (simply multiplying previous data by 8760). *Table 2.1* shows the result of this operation.

TABLE 2.1: DISTRIBUTION OF THE WIND SPEEDS IN MALMSLÄTT (AT 10 M)

speed (m/s)	total hours	rel. frequency	accumulated	hours/year
0<x<1	8347	0.03	0.03	237.28
1=<x<2	42242	0.11	0.14	963.53
2=<x<3	99672	0.19	0.32	1632.55
3=<x<4	156476	0.18	0.51	1614.76
4=<x<5	206235	0.16	0.67	1414.49
5=<x<6	243819	0.12	0.79	1068.39
6=<x<7	270305	0.09	0.88	752.91
7=<x<8	286167	0.05	0.93	450.91
8=<x<9	296051	0.03	0.96	280.97
9=<x<10	301647	0.02	0.98	159.08
10=<x<11	304806	0.01	0.99	89.80
11=<x<12	306530	0.01	0.99	49.01
12=<x<13	307380	0.00	1.00	24.16
13=<x<14	307808	0.00	1.00	12.17
14=<x<15	307988	0.00	1.00	5.12

Source: Own preparation with data from SMHI

4) This distribution can be approximated to a Weibull distribution, defined by “c” or “scale parameter” and “K” or “shape parameter”. Such parameters can be obtained from the real data, through some calculations with *Formula 2.1*:

$$F(V) = 1 - exp\left[-\left(\frac{V}{c}\right)^{K}\right]$$

FORMULA 2.1

From where:

- *V* is the wind speed
- *F(V)* is the probability of having a wind speed lower than *V*

So, using two pairs of values from the table, such as [2 m/s, 0.14] and [3 m/s, 0.32], *c* and *K* parameters can be estimated. Their values are 4.43 m/s and 2.4, respectively.

5) Now, *using Formulas 2.2* to *2.4*, *c* and *K* can be transformed into new values, which define the location’s Weibull distribution at the wanted height. In this case, the

selected height is 80 meters, corresponding with the height of the aerogenerator's tower.

$$c(z) = c_a \left(\frac{z}{z_a} \right)^{\alpha} \quad \text{FORMULA 2.2}$$

$$K(z) = \frac{K_a [1 - 0{,}088 \ln(z_a / 10)]}{1 - 0{,}088 \ln(z / 10)} \quad \text{FORMULA 2.3}$$

$$\alpha = \frac{0{,}37 - 0{,}088 \ln c_a}{1 - 0{,}088 \ln(z_a / 10)} \quad \text{FORMULA 2.4}$$

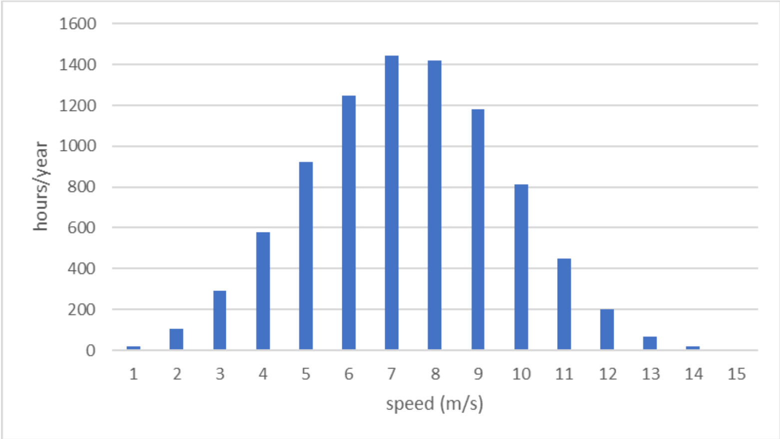
From where:

- z is the final height
- z_a is the reference height

New values for *c* and *K*, at 80 meters, are 8.14 m/s and 3.53, respectively.

6) With these values, the new Weibull distribution can be plotted:

FIGURE 2.1: DISTRIBUTION OF THE WIND SPEEDS IN MALMSLÄTT (AT 80 M)



Source: Own preparation with data from SMHI

7) Having this distribution and the power curve for the selected wind turbine, the amount of electricity that will be produced per year can be estimated. The selected aerogenerator is the Vestas' model *V90-1.8 (50 Hz)*. Its main characteristics are included in *Appendix 1*. *Table 2.2* shows the energy produced by every turbine in every speed interval, using the output power of the turbine and the amount of hours for every wind speed interval.

TABLE 2.2: OUTPUT ENERGY FOR EVERY TURBINE IN MALMSLÄTT, BY SPEED INTERVALS

V	F(V)	d(V)	hours	power AG (MW)	Energy (MWh/year)
1	0.00060	0.00211	18.51729832	0	0
2	0.00692	0.01220	106.8967397	0	0
3	0.02874	0.03340	292.6255559	0	0
4	0.07753	0.06585	576.8688987	0	0
5	0.16284	0.10530	922.4296779	0.2	184.4859356
6	0.28738	0.14239	1247.315705	0.4	498.9262822
7	0.44266	0.16469	1442.714088	0.6	865.6284526
8	0.60846	0.16238	1422.490648	0.8	1137.992519
9	0.75888	0.13485	1181.257465	1.07	1263.945487
10	0.87320	0.09266	811.6748487	1.35	1095.761046
11	0.94462	0.05155	451.5704378	1.7	767.6697442
12	0.98049	0.02265	198.4202756	1.8	357.156496
13	0.99462	0.00765	66.99944864	1.8	120.5990075
14	0.99888	0.00193	16.87905343	1.8	30.38229618
15	0.99983	0.00035	3.074367901	1.8	5.533862221
16	0.99998	0.00004	0.391639863	1.8	0.704951754
17	1.00000	0.00000	0.033701355	1.8	0.060662439
18	1.00000	0.00000	0.001889312	1.8	0.003400762
19	1.00000	0.00000	6.64538E-05	1.8	0.000119617
20	1.00000	0.00000	1.41054E-06	1.8	2.53898E-06

Source: Own preparation with data from Vestas and SMHI

From that table, the total amount of energy that every turbine produces per year can be calculated and equals to 6328.86 MWh. To reach an installed capacity of 50 MW, 28 turbines are needed, which together would produce 177207.81 MWh per year.

B) To calculate the incomes of the company

Wind speed is a random parameter, almost impossible to predict in middle or long term. Moreover, wind has its own impact on market prices, since it moves supply curve to the right, pushing down the prices. This effect is more noticeable in a system with larger wind power share of the installed capacity, like the Spanish case.
Taking this fact into account, it makes sense to consider the monthly evolution of prices:

1) The monthly average electricity price in the Nord Pool's spot market was obtained from its website. The total monthly wind power generation was also obtained from the same site.
2) Assuming that the wind power station would have a similar than the others distribution of electricity production during the whole year, the amount of energy that it will produced per month can be obtained.
3) With the pair of values (production, average price) for every month, the incomes can be calculated. They will be shown in *4. Simulation of power plants*.

C) To estimate the costs of the company, data from IRENA and Swedish Energy Agency was used. The costs per unit of power or energy considered here are along the same lines that the findings of the section *3.7 Costs*, and are the next ones:
   a. Fixed O&M cost: 25€/(kW*year)
   b. Variable O&M cost: 2€/MWh
   c. Installed cost: 1.47 €/W

2.2.2 Wind power station in Valencia (Spain)

In this case, the distribution of wind speed was directly provided, so steps A1, A2 and A3, did not have to be done. Such data appears in *Appendix 2*. Apart from that, the rest of the procedure is similar. *Table 2.3* was prepared applying the same method than in the Malsmlätt's one. Even the same turbine was selected.

The procedure to obtain the distribution of prices and wind power generation was also the same.

TABLE 2.3: OUTPUT ENERGY PER TURBINE IN VALENCIA, BY SPEED INTERVALS

V	F(V)	d(V)	hours/year	power AG (MW)	energy (MWh/year)
1	0.03495073	0.059582	521.941656	0	0
2	0.11171424	0.091308	799.8615213	0	0
3	0.21292173	0.109014	954.9588581	0	0
4	0.32595298	0.115355	1010.513062	0	0
5	0.44066375	0.112796	988.0894195	0.2	197.6178839
6	0.54943308	0.103899	910.1556575	0.4	364.062263
7	0.64717387	0.091127	798.2749308	0.6	478.9649585
8	0.73111247	0.076614	671.1383222	0.8	536.9106578
9	0.80038191	0.062024	543.3265102	1.07	581.3593659
10	0.85552304	0.048507	424.9242396	1.35	573.6477235
11	0.89798343	0.036738	321.8292138	1.7	547.1096635
12	0.9296792	0.026998	236.4992712	1.8	425.6986881
13	0.95265476	0.019279	168.8837117	1.8	303.990681
14	0.96884967	0.013395	117.3394424	1.8	211.2109963
15	0.97996279	0.009065	79.40628059	1.8	142.9313051
16	0.98739398	0.00598	52.38524166	1.8	94.29343498
17	0.99224025	0.003849	33.71647565	1.8	60.68965616
18	0.99532483	0.002418	21.18596795	1.8	38.13474231
19	0.99724217	0.001485	13.00430415	1.8	23.40774747
20	0.99840674	0.000891	7.801720446	1.8	14.0430968
total					4594.072864

Source: Own preparation with data from Vestas and Valencia's port

The considered costs per power or energy unit in this case are the following ones, also based on *3.7 Costs*:

- Fixed O&M cost: 40€/(kW*year)
- Variable O&M cost: 2€/MWh
- Installed cost: 1.3€/W

2.2.3 Solar PV station in Norrköping (Sweden)

For the solar PV power stations, as it has already been said, a specialized software called PVSyst was used. Both facilities are configurated with the exact same parameters, but the tilt angle, which is 45º in Valencia and 60º in Norrköping, due to technical and energy reasons. On the one hand, a tilt angle that is close to the latitude angle of the selected location improves the collection of energy, while a slightly higher tilt angle makes the collection of energy more even during the whole year (see *3.6.1 Solar Resource in Sweden*). On the other hand, 45º and 60º are standards in PV facilities, so this selection may reduce installed cost, compared to a different configuration with angles like 42.5º or 61.5º, for example.

Now it follows a brief description of the procedure to pre-design the solar PV station in Norrköping:

1) The first part consisted in obtaining the electricity that the power station would produce in Norrköping, introducing some parameters in PVSyst. *Table 2.4* shows a summary of the main parameters that determine the configuration of the power station. All parameters were equal in both power stations, but the tilt angle.

TABLE 2.4: PARAMETERS OF THE SOLAR PV POWER STATIONS

Module type	Standard
Technology	Monocrystalline cells
Mounting method	Ground based
Ventilation	No ventilation
PV-field nominal power (STC)	50 MW

PVsyst's output data is showed in *Appendix 3*.

2) With the output data, electricity production by month is obtained. However, taking the same prices than in the case of wind power would not be accurate enough, since solar PV technology only can produce electricity during the day, so there is no point in considering the monthly average price for the whole day. Therefore, what was done here was to calculate the average price per month but using only the period of time when the sun is up (between sunrise and sunset). *Table 2.5* shows the period of time considered for every month and the resultant average price:

TABLE 2.5: AVERAGE PRICE PER MONTH FOR SOLAR PV IN NORRKÖPING

Month	hours	Price for PV (€/MWh)
Jan	9->16	35.02
Feb	8->17	42.21
Mar	6->18	48.35
Apr	6->18	40.38
May	4->21	35.01
Jun	4->22	45.34
Jul	4->22	53.30
Aug	5->21	56.77
Sep	6->19	53.25
Oct	8->18	46.91
Nov	8->15	52.08
Dec	9->15	54.19

Source: Own preparation with data from Nord Pool

3) With the energy produced per month and the considered average price per month, the incomes can be calculated. The results are in *4. Simulation of power stations.*
4) Regarding costs, *Table 2.9* shows their considered breakdown. In this case, installed costs must be justified. Since almost all obtained data about costs belongs to reports from 2016 or earlier, but the Fraunhofer-Gesellschaft's one, which belongs to 2018, the selected installed cost is 800€/kW, which is the maximum value for German utility-scale solar PV stations in this report. If the reader wonders why not other values were chosen instead, the reason is that, as it is explained in *3.7.2 Solar PV Costs*, solar PV technology advances faster than expected, so data from 2016 is not very reliable nowadays.

TABLE 2.6: COSTS BREAKDOWN FOR SOLAR PV POWER STATION IN NORRKÖPING

Type of Cost	Value
Installed costs	
Module	0.408 €/W
BoS	0.304 €/W
Inverter	0.072 €/W
Installed cost/W	0.80 €
Total installed cost	40,000,000 €
O&M costs	
O&M per kW	20 €
Total O&M cost	1,000,000 €

Source: Own preparation with data from IRENA and Fraunhofer

2.2.4 Solar PV station in Valencia (Spain)

The procedure was exactly the same than in the Swedish case, so tables with some results are directly presented.

- *Table 2.7* shows the considered price per month for solar PV in Spain.

TABLE 2.7 AVERAGE PRICE PER MONTH FOR SOLAR PV IN VALENCIA

Month	hours	Price for PV (€/MWh)
Jan	8->18	63.70
Feb	8->19	53.66
Mar	7->19	48.98
Apr	7->21	50.47
May	7->21	55.51
Jun	7->22	59.15
Jul	7->21	62.85
Aug	7->21	65.94
Sep	8->20	72.89
Oct	8->19	67.04
Nov	8->18	63.70
Dec	8->18	63.70

Source: Own preparation with data from REE

The considered costs in this power station were equal to the costs in the Norrköping's power station.

2.2.5 Adding the support policies to the analysis

For the Swedish projects, the method to consider the effect of support policies is simply to add the electricity certificates sales to the incomes of the power station. This will not affect costs, but since the incomes will be quite higher, the profitability will improve.

For the Spanish projects, the only support considered was a certain subsidy to pay the investment cost, based on the administrative resolution of July the 27^{th}, 2017, that shows the results of the auction of 3000 MW of renewable power organized one month before.

2.2.5.1 Electricity Certificates Price in 2018

Since the price of the electricity certificates is as much or even more fluctuating than the price of electricity itself, there will be a high grade of uncertainty here. Yet, to offer some concrete numbers, monthly average prices during year 2018 were considered in the new profitability calculations. *Table 2.8* shows such prices.

TABLE 2.8: EVOLUTION OF ELECTRICITY CERTIFICATE PRICES

Month	Price (SEK/certificate)	Price (€/certificate)
january	81.00	7.87
february	100.00	9.72
march	97.00	9.43
april	145.00	14.09
may	176.00	17.11
june	152.00	14.77
july	197.00	19.15
august	270.00	26.24
september	233.00	22.65
october	150.00	14.58
november	170.50	16.57
december	163.00	15.84

Source: Own preparation with data from Svensk Kraftmäkling

Another parameter to consider is the ratio sold certificates/issued certificates. Since the demand in this market depends on the quota obligation and the electricity consumption of the large consumers, it is very difficult to estimate how many of the certificates that the power stations will obtain are going to be sold in the market.

In this project, the ratio considered was equal to the quotient cancelled certificates / issued certificates in *Table 3.3* in point *3.3.6 Support for renewables in Sweden*. This value is:

$$R \approx \frac{Cancelled\ Certificates\ (2015)}{Issued\ Certificates\ (2015)} = \frac{12.8}{21.8} = 0.59$$

2.2.5.2 Subsidies for solar PV and wind power stations in Spain in 2017

In the case of Spain, certain subsidies for the investment will be considered now. Such subsidies will be assumed to be the same than the resultant ones from the renewables auction in 2017, whose results are summarized in order ETU/315/2017.

Such auction resulted in the next values of subsidies:

- For wind power stations: 47,684 €/MW
- For solar PV power stations: 39,646 €/MW

Given the installed capacity of the power stations (50 MW), these values give the next final subsidies:

- For the wind power station: 2,384,200 €
- For the solar PV power station: 1,982,300 €

3. STATE OF ART

In this section, all the theories that are used in other parts of this report will be described. To do a proper analysis of both markets, it is crucial to understand different aspects of both countries. It is necessary to have a general comprehension of how the electric power is sold in the wholesale market and what price it usually has, to have in mind which factors determine the availability and potential of a renewable energy source and what costs can be expected from such kind of projects. Therefore, now it follows a series of explanations to all these subjects and more.

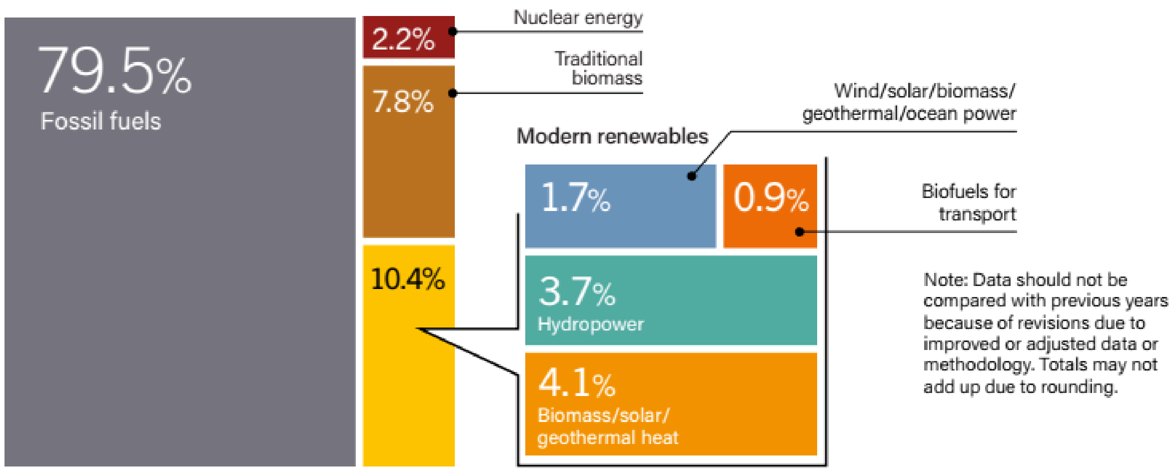
3.1 GLOBAL OVERVIEW ON RENEWABLE ENERGIES

In this part, a general overview of the global energy consumption will be presented, together with a brief analysis of the renewable installed capacity evolution.

3.1.1 Global Energy Balance

REN21 is "*the global renewable energy policy multi-stakeholder network that connects a wide range of key actors*" (REN21, 2019). After analyzing data from one of its reports (REN21, 2018) it can be said that, undoubtedly, the global energy system is still clearly based on oil, coal and natural gas. As *Figure 3.1* shows, almost 80% of total final energy consumption comes from fossil fuels, while renewable energies, both modern and conventional, share 18.2%. Nuclear energy presents 2.2% of total final energy consumption.

FIGURE 3.1: ESTIMATED RENEWABLE SHARE OF TOTAL FINAL ENERGY CONSUMPTION, 2016



Source: REN21

Taking a deeper look into renewable energies, it can be seen that the modern ones (solar PV, wind power, ocean power, geothermal, etc.) add just 1.7% of total energy use (electricity only), while hydropower and biomass represent almost all the remaining 16.5%.

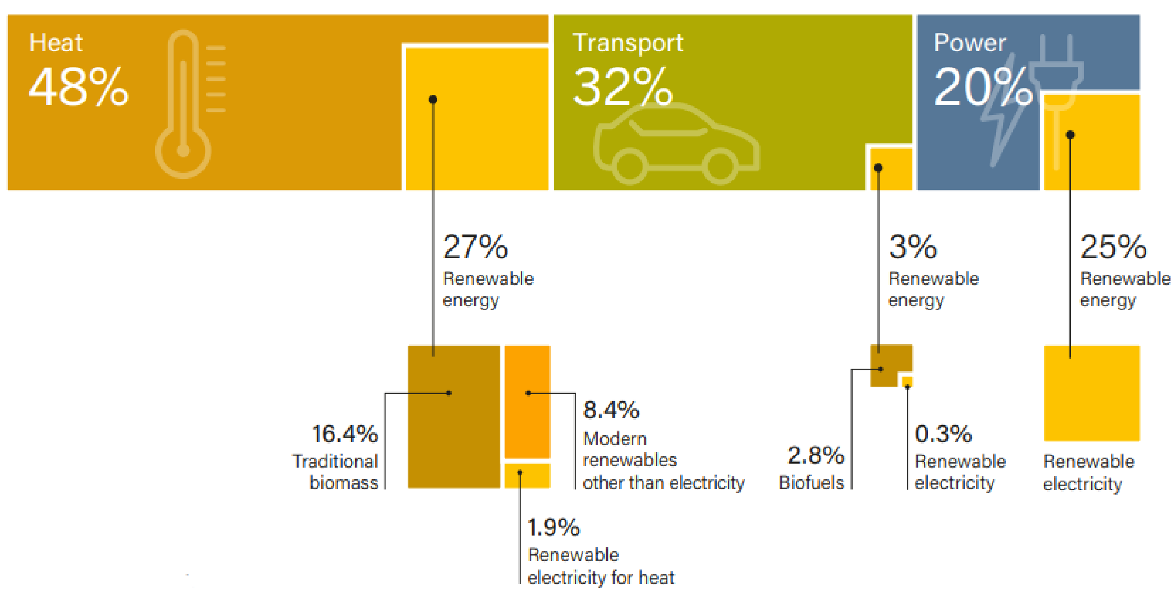
Figure 3.2 the involvement of renewable energies in the total energy consumption in 2015, by sectors. Firstly, the transport industry accounts for almost one third of total energy consumption, and as it could be expected, it is the sector where renewable energies have the least importance for now.

There is no relevant use of biofuels in aviation yet, while in marine transport, the Marine Environment Protection Committee approved a roadmap in 2017 to reduce greenhouse gases emissions from ships (REN21, 2018)

In road transport, different countries have launched their own projects to reduce greenhouse gases emissions from vehicles by raising the consumption of biofuels or the sales of electric vehicles, like the EV100 project in the US (REN21, 2018). On the other hand, in 2017 there were more than 3 million electric passenger vehicles worldwide. However, the reader should not forget that electric cars only save emissions if the electricity they use has been produced with non-polluting energies (REN 21, 2018).

Secondly, heating represents 48% of the total energy consumption, from which approximately one half goes for industrial processes and the other half for use in buildings. According to *Figure 3.2*, 27% of heat was produced with renewable energy, especially biomass. The importance of biomass in this sector can be easily attributed to the fact that it

FIGURE 3.2: RENEWABLE ENERGIES BY SECTORS (2015)



Source: REN21

is a traditional source of energy that has been used by humans for thousands of years. The problem here is that normally the traditional use of biomass becomes very inefficient, so the amount of useful heat that people get is low compared to the energy that could be extracted from biomass. Therefore, even if advanced technology is not needed to burn biomass, it could improve greatly the efficiency of this process.

There are three ways in which renewable energy can contribute to heating and cooling.

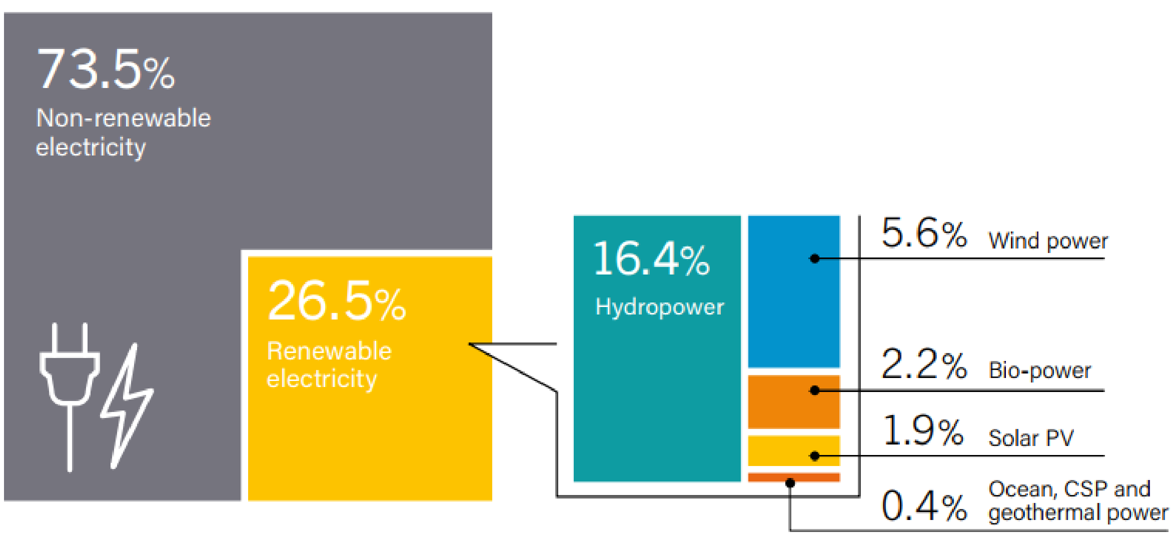
- Using other sources of heat, like geothermal and solar thermal energy
- Using electricity produced with any renewable energy source
- Using biomass as the fuel to burn (although it would be better if using a high efficiency boiler)

Finally, electricity represents 20% of total final energy consumption, from which 25% is produced with renewable energy. *Figure 3.3* shows the renewable energy share of global electricity production for 2017 (REN21, 2018).

Hydropower is by far the most important renewable source of energy for power worldwide, accounting for 16.4% of total electricity production. Secondly, wind power produced 5.6%, followed by bio-power and solar PV, with 2.2% and 1.9%, respectively. Ocean, Concentrating Solar Power and geothermal power only produced 0.4% all together.

Moreover, 17 countries generated more than 90% of their electricity using renewable resources in 2017. Being true that most of such electricity came from hydropower (which is renewable but conventional), in Uruguay, Costa Rica and Ethiopia wind power had also a significant production (REN 21, 2018).

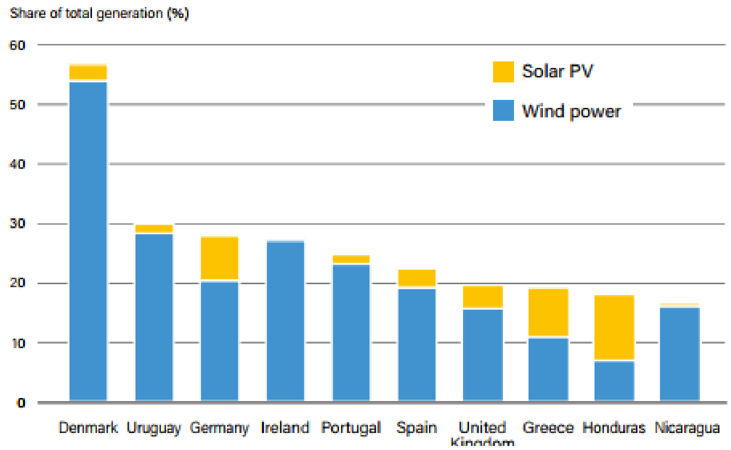
FIGURE 3.3: RENEWABLE ENERGY SHARE OF GLOBAL ELECTRICITY PRODUCTION, 2017



Source: REN21

Figure 3.4 offers a deeper insight of solar PV and Wind power in some countries where they both have acquired much importance. For example, in Denmark wind power accounted for more than half of the total electricity produced in 2017. On the other hand, bigger countries like Germany or Spain managed to produce 28% and 23% of their electricity with solar PV and wind power, respectively (REN 21, 2018).

FIGURE 3.4: SHARE OF ELECTRICITY GENERATION FROM VARIABLE RENEWABLE ENERGY, TOP 10 COUNTRIES, 2017



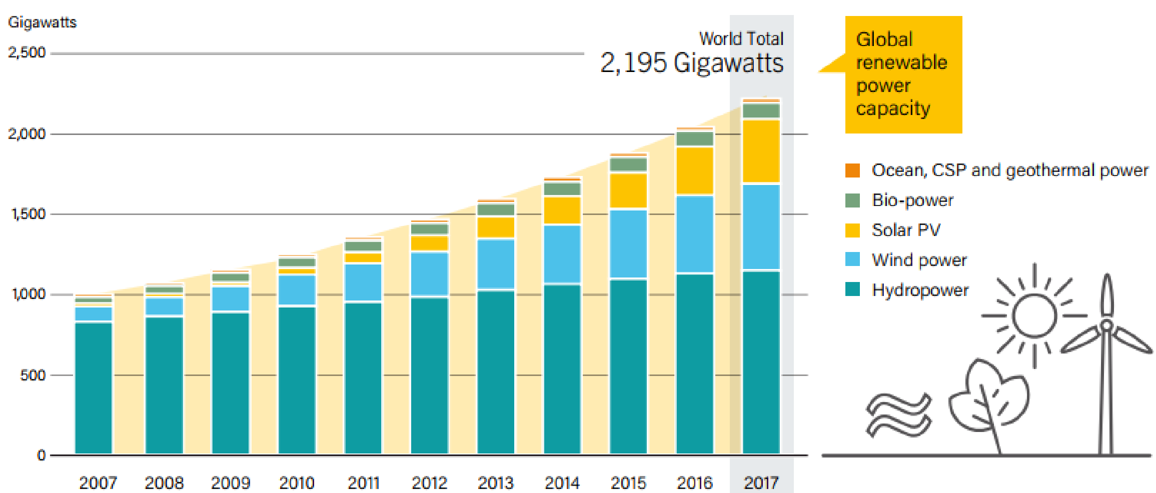
Source: REN21

3.1.2 Global Renewable Power Capacity

Regarding power capacity, in *Figure 3.5* it can be observed how non-hydropower renewable energies have been growing rapidly in the last 10 years. Even taking hydropower into consideration, total renewable power capacity was more than doubled in this period of time.

There was a global investment in renewable energies of almost $280 billion ($127 billion only in China) in 2017 (Frankfurt School-UNEP Centre, 2018).

FIGURE 3.5: GLOBAL RENEWABLE POWER CAPACITY, 2007-2017



Source: REN21

It is estimated that only in 2017, 178 GW of renewable power were installed worldwide, being the biggest annual growth ever. Solar PV and wind power accounted for 55% and 29% of such new power capacity, respectively. This proves that they are the most profitable non-conventional sources of energy. With this, 2017 closes with around 2195 GW renewable power capacity worldwide.

This growth can be explained through different factors, such as the rising electricity demand in some countries, support mechanisms from governments and continuing cost declines. The evolution of such costs will be explained more in detail in *3.7 Costs*.

Europe has been one of the continents where renewable energies have been developed the most. In 2017 they generated 30% of total electricity and 85% of newly installed power capacity was renewable. However, this growth is not equal in all the countries. Germany and the UK accounted for 57% of the EU's renewable capacity expansion between 2014 and 2017. (REN 21, 2018)

3.2 PAST AND PRESENT OF THE SPANISH' ENERGY SYSTEM

Spain is a country with many different good sources of renewable energy. The Iberian Peninsula is located between 36 and 42 degrees north. That is close enough to the equator to be one of the countries in Europe with the best solar resource per km^2 (Hernández, 2018).

The wide mountain systems across the Iberian Peninsula provides it with many air streams that can be used by onshore wind farms. Precisely for being made of a big peninsula and two archipelagos, Spain has thousands of kilometers of coast, so there are many places to build offshore wind farms too (IDAE, 2011)

Moreover, since an important part of the Spanish economy is based on agriculture and livestock, there is a large amount of agricultural biomass, added to all the wood that can be extracted from the Spanish forests in a sustainable way.

Further information will be given in point *3.5 Renewable energy resources in Spain.*

On the other hand, Spain barely has reserves of oil, natural gas and coal, so it depends strongly on external supply. Actually, 99.9% of oil and natural gas that is currently used in Spain is imported (APPA, 2017)

Due to its high energy dependence on other countries, the government has been promoting renewable energies in Spain for several years, in an attempt of taking advantage of the large resource there is in this country.

3.2.1 Energy balance

The Spanish energy system is definitely still based on fossil fuels. As *Figure 3.6* shows, oil accounts for 52% of the total final energy consumption, which, together with coal and natural gas, sums 70% (678 TWh). Electricity is the second largest energy carrier, with 24% (235 TWh), and the rest is based on biomass (5%, 47 TWh), other renewables (1%, 6 TWh) and wastes (0%, 0.1 TWh).

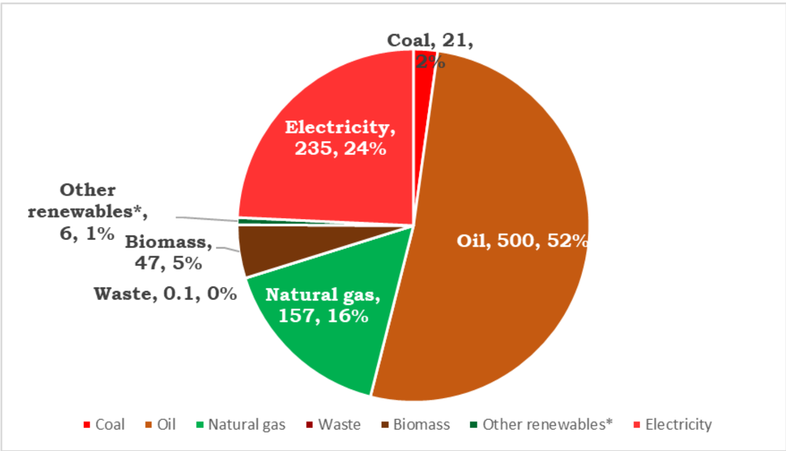
Figure 3.7 shows the distribution of final consumption in Spain, by sectors.

The distribution of the final energy consumption results in 229 TWh (22.8%) for the industry sector, 450 TWh (44.8%) for the transport sector and 326 TWh (32.4%) for services, residential sector, fishing, agriculture and others.

Regarding industrial sector, it is the one with the most heterogeneous consumption, with similar use of electricity and natural gas (35% each one). Oil and coal are also important within this sector (14% and 9%, respectively). Finally, biomass has some relevance as well, with 7% of total consumption.

The transport sector is still strongly dependent on oil, which accounts for almost all its consumption (88%).

FIGURE 3.6: FINAL ENERGY CONSUMPTION, BY TYPE OF ENERGY, IN SPAIN, 2017 (TWH)



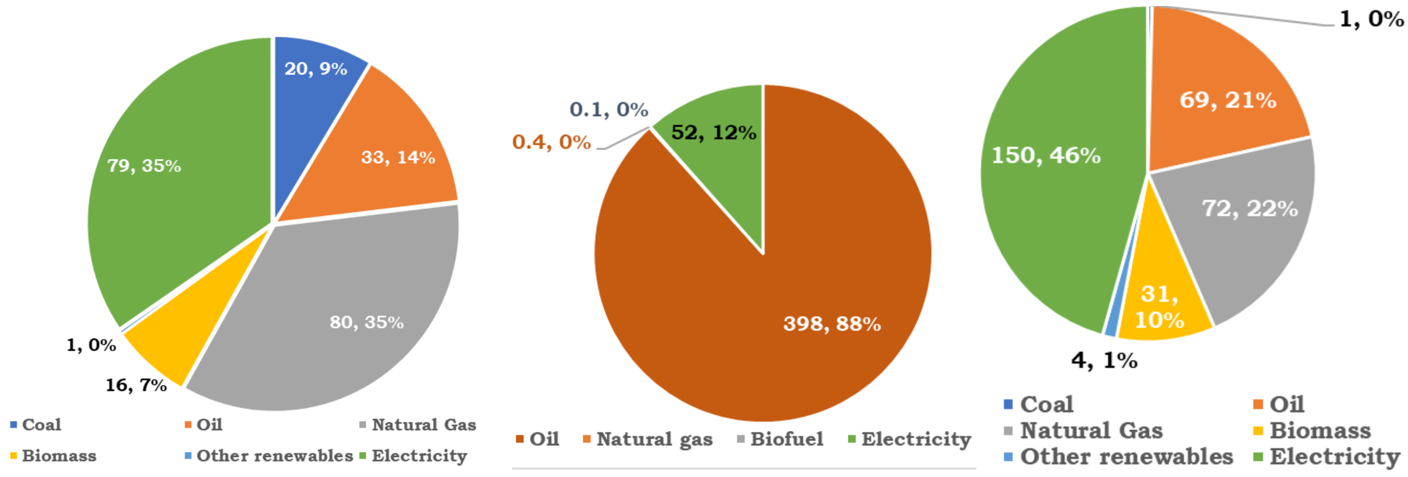
Source: Own preparation with data from IDAE

*Solar Thermal, Geothermal, Biogas, Charcoal, Biofuel

The only significant alternative is electricity, with a share of 12%. However, electric vehicles still do not have a remarkable share of the private means of transport. Such 12% (52 TWh) correspond mainly to public transport, such as trams, metros or trains.

Finally, in the service, residential and "others" sector, electricity becomes the most important source of energy, with 46% of the total consumption, while oil, natural gas and, to a lesser extent, biomass; are also significant, with a share of 21%, 22% and 10% of the total consumption, respectively (IDAE, 2019).

FIGURE 3.7: FINAL ENERGY USE IN INDUSTRIAL (LEFT), TRANSPORT (MIDDLE) AND VARIOUS USES* (RIGHT) SECTORS. 2016, TWH.



Source: own preparation with data from IDAE

*Residential, services, fishing, agriculture, livestock and others

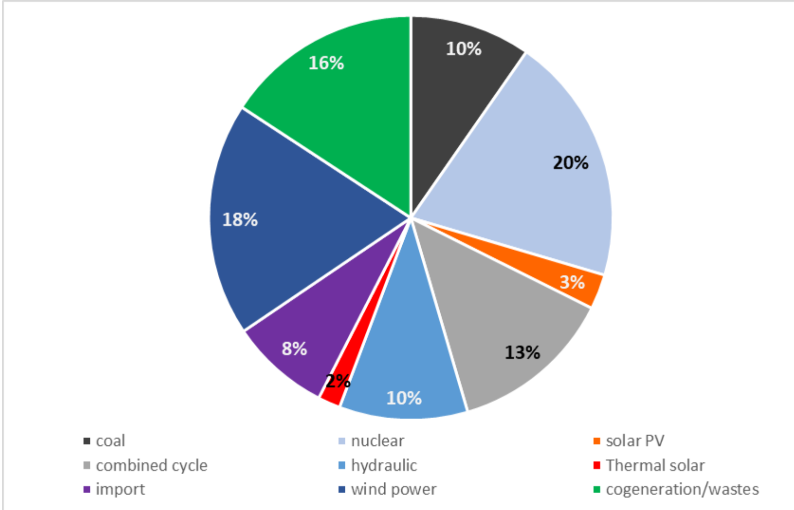
3.2.2 Electricity Generation

To contextualize this report, the first step when analyzing an electricity market is going to be to look at the volume of energy and money that are traded on it. According to official data from OMIE (description of OMIE in *3.4.1 Mibel*), in year 2018 the total amount of energy traded in the spot market (day-ahead and intraday markets) was more than 276 TWh, from which 237 were traded on the day-ahead market, and the rest in the intraday market. The value of such amount of electricity was more than €16 billion. Only in Spain, the energy traded was more than 216 TWh.

In *Figure 3.8*, the distribution of electricity generation for 2018 and 2017 can be observed.

The distribution of electricity generation in Spain is quite heterogeneous, according to the picture. The differences between both years can be understood by knowing that 2017 was one of the driest years in the recent history of Spain and, therefore, water reserves were not enough to produce the usual amount of electricity. As it will be shown later, the new power capacity installed in 2018 was not big enough to have a significant impact in the distribution of electricity generation.

FIGURE 3.8: ELECTRICITY GENERATION BY TECHNOLOGIES IN SPAIN



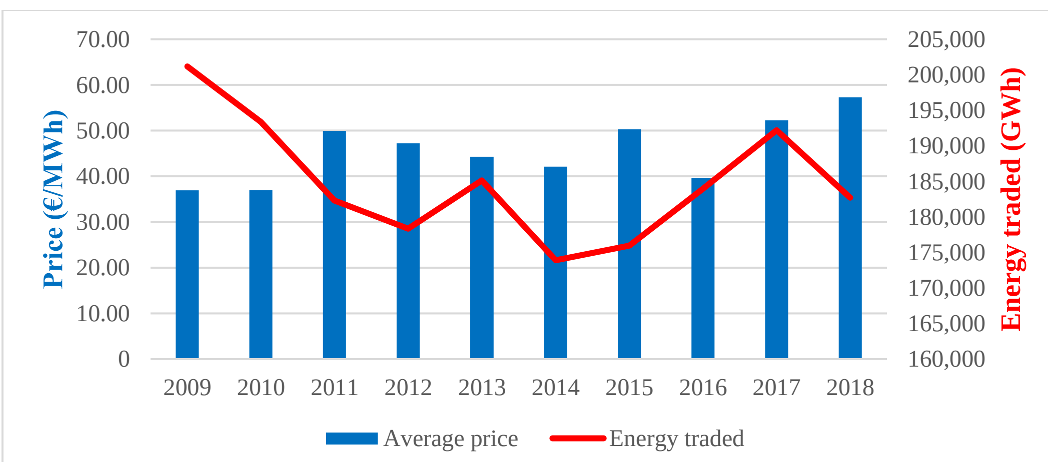
Source: own preparation with data from OMIE

The electricity produced with renewable energies accounts for 46.1% of the total produced, which, adding the electricity from nuclear power stations, results in a 66% of free-emissions electric energy (OMIE, 2018).

3.2.3 Price evolution in the spot market

Most of the electricity used in Spain is traded on the Mibel's spot market, managed by OMIE (see *3.4.1 Mibel*). Therefore, to observe price of the MWh in the day-ahead market is a good way to discover what prices an electricity producer can expect to get paid for its energy. In *Figure 3.9* we can see the evolution of both the average price and the energy traded in the day-ahead market in Spain.

FIGURE 3.9: PRICE AND ENERGY TRADED IN DAY-AHEAD MARKET. EVOLUTION FROM 2009

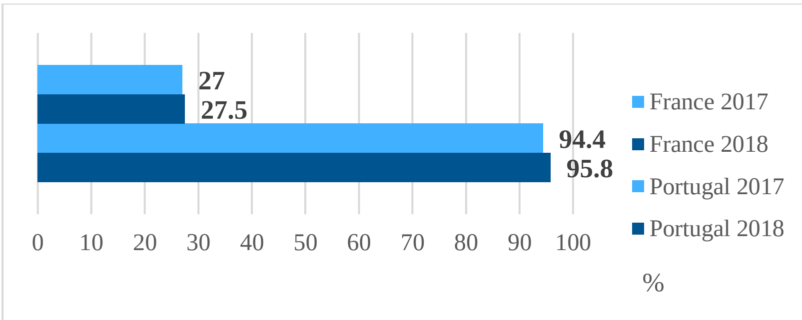


Source: Own preparation, based on data from OMIE's website.

3.2.4 Shared price with Portugal and France

Portugal is the other region inside Mibel, together with Spain. When two regions are connected so that electricity interchange is possible between them, it is common that the region with the lowest price sells energy to the other one, until they both have the same price or until the interconnections get collapsed, whatever happens before (Alcázar 2019). In other words, having good connections with other countries influences the price and pushes the electricity producers to be more competitive.

FIGURE 3.10: TIME WITH A SIMILAR PRICE IN SPAIN AND PORTUGAL AND FRANCE



Source: Own preparation with data from OMIE's website

In the case of Spain and Portugal, the interconnections are prepared to conduct huge amounts of electricity, so they share the energy price during most of the year, as *Figure 3.10* shows.

On the contrary, it is much less common that France and Spain have similar prices. This is due to the fact that France's electricity price is normally quite lower than Spanish' one, since the nuclear power-based electric system in France has managed low prices in this country. Therefore, the connection network between Spain and France gets collapsed often and both countries have different prices.

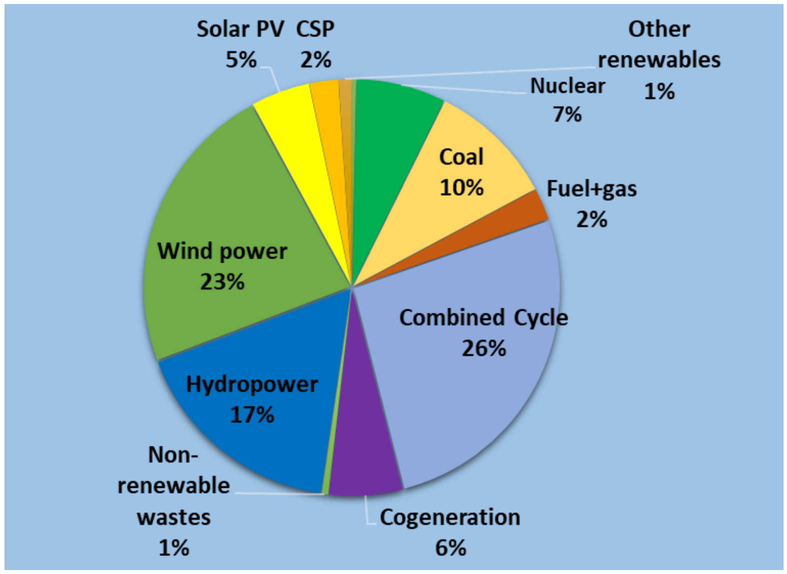
3.2.5 Installed power capacity

As it can be observed *in Figure 3.11*, the total installed power capacity in Spain is 104,122 MW. 46.3% belongs to renewable energies, from which almost one half (22.2% of the total) is wind power. Hydropower accounts for 16.4% of total installed power. Apart from that, the rest of renewable technologies still do not represent a big part of the installed power capacity.

The most widespread technology is combined cycle, offering a high-efficiency solution when the demand is high enough to raise the prices over its fuel's costs.

One striking piece of information is that Spain is the world leader in Concentrating Solar Power, with 2.3 GW, although the tendencies show that it may lose its position soon, in front of the US or China development in this field.

FIGURE 3.11: BREAKDOWN OF INSTALLED POWER CAPACITY IN SPAIN, AT THE BEGINNING OF 2018.



Source: Own preparation with data from REE

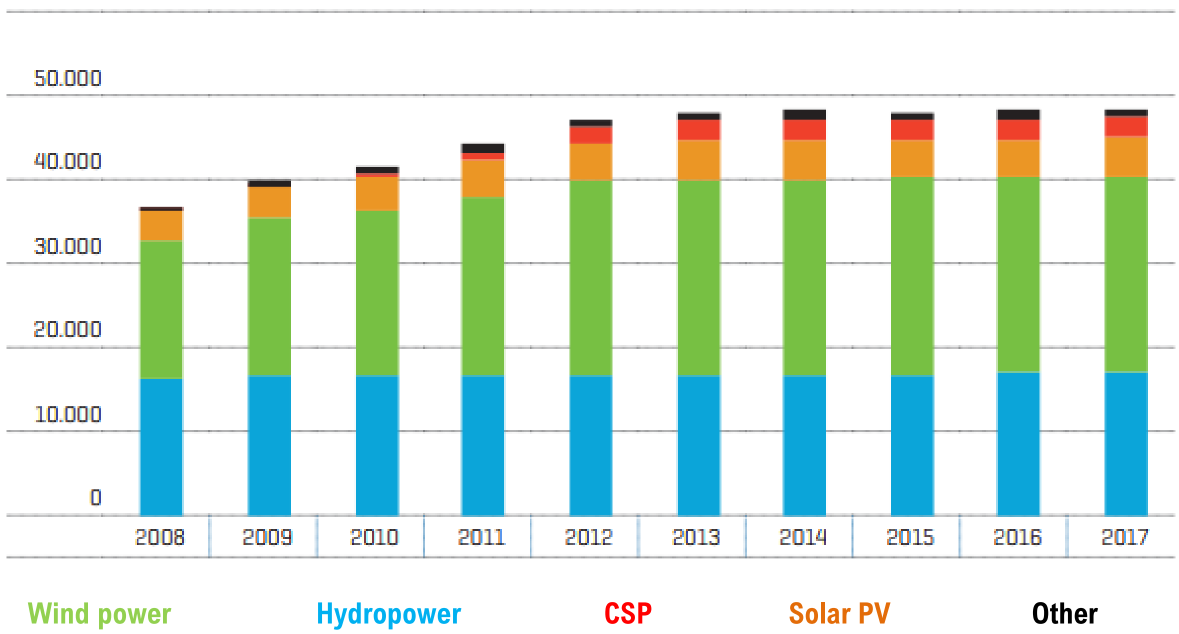
3.2.6 Support systems for renewables

The support system for renewable energies has been a very controversial issue in Spain. Many laws and royal decrees have been written to manage how the State faces the renewable energies challenges, being decisive in their development. In the past, when the current legislation was favorable to renewable energies, the investments were generous and plentiful; but when it turned less helpful, the renewables growth broke suddenly.

Supporting renewable energies with legislation from 2004 (royal decrees 436/2004 and 661/2007, among others), Spain started to use a Feed-in Tariff model. In 2007, power stations in Spain classified as "special regime" (that is, renewable energies, high efficiency cogeneration and wastes) received a special bonus for every MWh sold, whose value depended on the electricity price in the spot market. With such bonus, the lowest price that electricity from renewable sources could get was 73€/MWh. Consequently, the business became very profitable, and many companies started to invest in the sector.

However, a few years later, in 2013, a new government claimed that such situation was economically unsustainable, so the system was changed retroactively to reduce the public debt. With the law 24/2013 of the electric sector, supported by the royal decree 1/2012, the royal decree-law 9/2013 and the order ETU/315/2017, among some others, the Feed-in Tariff was over in Spain. Since then, the system changed to the current model, which may also be modified in the next years by the new government. *Figure 3.12* shows how the tendency changed in 2013, stopping the renewable growth of the previous years (REE, 2017).

EVOLUTION OF RENEWABLE INSTALLED CAPACITY (MW)



Source: REE

With the current system, as law 24/2013 says, the companies can get investment aids and a lower limit for the selling price of the electricity they produce. The system tries to favor the most competitive companies, through a public auction.

The companies present their new projects of power stations in the public auction, announced by the government. They must indicate the exactly amount of power they want to install and the percentage of the investment aid they are prepared to renounce to, so the bids are ordered according to this percentage, until the capacity that the government is auctioning gets completed. In other words, the companies that renounce to the biggest percentage of investment aids are more likely to get into the capacity fixed by the government and, therefore, receive the subsidy.

The starter subsidy is calculated from the investment and other costs of a hypothetical power station of every kind. Then, after the auction takes place, a certain percentage of this investment would be covered with such subsidy. To understand this better, now it follows an example:

1) The government calculations conclude that a standard wind power station will need an investment of 1,200,000 €/MW and the subsidy would cover up to 155,000 €/MW. That is, 12.92% of the investment.
2) When the public auction takes places, different companies present their different projects, with the percentage they are prepared to renounce to.

3) Such bids are sorted, from the one that renounced to the highest percentage to the one that renounced to the lowest percentage.
4) The power capacity auctioned fixes the limit for the last project in getting the subsidy.
5) The percentage of the initial subsidy that this last project was prepared to renounce to fixes the final subsidy for every project. For example, if this last project wanted to renounce to 6.92% of the subsidy, all the projects that were prepared to renounce to a higher percentage will get 12.92-6.92=6% of 1,200,000 €/MW installed, that is, 72,000 €/MW.

On the other hand, the before mentioned "lower limit" is some kind of bonus that the projects that managed to get the subsidy also will receive. The bonus would only cover the difference between the incomes of the power station and the costs, when the latter are higher than the former.

3.3 PAST AND PRESENT OF SWEDISH ENERGY SYSTEM

Swedish energy system is based on electricity, biofuels and oil. It has 3 large nuclear power stations that produce about 40% of the electricity every year and many hydroelectric power stations that take advantage of its plentiful hydric resource.

District heating has replaced oil as the main heat carrier for residential and service sector. Several cities in Sweden have their own CHP stations that burn wastes, biomass or oil to produce both heat and electricity, while they are removing residues simultaneously.

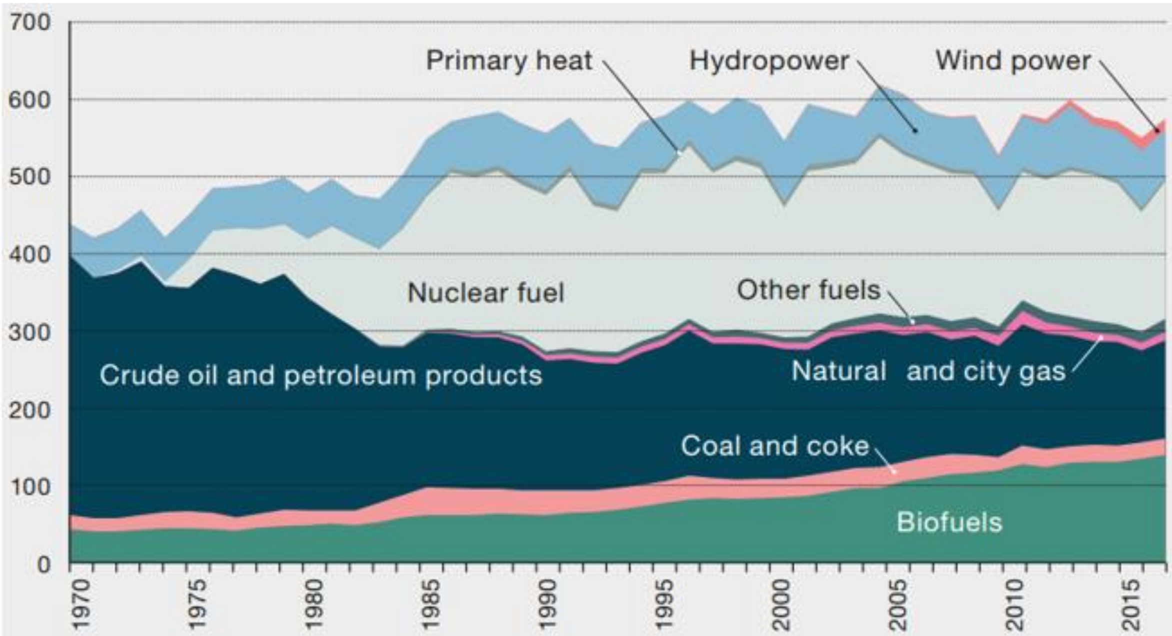
Like in the Spanish case, Sweden does not have any relevant coal, natural gas or petrol production, so nuclear power and renewable energies seem to be the best solution to meet the energy demand in this country.

3.3.1 Energy balance

Any country's final energy use can be divided in three sectors: transport, industry and service and residential sector. The two last ones have typically similar demand. As an example, in 2016, the industrial sector consumed 142 TWh and the residential and service sector consumed 146 TWh, while the transport sector used 87 TWh (total: 375 TWh). *Figure 3.13* shows the evolution of supplied energy from 1970 to 2016, by technologies. There was a notable increment during the 80s and since then the total consumption has remained practically even, with a faint decrease in the last years, probably due to the government's and companies' effort to increase energy efficiency (Swedish Energy Agency, 2018).

It is also noted how the nuclear power became one of the main sources of energy for the Swedish system from the 70s.

FIGURE 3.13: EVOLUTION OF SUPPLIED ENERGY IN SWEDEN (TWH)

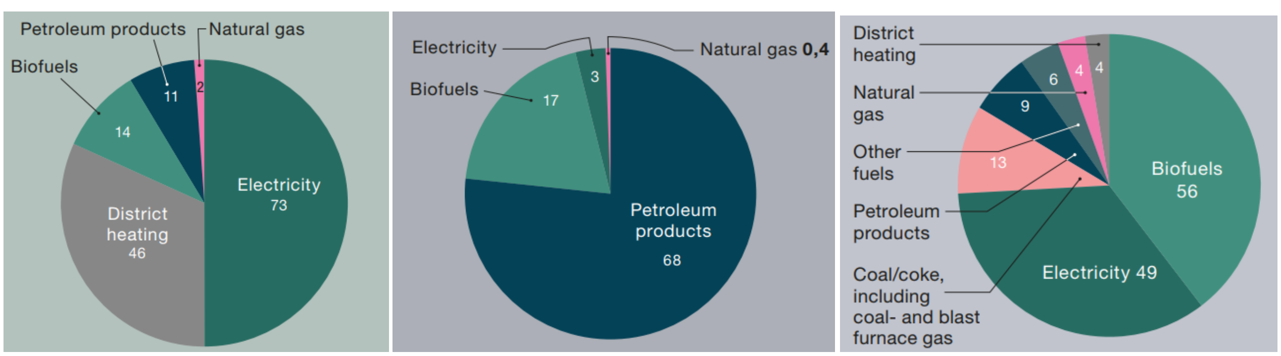


Source: Swedish Energy Agency

On the other hand, the consumption of petroleum products and crude oil has been reduced, in front of a larger use of biofuels, while coal and coke has remained approximately constant. This happened partly because many small heating facilities in residences were no longer used after district heating was implemented in many cities.

Regarding renewable energies for electricity generation, hydropower has had a constant and relevant use as well, while wind power acquired certain degree of importance since 2010.

FIGURE 3.14: FINAL ENERGY USE IN RESIDENTIAL AND SERVICE (LEFT), TRANSPORT (MIDDLE) AND INDUSTRIAL (RIGHT) SECTORS. 2016, TWH.



Source: Swedish Energy Agency

Firstly, in the residential and service sector one half of the final energy consumption is electricity, which is mainly produced with renewable energies and nuclear power, as it will be explained later. More than one fourth is district heating, which normally comes from big power stations that usually use biomass as fuel. The rest is covered with biofuels, petroleum products and natural gas. Thereby, it could be said that this sector is the least polluting, being based in electricity and biomass.

Secondly, regarding the transport sector, it is still based on petroleum products, such as gasoline and diesel. They account for more than three fourths of total consumption, which is filled up with biofuels (19.2%), electricity (3.4%) and natural gas (0.45%). Therefore, transport sector is the most polluting in the Swedish energy system, even if the use of biofuels is more extended than in many other countries. Electric vehicles have not achieved meaningful numbers yet.

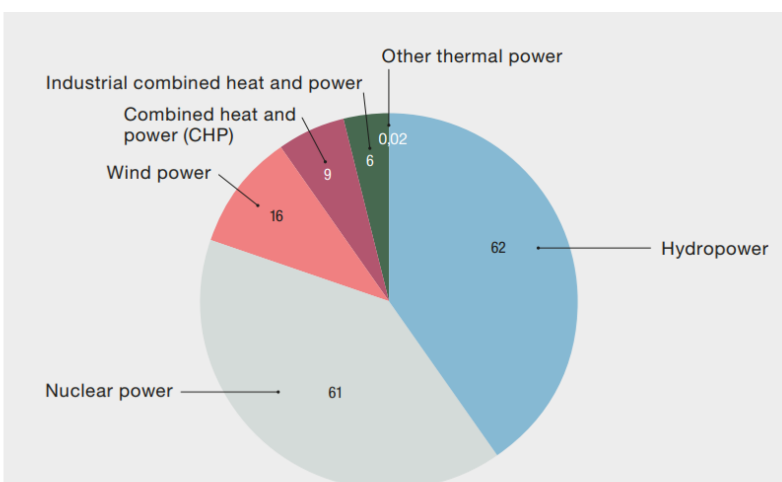
Finally, the industrial sector is the most heterogeneous one. Approximately one third of its total consumption comes from electricity and another third comes from biofuels, which are often produced in the same factory they are consumed. The rest of the consumption is a mix of petroleum products, natural gas, coal and coke, district heating and other fuels. One particularity in the Swedish industrial sector is that half of its total consumption comes from the pulp and paper industry (Swedish Energy Agency, 2018).

3.3.2 Electricity Generation

Figure 3.15 shows the distribution of electricity generation in Sweden in 2016. More than 40% was produced in nuclear power stations and another 40% was produced with hydropower. Wind power accounted for 10% and the rest was Combined heat and power, from both power stations and industries.

Hydropower is not only important for producing more than 40% of the total electricity in Sweden, but also for its balancing function, since it is used to store energy when the supply

FIGURE 3.15: ELECTRICITY GENERATION IN SWEDEN BY TECHNOLOGIES, 2016



Source: Swedish Energy Agency

is higher than the demand and then use the reserves to produce electricity when the demand is overcoming the supply. Its versatility is such that it can be used to correct the frequency of network when it is differing from 50 Hz.

3.3.3 Price evolution in the spot market

Prices in the Swedish spot market are known for being some of the lowest ones in Europe. This may be due to the fact that Swedish electric generation system is based on hydropower and nuclear power, two of the cheapest sources of electricity. The system is divided into 4 sectors, which can have different prices, although commonly they are all very similar.

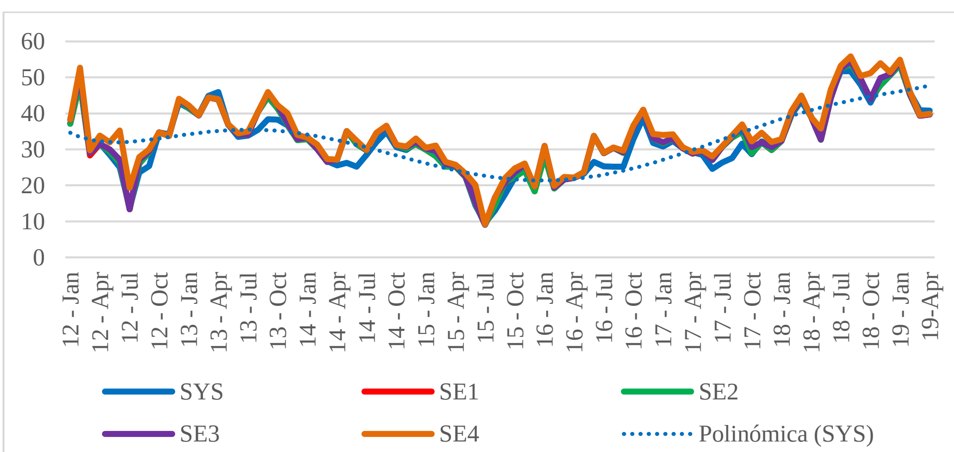
As it can be seen in *Figure 3.16*, all the prices of the different sectors ("SE-X") are close to each other during all the sample. "SYS" means "System Price". It represents the price that there would be in the whole Nordic market if there were no physical limitations in the network. That is, if the interconnections between all the countries could conduct as much energy as needed to reach the same price in every country of the Nord Pool. It is the main reference for traded long term financial Nordic contracts (Nord Pool, 2019).

The dotted line shows the tendency of the price's evolution. The tendency in the last 3 years seems to be increasing.

The majority of the electricity produced in Sweden comes from the north of the country, while the largest use is in the south. This creates small differences in price between Sectors 1 and 2 (north) and sector 3 and 4 (south).

The latter ones tend to be higher, as it can be observed in the *Table 3.1* (Nord Pool, 2019). Lowest minimum, maximum and average prices are sector 1, while the highest ones are in sector 4, due to the law of supply and demand effect already commented.

FIGURE 3.16: PRICE EVOLUTION IN THE SPOT MARKET IN €/MWH, BY SECTORS. (2012-2019)



Source: own preparation with data from Nord Pool 2019

TABLE 3.1: MINIMUM, MAXIMUM AND AVERAGE PRICES IN SWEDEN (2012-2019)

€/MWh	SYS	SE1	SE2	SE3	SE4
min	9.55	9.07	9.07	9.07	9.19
max	53.78	53.73	53.73	54.53	55.85
average	32.1	33.06	33.067	33.466	34.39

Source: own preparation with data from Nord Pool's website

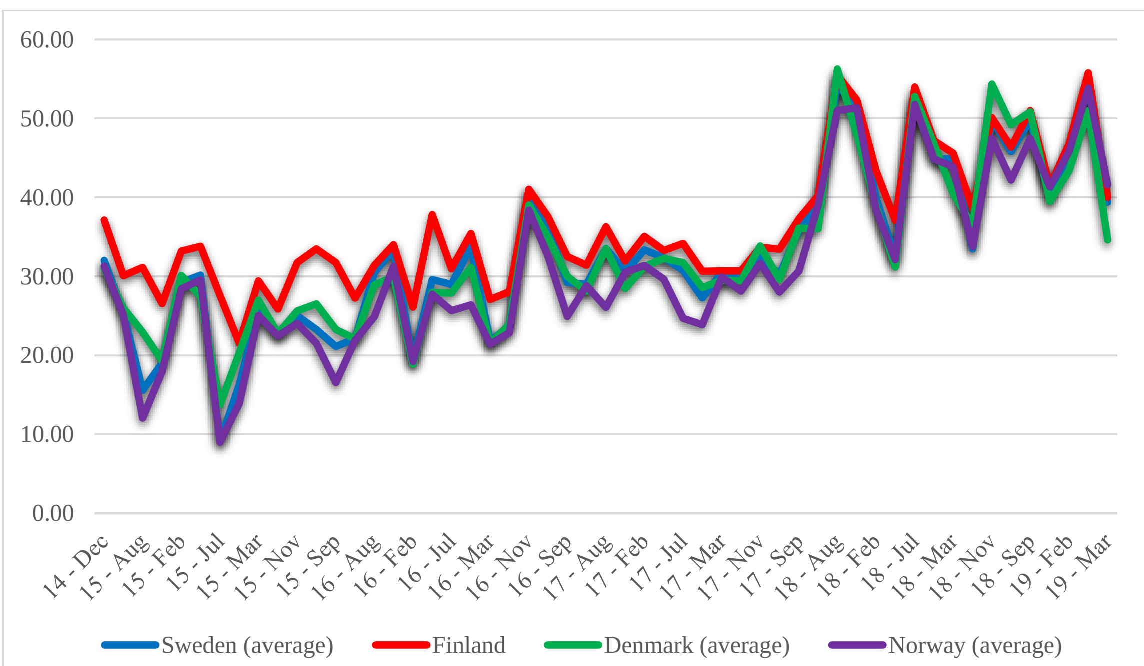
3.3.4 Shared price with neighbor countries

Data similar to Mibel could not be found, so equivalent information was developed using other data from Nord Pool. *Figure 3.16* shows the average price in the day-ahead market in Sweden, Finland, Norway and Denmark.

According to the graph, prices in Sweden have been very similar to prices in Norway and Denmark. Finland had showed higher prices than the other countries but since 2017 it seems to have reached the same values.

Comparing only Norway and Sweden, similarity becomes even more evident. Apart from a few discrepancies around September 2015, July 2016 and July 2017, both curves are practically superimposed.

COMPARISON BETWEEN DAY-AHEAD PRICES OF SWEDEN AND ITS NEIGHBOR COUNTRIES (2014-2019)



Source: own preparation with data from Nord Pool (2019)

Additional data is offered in *Table 3.2*.

TABLE 3.2: MINIMUM, MAXIMUM AND AVERAGE PRICES IN SWEDEN, FINLAND, DENMARK AND NORWAY (2014-2019)

€/MWh	Sweden	Finland	Denmark	Norway
max	54.46	55.78	56.27	53.83
min	9.10	21.52	13.72	8.98
average	32.76	36.34	32.72	31.00

Source: own preparation with data from Nord Pool's web page

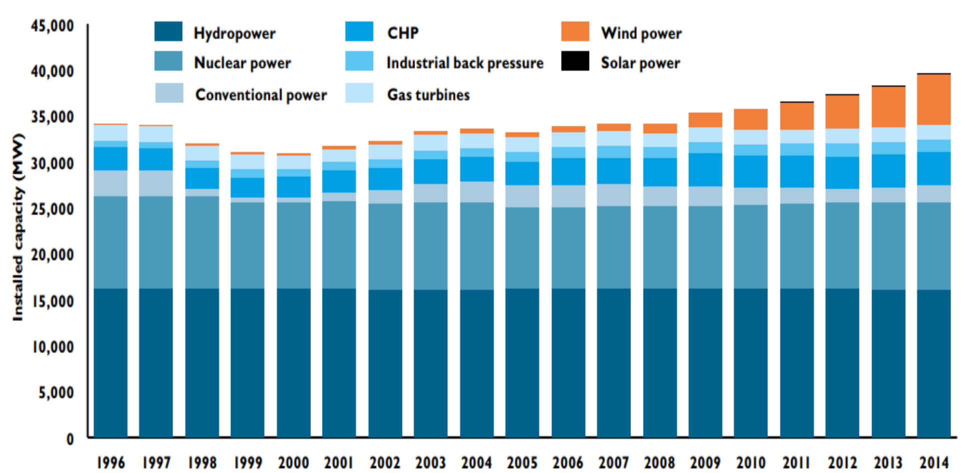
As it can be seen, the four countries have very similar maximum prices, while the minimum prices are quite far from each other. Regarding the average price in this period, the only relevant difference between countries is the one between Finland and the rest of them.

From the point of view of electricity producers, it is interesting that the country where they have their power stations is well connected with other countries, especially if the price in their country is lower and the interconnections can conduct large amounts of energy. That means they might sell energy to other countries, with higher prices, and consequently, obtain greater incomes.

3.3.5 Installed power capacity

Figure 3.17 shows the evolution of installed power capacity in Sweden, by technologies. The system has not changed a lot in the last 20 years. The two most remarkable facts are the shutting down of some conventional power stations in the late 90s and the rapid growth of wind farms from 2009 to 2014. As it has already been said, the Swedish electricity system is currently based on renewable energies and nuclear power, and so was it since the 90s.

FIGURE 3.17: EVOLUTION OF INSTALLED POWER CAPACITY FROM 1996 TO 2014

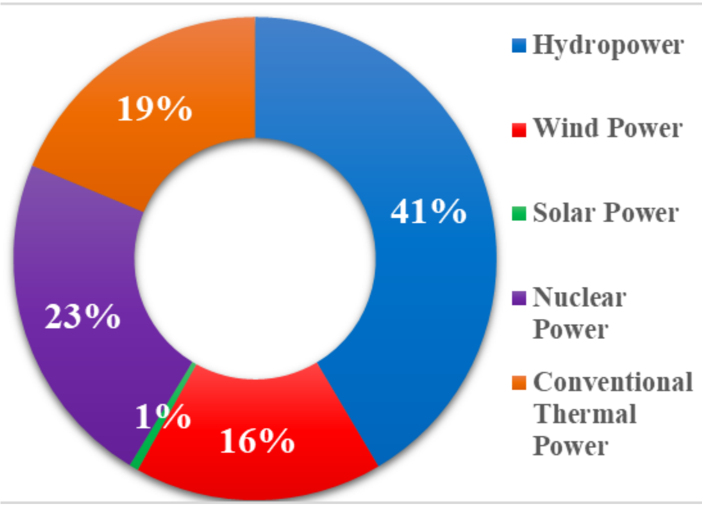


Source: IVA

The evolution from 2014 is missing, but the total installed power capacity for 2017 was found. It is showed in *Figure 3.18*, where "Conventional Thermal Power" includes conventional power, CHP, gas turbines and industrial back pressure.

Comparing data from both figures, it seems clear that no relevant changes occurred between 2014 and 2017, apart from a timid growth of wind power capacity.

FIGURE 3.18: INSTALLED POWER CAPACITY IN SWEDEN. 2017



Technology	Power (MW)
Hydropower	16502
Wind Power	6611
Solar Power	244
Nuclear Power	8999
Conv. Thermal Power	7442
Total	**39798**

Source: Own preparation with data from IVA and SCB

3.3.6 Support systems for renewables

Sweden promotes renewable energy using different methods. The most important one is the green certificates system, but the government also offers tax regulation mechanisms and subsidies to power stations that use renewable sources.

The green certificates system is working in other European countries like the UK, Italy or Belgium. Its working is based on the creation of the green certificates, which must be acquired by the energy buyers, together with the electricity (Energía y Sociedad, 2019).

The electricity producers receive a certain amount of green certificates, depending on the amount of energy they produce. Afterwards, they can sell it in a parallel market and get extra incomes.

Every year, electricity buyers must prove they have acquired a certain amount of green certificates, or they will get fined.

THE SWEDISH MODEL

It has just been explained how the green certificates system works in general, but the Swedish model has some particularities.

First of all, the certificates market in Sweden includes Norway too. This joint market was created in 2012, but it was based on the already existent Swedish one, which was created in 2003. The aim of this market is to raise renewable electricity production 26.4 TWh in 2020, compared to 2002.

The quota obligation is used to calculate the amount of certificates that a large consumer is required to purchase. It is a value fixed by the government every year. To find out how many certificates a company needs to buy, it can simply multiply the quota obligation by its electricity use in MWh.

Electricity buyers cancel their certificates every 31st of March, and if they do not present enough certificates to meet their requirements, they will have to pay for every non-cancelled one. The price they pay is equal to 150% of the average price in the market. As it can be observed in *Table 3.3*, the quota obligation fulfilment was 100% in both countries. (Swedish Energy Agency, 2016).

The renewable electricity producers receive 1 certificate for every MWh they produce.

TABLE 3.3: KEY FIGURES OF THE NORWEGIAN-SWEDISH CERTIFICATE MARKET, 2015

Key figures A	Norway	Sweden
Issued electricity certificates (million certificates)[1]	2.8	21.8
Certificates issued to plants that are included in the joint electricity certificate target (million certificates)	2.1	10.7
Certificates issued to plants that are not included in the joint electricity certificate target (million certificates)	0.8	11.1
Normal annual production for plants that are included in the joint electricity certificate target (TWh)	2.3	11.6
Cancelled electricity certificates (million certificates)	6.9	12.8
Quota obligation fulfilment (%)	100	100

Source: Swedish Energy Agency

Table 3.3 also emphasizes the fact that most of the certificates are issued in Sweden (21.8 million versus 2.8 million in Norway).

Figure 3.19 shows the real evolution until 2015 and programmed evolution until 2035 of the quota obligations for the electricity buyers.

For example, in 2007 in Sweden this percentage was 15%. That means that a Swedish company that acquired 100 GWh in the market had to buy an amount of green certificates equivalent to 15 GWh too.

FIGURE 3.19: EVOLUTION OF QUOTA OBLIGATIONS IN SWEDEN AND NORWAY

Source: Swedish Energy Agency

The shape of both curves was designed to fulfill the aim of increasing the share of renewable energies in the electricity production in a cost-efficient way. They can be adjusted if the results deviate from what was expected. Actually, the curves were adjusted in 2015. The evolution of the certificate's price is showed in *Table 3.4*.

TABLE 3.4: EVOLUTION OF THE ELECTRICITY CERTIFICATE'S PRICES

År	Volume-weighted average annual price of certificates (Cesar, NECS) [SEK per certificate]	Quota Sweden	Electricity customers' average costs for electricity certificates in Sweden [öre/kWh]*
2003	201	0,074	1,5
2004	231	0,081	1,9
2005	216	0,104	2,3
2006	167	0,126	2,1
2007	195	0,151	3,0
2008	247	0,163	4,0
2009	293	0,179	5,3
2010	295	0,179	5,3
2011	247	0,179	4,4
2012	201	0,179	3,6
2013	201	0,135	2,7
2014	197	0,142	2,8
2015	172	0,143	2,5
2016	158	0,231	3,6

Source: Swedish Energy Agency

One way of checking if this system is working properly is to look at the prices and quota evolution jointly. Even if the quota obligation is increasing (as *Figure 3.19* shows and *Table 3.4* confirms) the price of the certificates is decreasing. That means that supply is growing faster than demand. In other words, the production of renewable electricity is growing satisfactorily.

Nevertheless, this is not the only method that the Swedish government has planned to use for supporting renewable energies. According to The Ordinance (2009: 689), there is a special budget of 736 million SEK to support investments in solar cells. This subsidy would cover up to 20% of an investment of this kind, with a maximum of 1,200,000 SEK for every project, which might be a great help with small and medium-scale projects.

Finally, Swedish Environmental Protection & Swedish Energy Agency are currently working together to develop a new support system for wind power, although their meetings are not over yet. Such system is expected to be announced and start working as soon as in 2020 (Swedish Environmental Protection and Swedish Energy Agency, 2018)

3.4 DESCRIPTION OF HOW THE SWEDISH AND SPANISH ELECTRICITY MARKETS WORK

In this point, the general description of how electricity is sold in Spain and Sweden is presented. The countries themselves are very different, but their respective markets are quite similar to some extent, actually. However, before talking about electric markets, it is necessary to talk about the electric power itself, since some of its characteristics determine the way the market is.

Firstly, electric power is brief. That means that it is very difficult (or very expensive) to store it while it is being produced so that it can be used afterwards. As a consequence, it needs to be used at the same time that it is being produced. Achieving this complex state is one of the main purposes of the system operator.

Secondly, it must meet some requirements. For instance, the frequency of the network in Spain and Sweden has to be as close as possible to 50 Hz, and therefore, the system operator will take care of it. Another example is the existence of harmonics. The presence of many considerable harmonics means that the electricity has low quality and it might damage some electric machines that are connected to the network.

Thirdly, it is anonymous. Even if two parties make an agreement and one of them buys an amount of energy to the other, the physical delivery of the energy does not have to come from the party that sells it. However, at the end of the day, the total amount of energy that all the buyers bought will match the amount of energy that all the sellers sold (if we disregard system losses), and everyone will have bought or sold the exact amount of energy that they had agreed to.

Finally, its demand varies widely. That makes impossible to do a perfect prediction of how much energy the consumers will use. Therefore, the system agent needs to develop strategies and protocols to face this situation.

Having all these characteristics in mind, it is easier to understand what agents take part in all the activities related to the electricity sector, and what functions they have.

Every electric system has the same agents, which are:

- **System operator**. It is the organization responsible of the technical aspects of the market. It takes care of the quality of the electricity, the reliability of supply and the technical viability of the transactions.
- **Electricity generators**. They are the companies who produce the electricity and sell it in the wholesale market. The companies own the Power Stations and manage them to make benefits by selling the electricity they produced.
  Small consumers may eventually be electricity generators too. This happens when they have small generators and do not consume all the electricity they produce, so they can store it in batteries or send it to the network. These small generators are normally residential solar PV systems, or residential wind turbines.
- **Large consumers.** They are consumers (normally industries) who use so much energy that they acquire it directly in the wholesale market. They can come to a bilateral agreement with a electricity generator or take part in the regulated market.
- **Electricity Suppliers.** They buy a large amount of energy in the wholesale market to sell it to small consumers afterwards. They make benefits because the price they pay for the electricity is lower than the price their customers pay.
- **Market operator**. It is the organization responsible of the economic aspects of the market. It receives all the buy offers and sales offers and organizes them
- **Transporters and distributers.** They are responsible for the electricity transmission. They build and maintain the networks to make possible the transport of energy from the Power Stations to the supply points (factories, cities, other facilities…). Normally they get paid for the amount of energy that their networks conduct.
- **Regulatory Agency.** It supervises the working of the system and the actions of the Market Operator. It also elaborates reports to improve the working of the market. (Alcázar, 2019)

3.4.1 Mibel

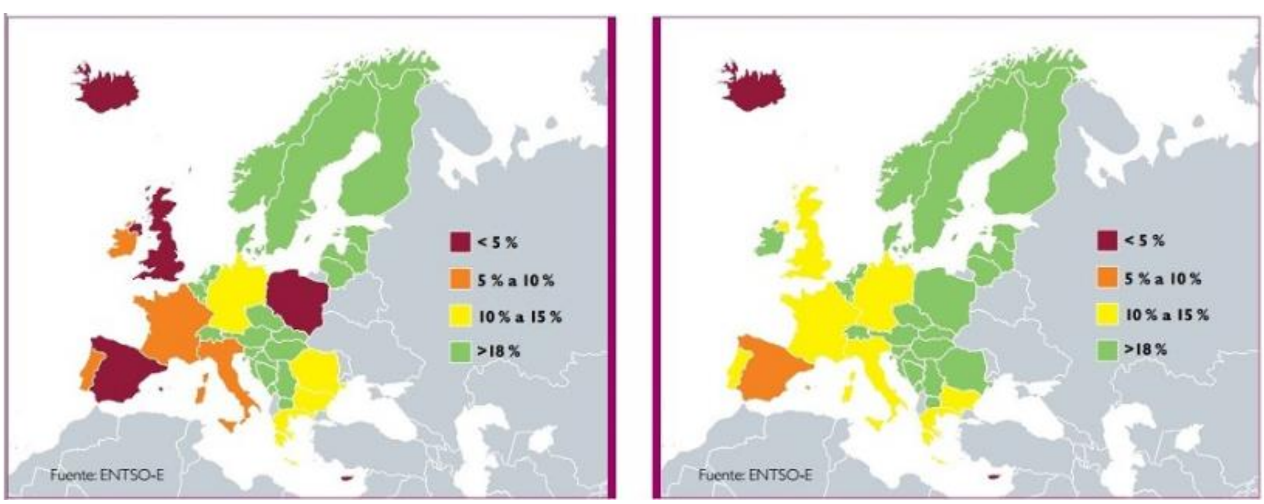
Mibel is the Iberian Market of Electricity. It operates in Spain and Portugal. According to the Spanish Pole of the Iberian Market Operator (OMIE) the total amount of energy traded in Mibel in 2017 was 281 TWh. 192 TWh was the amount of energy traded only in Spain during the same year.

As it can be observed in *Figure 3.20*, Spain has many connections with Portugal and France, but its level of interconnection is one of the lowest in Europe, as *Figure 3.21* indicates.

FIGURE 3.20: INTERCONNECTIONS BETWEEN SPAIN AND ITS NEIGHBORING COUNTRIES

Source: REE (2019)

FIGURE 3.21: INTERCONNECTION RATE IN EU COUNTRIES IN 2011 (LEFT) AND FORECAST FOR 2020 (RIGHT)



Source: REE (2019)

The system operator in Spain is **Red Eléctrica Española** (REE, Spanish Electric Network). It guarantees reliability and continuity of supply, forecasts the evolution of the electricity demand and manages the balance market. It acts also as the only transporter in the Spanish electric system.

There are two market operators in the Mibel. Their names include “Spanish pole” or “Portuguese pole”, but it does not have anything to do with the country where they operate, since both organizations operate in both countries:

- **OMIE** (Operador del Mercado Ibérico. Polo Español). It is the market operator that manages the spot market in the Mibel (that is, day-ahead market and intraday market). Therefore, it is responsible for matching sell bids with buy bids so that the price of the electricity is determined for every hour.
- **OMIP** (Operador del Mercado Ibérico, Polo Portugués). It is the market operator that manages the hedging market in the Mibel. It defines the rules, controls its compliment and manages the admission and expulsion of the negotiators in the hedging market. It can also supervise and standardize bilateral agreements.
  Actually, there are two market operators in the hedging market. While OMIP looks after the negotiations, **OMIClear** is the entity in the charge of the economic management of the hedging market. It is responsible for collecting money from the buyers and paying to sellers. That is, it acts as the compensating party (Alcázar, 2019).

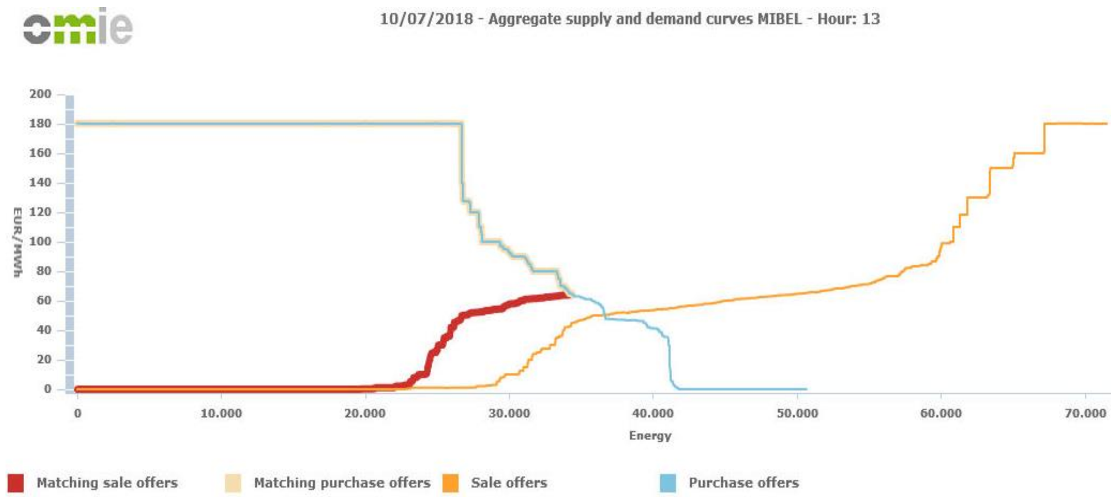
There are also two regulatory agencies. The **ERSE** (Entidade Reguladora Dos Serviços Energéticos) from Portugal, and the **CNMC** (Comisión Nacional de los Mercados y la Competencia) from Spain. They act together to supervise the well working and proper competition in the Mibel. They write proposals about current rules and new ones to improve its working.

There are different private companies who own the distribution networks across Spain. Most of them are part of large companies that in the past participated in different activities within the energy sector. They get paid, just like REE, for the amount of electricity their networks conduct.

The electricity trading system in Spain is organized into four submarkets:

- **Hedging market**. As it has been said before, it is managed by OMIP and OMIClear. Unlike the spot market, in this case every buy bid is matched with a sell bid, regardless of the characteristics of the other offers. The final price is such that all parties obtain benefits. The bids can be made up to 4 years before the supply day.
- **Day-ahead market**. It is managed by OMIE. The price is the same for Spain and Portugal, except in case of market splitting, which happens when the interconnection network between Spain and Portugal gets collapsed. Such price is determined by the most expensive kWh that is sold in every hour. *Figure 3.22* represents the matching of supply and demand curves in the spot market, made by OMIE.

FIGURE 3.22: MATCHING OF SUPPLY AND DEMAND CURVES



Source: OMIE (2019)

The bids can be made until 12 noon of the day before of the supply day. OMIE coordinates with REE to guarantee cost-efficiency and technical viability.

- **Intraday market.** This market, managed by OMIE, allows the agents to adjust their buying or selling program after the day-ahead session has been closed, so that supply and demand are closer to each other.
  Actually, those who made buy offers the day before are now able to make sell offers, and vice versa.
  Currently, there are two ways of trading energy in this market.
  - Intraday auction. There are 6 daily sessions where OMIE performs the matching of supply and demand curves, but only those who participated in the day-ahead market or had bilateral agreements for the day after are allowed to participate in such sessions.
  - Continuous trading. Using the XBID program, trades can be made between market stakeholders from different countries across the EU.
- **The balance market**. REE receives the results of the matching supply and demand curves from OMIE, analyses them, and then modifies them, applying technical viability criteria. There are mandatory operations for both producers and consumers and others are optative. They are all remunerated (Alcázar, 2019).

3.4.2 Nord Pool

Nord Pool is the electric market that operates in the Nordic region and Baltic states. That includes Sweden, Norway, Finland, Denmark, Latvia, Estonia, Lithuania and the UK.

The amount of electric energy traded on the Nord Pool in 2017 was 394 TWh. 140 TWh was the consumption only in Sweden, including losses. Furthermore, 90% of all the electricity consumed in the Nordic region is traded on Nord Pool, while the rest is traded through bilateral agreements (Ei, 2017).

FIGURE 3.23: THE NORDIC/NATIONAL GRID

Source: Ei

Svenska kraftnät is the state enterprise that acts like the system operator and owns transmission network in Sweden. Its job is to develop and administer the power transmission system. This is supervised by *Ei (*, as the EU's Internal Marketing Electricity Directive says. Moreover, the local utilities are responsible for the maintenance of their own networks, so that the reliability of supply can be guaranteed. Furthermore, *Ei* is part of the cooperation organization NordREG (Nordic Energy Regulators), formed by the different Regulatory Agencies from all the countries where the Nord Pool develops its activities.

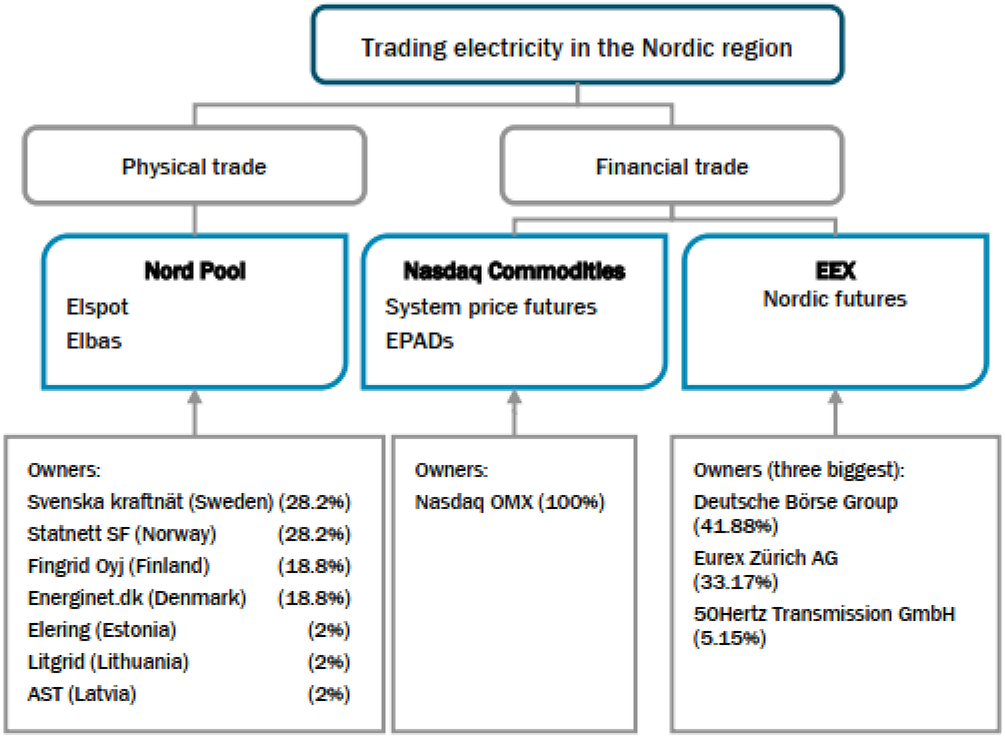
One of the directives of the EU in the energy area is to increase reliability of supply of electricity and gas within European countries. The Projects of Common Interest (PCI) have been developed to achieve this. They are key cross border infrastructure projects that link the energy systems of EU countries, so that they improve market integration in at least two of them. They offer the possibility to apply for special EU funding, whose fund for the 2014-2020 period is €5.85 billion. This is called the CEF fund (Connecting Europe Facility).

As it can be observed in *Figure 3.23*, the Swedish network is already connected to many other countries (Norway, Finland, Denmark, Lithuania, Germany and Poland), and such countries also have their own connections with their neighbors. This fact improves the competition of the system and softens the differences in electricity prices between countries of the area, although taking advantage of the CEF fund the situation could be improved even more, especially for the countries that have higher electricity prices.

The electricity trading system in Sweden is divided into four submarkets:

- **Hedging market**. In this submarket, trades can be done up to 10 years before the delivery takes place. They are priced according to pay-as-bid, which means that there is no supply and demand curves matching, but each purchase offer gets matched with a similar sell offer. This allows market stakeholders to manage the financial risks related to the variation of prices over time and also helps to delimit electricity prices in the future. In this market there is the possibility to acquire *Electricity Price Area Differentials* (EPAD), to hedge the difference between the system price and the price in a specific region. The platforms where these operations can be made are *EEX* and *Nasdaq Commodities*.
- **Day-ahead market**. It is frequently known as the spot market, the platform where trades for the next 12-36 hours take place. In Sweden it is known as *Elspot*. Stakeholders submit their bids for each hour of the next day, which specify how much electricity the stakeholder wants to sell or buy, at what price and in which electricity region. After 12 noon, all the bids are organized so that all the sell bids that are lower than the established price force their producers to sell the amount of energy they offered, at the time they offered it in the bid. Similarly, buy bids higher than the established price force their consumers to buy the amount of energy they demanded, at the time they demanded it in the bid.
- **The intraday market**. It opens at 2pm the day before the trades take place and closes one hour before the hour of supply. Therefore, it is possible to introduce adjustments to the final trades of the spot market, which can be very useful, in case any condition has changed after the closing of it. This market is also known in Sweden as Elbas.
- **The balance market**. This market was made to guarantee the equality between energy demand and supply in real-time in a cost-effective way. *Svenska kraftnät* manages automatic reserves, whose price depends on capacity and energy. There are also manual reserves, managed through the Nordic regulating power market, where voluntary bids can be submitted from 14 days to 45 minutes before the supply hour.
  Figure 3.24 summarizes the information just given. It was prepared by *Ei*, using data from Nord Pool, Nasdaq and EEX.

FIGURE 3.24: TRADING PLATFORMS FOR ELECTRICITY IN THE NORDIC REGION



Source: Ei

Regarding Electricity Suppliers, according to *Ei*, there were 123 different companies registered on its price comparison site, although the three biggest electricity suppliers shared 41% of the total number of customers.

3.5 RENEWABLE ENERGY RESOURCES IN SPAIN

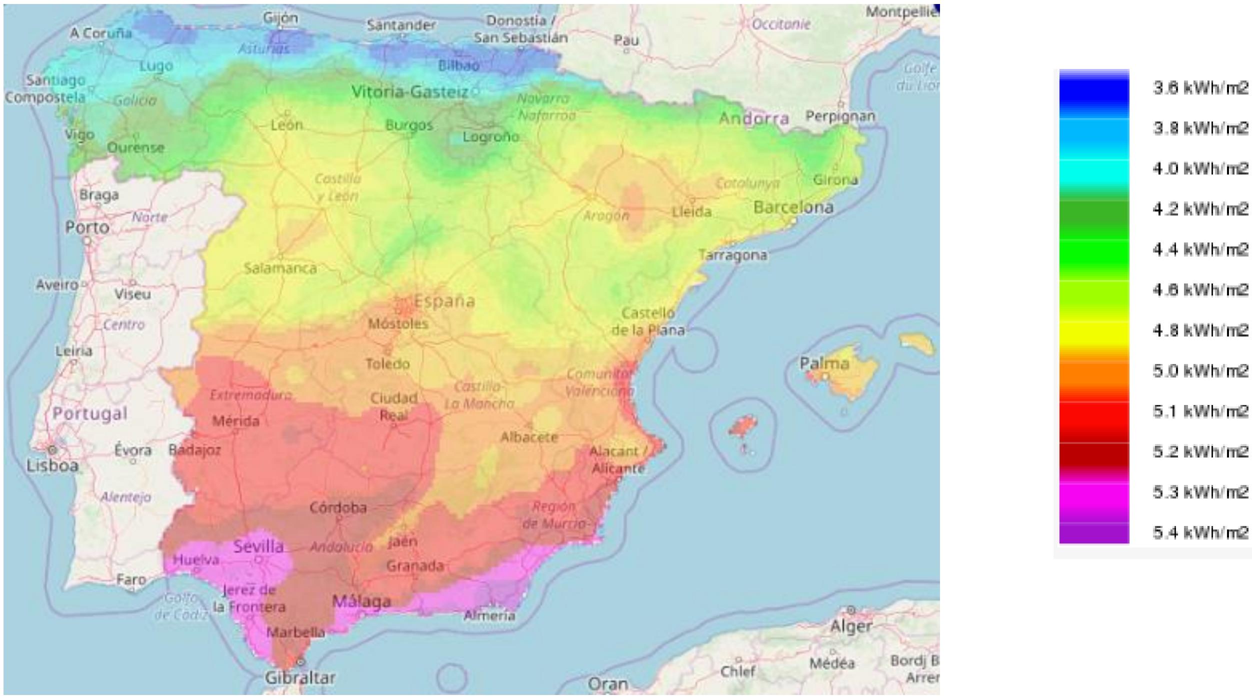
Now it follows a briefly description of solar and wind resource in Spain.

3.5.1 Solar Resource

Spain is known for being one of the countries in Europe with the greatest solar resource, especially because it is close to the equator (if compared with other countries in Europe), but also because its territory is quite ample.

Figure 3.25 shows the distribution of the average daily solar radiation in the Iberian Peninsula. As it could be expected, the further south, the more solar resource there is. This is the main reason that justifies the existent difference between the resource in Seville (5.4 kWh/(m^2*day)) and Lugo (4 kWh/(m^2*day)), for instance.

FIGURE 3.25 AVERAGE DAILY SOLAR RADIATION IN THE IBERIAN PENINSULA



Source: ADRASE

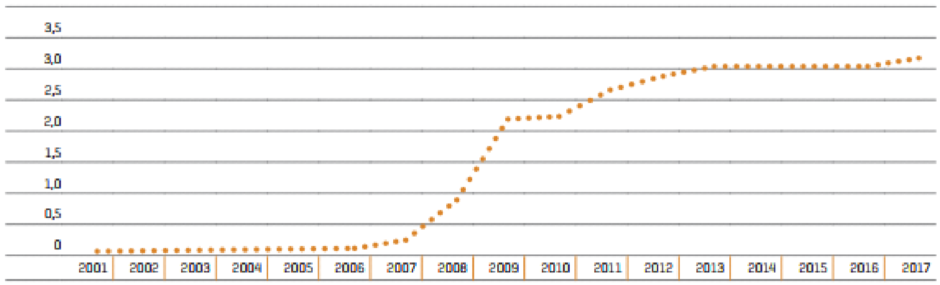
However, projects in many locations with a high potential are not feasible because the land is too steep to place the cells there. This is due to the mountain system that exists across the Peninsula.

Another issue that should be addressed here, is the fact that for being a hot country, the efficiency of the PV cells is generally lower than in a colder country like Sweden.

This happens because the conductivity of the cables is reduced when the temperature raises, so that the electricity losses are also increased.

In 2017 solar power (both PV and thermal) accounted for 6.7% of total installed power capacity (6991 MW) and produced 13.7 TWh of electricity (5.2% of total electricity produced in Spain). That makes solar power the third most important source of renewable energy in Spain, currently. However, given the available resource showed in *Figure 3.25*, it seems obvious that these numbers still have a wide room of growth (REE, 2017).

FIGURE 3.26: CONTRIBUTION OF SOLAR PV POWER TO THE ELECTRICITY PRODUCTION



Source: REE

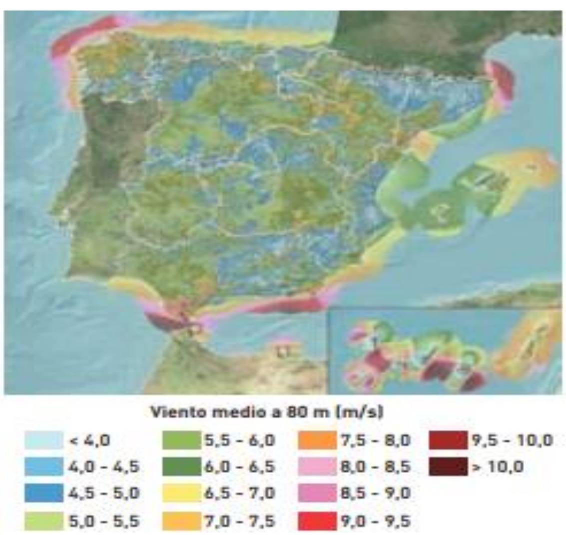
One possible explanation to the under-use of solar resource in Spain could be the lack of legal policy support 2013 (further information in point *3.2.6 Support system for renewables*). Nevertheless, given the last fall in costs (that will be explained in detail in *3.7.2 Solar PV costs*) it is expected that more and more solar PV power stations are built in the following years.

3.5.2 Wind Resource

As it has already been explained in section *3.2 Past and present of the Spanish' energy system (introduction)*, the same mountain system that makes it harder to install PV cells in locations with good resource provides Spain with air streams that are fast enough to produce electricity. *Figure 3.27* shows the average wind speed at 80 meters height. This height was chosen because is one of the typical sizes for the aerogenerators' towers.

The image was extracted from a technical report made by IDAE and used as a support document for the PER 2011-2020 (Plan for Renewable Energies in Spain).

FIGURE 3.27: WIND SPEED AT 80 M



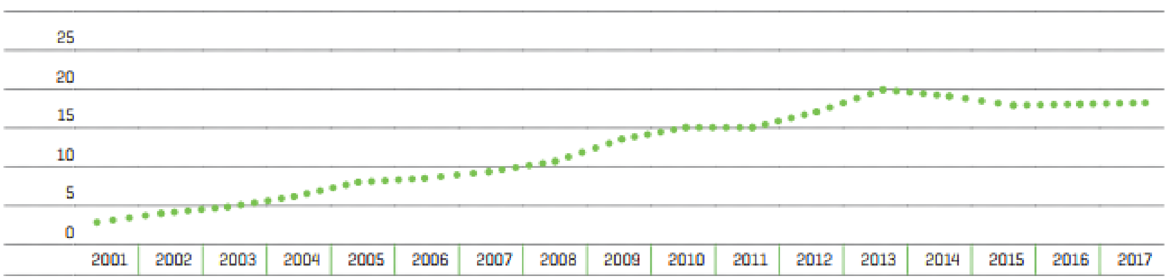
Source: IDAE

It also contains an interesting analysis that presents the available surface where it is possible to build wind power stations, after applying environmental and technical-economical filters. Of course, the technical-economical filters are susceptible to be changed in the next years if the necessary technical advanced are reached.

According to this report, after applying such filters, 16.42% of the Spanish territory has a higher than 6 m/s wind speed (at 80 meters). That is 83,120 km^2 (IDAE, 2011)

According to data from REE, in 2017 wind power accounted for 22.2% of total installed power capacity (23,132 MW) and produced 47.9 TWh of electricity (18.2% of total electricity produced in Spain). That makes wind power the second most important energy resource in the electricity system, just behind the nuclear power.

FIGURE 3.28: CONTRIBUTION OF WIND POWER TO THE ELECTRICITY PRODUCTION



Source: REE

As it can be observed in *Figure 3.12* of point *3.2.6 Support systems for renewables*, the wind power installed capacity growth stopped around 2013, just like solar power. In the case of solar power, however, the energy production was practically even during the following years, while in the case of wind power, it can be observed in *Figure 3.28* that the oscillation of its electricity production is significant. Since no relevant changes in the total installed power capacity occurred during those years, one possible explanation to this could be the fact that wind power is more sensitive to randomness than solar power is.

3.6 RENEWABLE ENERGY RESOURCES IN SWEDEN

Now it follows a briefly description of solar and wind resource in Sweden.

3.6.1 Solar Resource

For Sweden equivalent to Spanish data could not be found, so the approach was different.

A document called "Measurements of Solar Radiation in Sweden 1983-1998", made by the Swedish Meteorological and Hydrological Institute in 2000 contains tables of radiation for different cities in Sweden from 1983 to 1998. From this data, several cities across the country were selected to evaluate the solar resource in different points of it. The selected cities can be seen in *Figure 3.29*. They are the 10 cities pointed in blue, from Lund to Kiruna (SMHI, 2000)

FIGURE 3.29: SELECTED CITIES FOR SOLAR RESOURCE

Source: Own preparation. Blank map from Wikipedia

TABLE 3.5: AVERAGE RADIATION IN 10 SWEDISH CITIES (IN KWH/M²)

Cities	Average/year	Average/day
Stockholm	927.2	2.5
Lund	973.4	2.7
Gotenburg	935.6	2.6
Kiruna	780.0	2.1
Karlstad	963.9	2.6
Visby	1040.7	2.9
Borlänge	996.9	2.7
Östersund	880.3	2.4
Umeå	877.3	2.4
Luleå	862.2	2.4

Source: Own preparation with data from SMHI

Average daily radiation in Sweden varies from 2.1 kWh/(m^2*day) in the north (Kiruna) to 2.9 kWh/(m^2*day) in the south (Visby). As the reader may have predicted, solar resource is widely higher in Spain than in Sweden. Moreover, since days are much shorter in the winter and much longer in the summer, the difference between the electricity produced in both seasons is bigger than in the Spanish case. *Figures 3.30* and *3.31* evince that.

FIGURE 3.30: IRRADIATION ON HORIZONTAL PLANE (WH/(M^2*DAY)

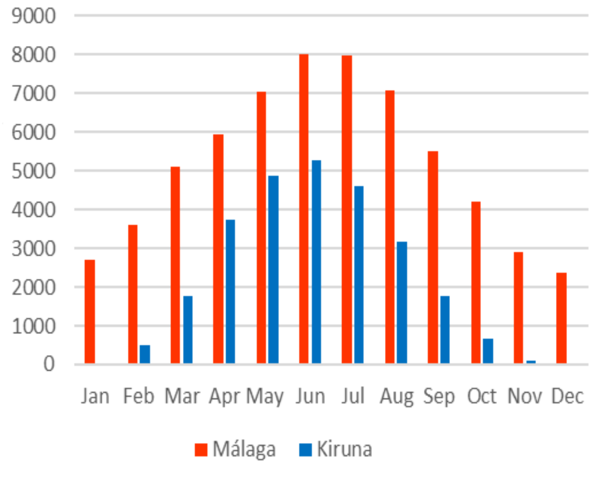
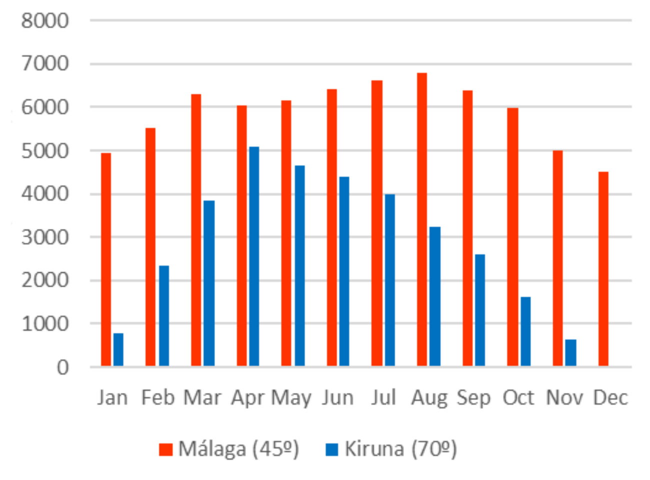


FIGURE 3.31: IRRADIATION ON PLANE AT A CERTAIN ANGLE (WH/(M^2*DAY)



Source: Own preparation with information from PVGIS

Figure 3.30 shows the average irradiation on horizontal plane by months in Málaga (south of Spain) and Kiruna (north of Sweden). Such locations were selected to make the differences more evident.

Forgetting about the differences in annual production, it is also flashy to notice that the irradiation in Málaga during July (8000 Wh/(m^2*day)) doubles the irradiation in October (4000 Wh/(m^2*day)), but comparing the same months in Kiruna, the difference is much larger (4600 Wh/(m^2*day) in July versus 700 Wh/(m^2*day) in October). That is almost 7 times higher in July than in October, while in December and January the irradiation equals 0.

Figure 3.31 shows how a proper selection of the inclination angle of the cells can adjust the irradiation they receive to make it more constant throughout the year. The selected angle is higher than the optimum angle suggested by PVGIS. This makes the sun's rays strike more perpendicularly in winter, although the total annual production is a little bit lower.

According to data from the Royal Swedish Academy of Engineering Sciences (Electricity Production in Sweden, 2016), "at the end of 2014 solar capacity connected to the grid in Sweden was providing around 79 MW. Electricity generation is estimated at around 75 GWh". However, most of this power is based on small-scale projects, especially cells placed in roofs, for private use. There are also a few power plants of 1 MW.

Unlike in the case of Spain, where the solar resource is plentiful but under-used, in Sweden the policies of support to solar power seem to have achieved an impact appropriate to the available resource, especially in the small-scale projects

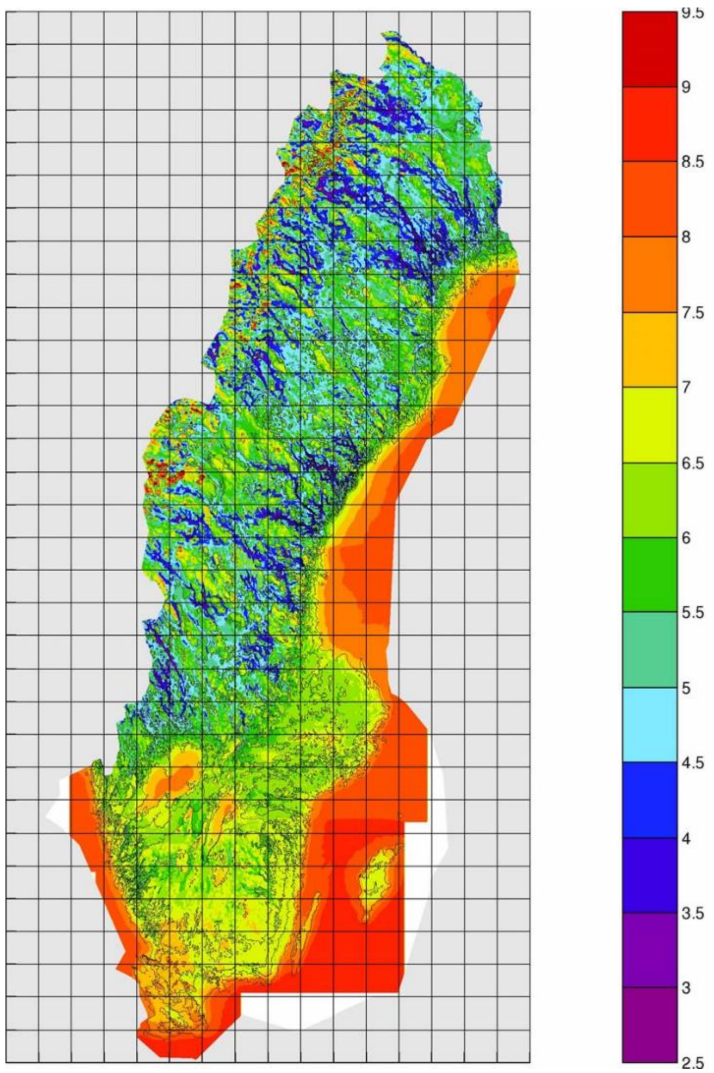
3.6.2 Wind Resource

Figure 3.32 shows a map of Sweden with the average annual wind speed at 72 meters height

Clearly the wind resource is bigger in the south of the country and in the coast. The mountains are an obstacle to the wind, so it is quite difficult to find good resource around them. Nevertheless, at the top of the mountains the wind speed is very high, since there wind has no obstacles, but it is technically very complicated to install aerogenerators there.

Therefore, the best locations to place a wind power station are the lands at the south of the country and in the sea. It must be considered, however, that offshore technology is out of the limits of this project.

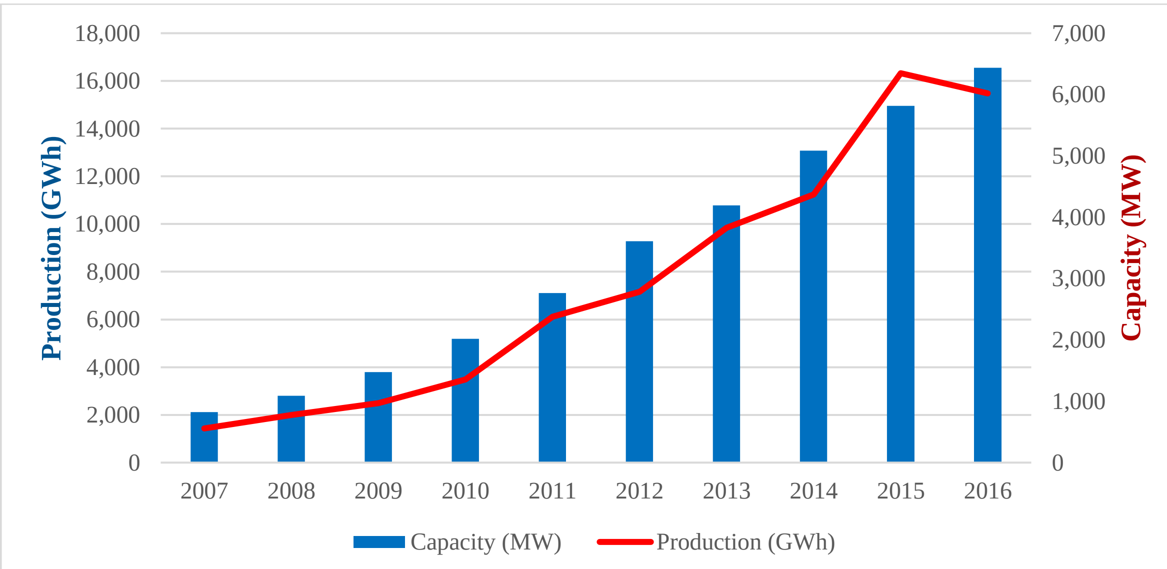
FIGURE 3.32: WIND RESOURCE IN SWEDEN



Source: Bergström, 2007

Figure 3.33 shows the evolution of both the installed capacity and the electricity production of wind power from 2007 to 2016. The capacity has experienced a quite rapid growth from the beginning, but at the same time, it is showy to see how even if some aerogenerators were installed in 2017, the generation in that year was lower than in the previous one. That supports the idea of the sensitivity that wind power has to randomness (see *3.5.2 Wind Resource, Renewable Energies Resource in Spain*).

FIGURE 3.33: EVOLUTION OF CAPACITY AND ELECTRICITY PRODUCTION OF WIND POWER



Source: Own preparation with data from Nord Pool site

3.7 COSTS

This section will focus on the evolution and current state of solar PV and wind power costs. It is based on several reports made by the International Renewable Energy Agency (IRENA), the "*Instituto para la Diversificación y Ahorro de la Energía"*, that is, Institute for the Diversification and Saving of Energy (IDAE) and the Swedish Energy Agency.

Some aspects related to how this data was collected by the different institutions must be explained before showing it.

First of all, although what is intended to present here are costs, the real data are actually prices, and there is a subtle but not insignificant difference between them. While costs depend on the available technology, how much optimized are the production processes and the value of the materials (such as steel, cupper or silicon) among others, price also depends on the law of supply and demand. Therefore, an unknown difference between price and cost will always exist and must be considered when reading the following cost findings.

Secondly, the prices here presented are based on research in power stations of very different sizes, from some kW to hundreds of MW. In this field, economies of scale make the difference, and the cost of 1 MWh of electricity generated in a 500 kW power station can be really far from the cost of the same amount of energy generated in a 500 MW power station, even if talking about the same technology. This must be had in mind too.

Finally, and being maybe the most important comment to do, there is the fact that the costs in wind power and PV technology change by leaps and bounds, especially in the latter case. For example, data from PER 2011-2020, written in 2010, failed to predict the fall in costs of wind power, since the evolution was faster than expected. For example, in such document, IDAE predicted a LCOE for onshore wind projects of 6.1 c€/kWh in 2016, while the IRENA's report from 2017 states a real LCOE of 0.05 USD/kWh, which, applying the average exchange rate for that year (1.1 $/€) becomes 4.54 c€/kWh. That is 25% cheaper than expected.

As a conclusion, the following data must be addressed prudently, understanding that the given prices are approximated and subject to great uncertainty.

Up to three different costs will be discussed in this point, which are the following:

- Installed costs. Here all the costs related to the initial investment to develop the projects are considered. This includes, among others, the cost of the equipment, the land acquisition costs and the financial costs.
- Operation & Maintenance (O&M). Here all the fixed and variable costs that are related to the operation of the power station are included, together with the necessary maintenance costs. This includes personnel salaries, energy costs, insurances and every service related to maintenance (reviews, repairs, etc.)
- Levelized Cost of Energy (LCOE). This number represents the average cost per unit of energy during the whole useful life of the power station. It is calculated taking into account both the installed and O&M costs, following *Formula 3.1*:

$$\mathrm{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

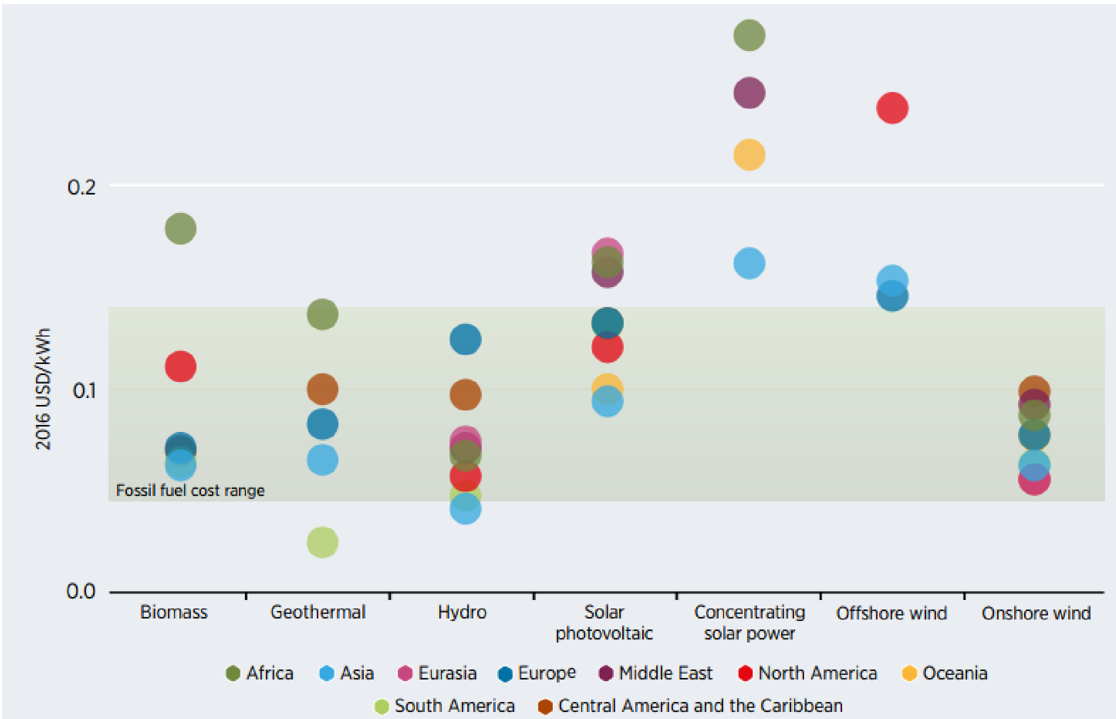
FORMULA 3.1

From where:

- LCOE: the average lifetime levelized cost of electricity generation
- It: investmen expenditures in the year t
- Mt: O&M expenditures in the year t
- Ft: Fuel expenditures in the year t
- Et: electricity generation in the year t
- r: discount rayte
- n: life of the system

Before going to the wind power and PV costs, it is interesting to observe the *Figure 3.34*. It shows the LCOE of the different renewable technologies classified by regions. It also includes the fossil fuel-based power stations cost range, so that it can be taken as a reference. What the image proves is that biomass, geothermal, hydropower, solar PV and onshore wind power were already competitive in 2016 practically worldwide, while CSP and offshore wind power still have to improve their costs to present a profitable alternative to fossil fuels.

FIGURE 3.34: REGIONAL WEIGHTED AVERAGE LCOE BY RENEWABLE POWER GENERATION TECHNOLOGY, 2016



Source: IRENA

3.7.1 Wind Power Costs

Wind power is the non-conventional renewable technology which had the earliest development, with a total worldwide installed capacity of 420 GW in 2015. It became the first large-scale cost-competitive renewable energy (after hydropower) and this is reflected on its costs.

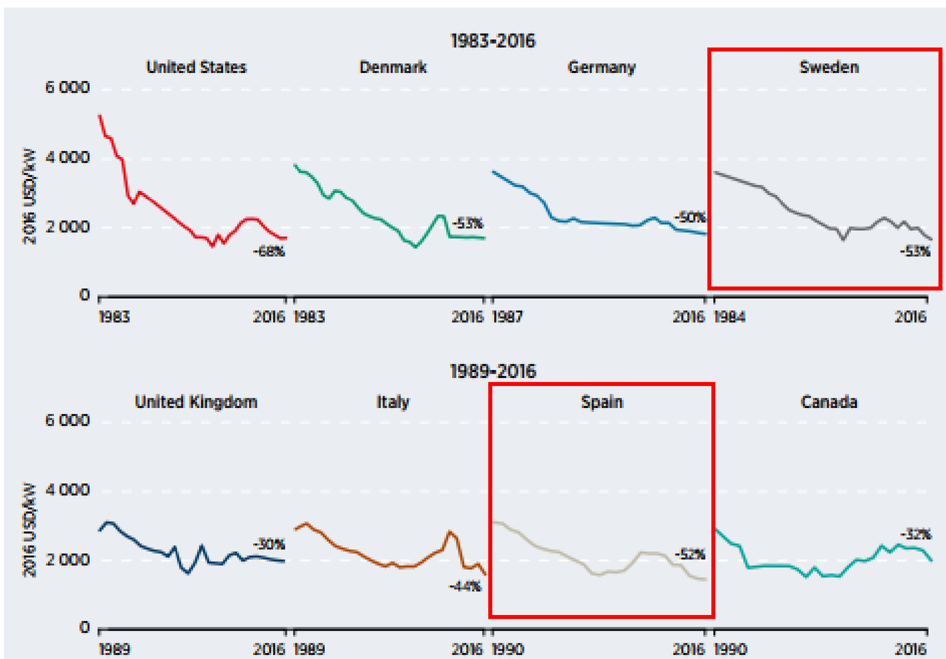
Even if normally all the cost evolution curves in the renewable technologies tend to be monotonically decreasing, in the case of wind power there was a rise in prices between 2007 and 2010. This happened because of two reasons. On the one hand, construction costs raised right before the financial crisis (materials, labor and civil engineering) and, on the other hand, demand overcame supply after the favorable to wind power policies that the governments started to adopt by those years (IRENA, 2015).

Since then, prices have not stopped decreasing. For example, between 2010 and 2016, costs fell by 19% in Europe and 22% in North America. However, India became the country with the lowest installed costs in 2016, with 1121 USD/kW (1019 €/kW).

3.7.1.1 Installed cost reduction potential

Data shows a global tendency to homogenize installed costs. This implies that countries that are already very competitive, such as China and India, will experience lower than average cost reductions, while those which currently have the higher costs will experience above average cost reductions. Overall, the global weighted average total installed costs could fall by around 12% between 2015 and 2025, thanks to bigger turbines, more advanced blades and better production techniques. (IRENA, 2016).

FIGURE 3.35: WEIGHTED AVERAGE INSTALLED COSTS EVOLUTION FOR 8 COUNTRIES



SOURCE: IRENA

Figure 3.35 shows average installed costs for different countries, like Sweden and Spain, which had approximate installed costs of 1640 €/MW and 1450 €/MW, respectively. Taking a little lower than the average reduction potential (10% instead of 12%), it leads to an estimation of 1470 €/MW and 1300 €/MW, respectively, in 2025.

3.7.1.2 Operation and maintenance cost reduction potential

O&M costs are probably the most difficult ones to estimate and predict, since that prediction depends on the experience of maintenance of the different wind power technologies, which evolve fast. Thereby, the needed experience for doing a reliable prediction cannot be reached as quick as the technology changes.

However, some available data could be found out and presented. For example, *Table 3.6* presents some reported costs of different OECD countries, among which Spain and Sweden were selected.

Another reliable piece of information is the share of O&M costs in the onshore's LCOE, well known for having a value between 20-25%, generally depending on the cost of capital.

TABLE 3.6: REPORTED O&M COSTS IN SOME OECD COUNTRIES

	Variable (2015 USD/kWh)	Fixed (2015 USD/kW)
Austria	0.040	
Denmark	0.0161-0.018	
Finland		37-40
Germany		75
Italy		50
Ireland		74
Japan		76
The Netherlands	0.0138-0.0180	
Norway	0.022	
Spain	0.029	
Sweden	0.0106-0.0351	
Switzerland	0.046	

Source: International Energy Agency, 2011

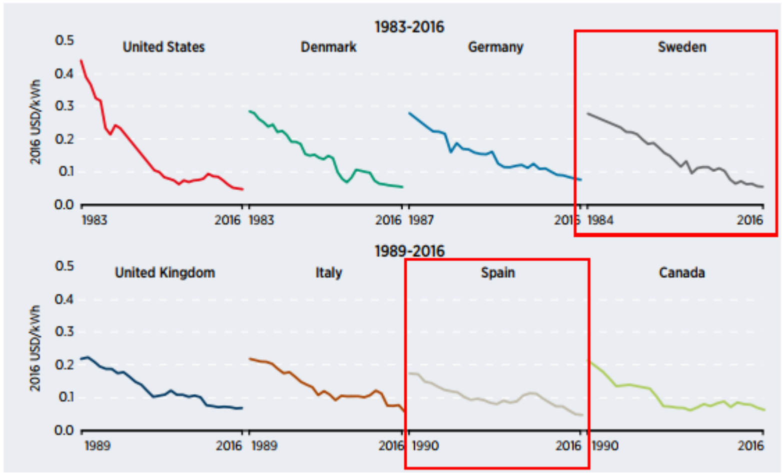
The table shows illustrative values for both variable and fixed costs in 2010. Spain had variable costs of 2.7 c€/kWh and Sweden had an average variable cost of 2.1 c€/kWh. While reference countries like Finland or Italy had fixed O&M costs of 35.6 €/(kW*year) and 46.85€/(kW*year), respectively. Other data from shows fixed O&M costs in Sweden of around 30 €/(kW*year) (IRENA; 2016).

3.7.1.3 Levelized cost of electricity reduction potential

Weighted average onshore LCOE in Europe during 2015 was 6.56 c€/kWh and its projected reduction from 2015 to 2025 equals to 1.7 c€/kWh. This reduction is motivated for savings in towers, turbines and blades, better wind farm practice and, especially, for the expected rise in the capacity factor (IRENA, 2016).

Such reduction, with the starting point (2016) for Sweden and Spain, which can be observed in *Figure 3.36*, gives an approximate LCOE in 2025 of **3.81 c€/kWh** and **2.9 c€/kWh**, respectively. [Note: for these calculations, the considered LCOE in 2016 was 5.45 €/kWh for Sweden and 4.54 €/kWh for Spain. The average exchange ratio in 2016 was 1.1 USD/€.]

FIGURE 3.36: WEIGHTED AVERAGE LCOE EVOLUTION FOR 8 COUNTRIES



Source: IRENA

3.7.2 Solar PV Costs

Solar PV is the renewable technology that is currently experiencing the faster growth and development. Total installed capacity worldwide exceeded 6 GW in 2006 and only 10 years later, it reached 291 GW (IRENA, 2017).

This growth in installed capacity has been motivated by the rapid cost reduction, and vice versa. Costs reduction drives the development of new and larger projects, which become more profitable every year, while such increasing demand pushes costs to be further decreased.

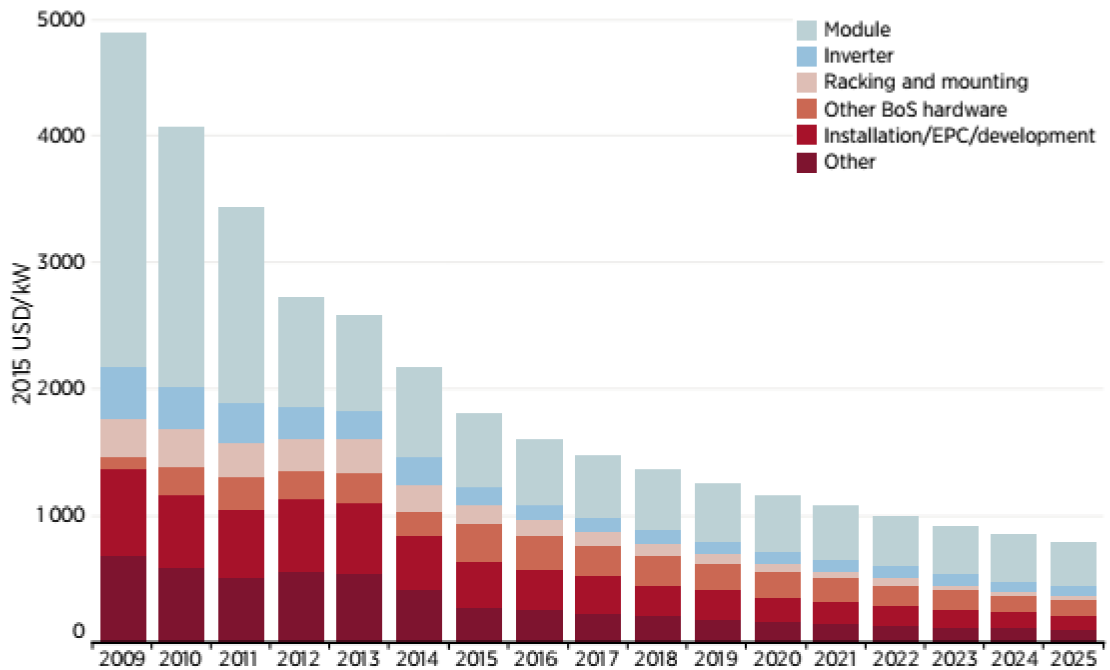
Such situation explains how PV module prices declined by around 80% between 2009 and 2015, or how total installed cost of utility-scale projects declined by around 56% between 2010 and 2015, for example (IRENA, 2016)

The distribution of costs has also changed noticeably. If traditionally O&M costs were not a relevant part of the solar PV's LCOE, after the quick fall of installed costs, it has gained some importance. Data shows that in some OECD countries, O&M costs account for 20-25% of the LCOE.

3.7.2.1 Installed cost reduction potential

Central case examined by IRENA concludes that global average total installed cost of utility-scale PV systems could be reduced to 0.75 €/W in 2025, especially due to the production of cheaper balance of system (that is, all the devices but the inverter and the module), where the higher cost reduction potential exists. *Figure 3.37* shows such evolution, with the cost's breakdown.

FIGURE 3.37: EVOLUTION AND BREAKDOWN OF THE INSTALLED COSTS FOR SOLAR PV (2009-2025)

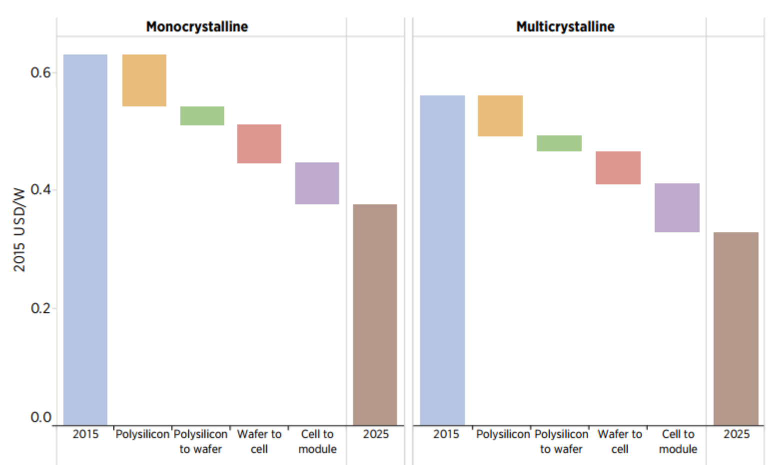


Source: IRENA

A deeper look can be taken into the installed costs of solar PV. On the one hand, IRENA's report (2016) offers the expected evolution of costs for monocrystalline and polycrystalline modules. *Figure 3.38* shows such prediction.

According to this image, average monocrystalline and multicrystalline could fall from 0.58 €/kW and 0.52 €/kW to 0.36 €/kW and 0.31€/kW, respectively.

FIGURE 3.38: MONO AND MULTICRYSTALLINE SILICONE MODULE COST REDUCTIONS



Source: IRENA

On the other hand, balance of system cost is expected to decrease from 1.1 €/W in 2015 to 0.35€/W in 2025, what would prove the already mentioned hypothesis of being the main cost decreasing driver.

Finally, the inverter's cost is expected to be reduced from 0.15 €/kW in 2015 to 0.084€/kW in 2025.

More specific data can be extracted from PER 2011-2020, which predicted total installed costs for solar PV in Spain 1.15€/W. However, this prediction was made in 2010, and real data from IRENA's reports (2017) already confirmed a faster than expected reduction in prices.

On the other hand, total installed costs for larger than 1 MW solar PV projects was 13.7 SEK/W (1.51 €/W with the average exchange rate in 2014). This value was taken from one of the only two existent power stations of that kind in Sweden (Swedish Energy Agency, 2014).

The newest and probably most reliable data was found through a report made by Fraunhofer-Gesellschaft (2018). This report analyses current LCOE of renewable energies and fossil fuel-based energies in Germany in 2018, and also predicts its evolution until 2035. Such analysis states that solar PV's installed cost was contained between 600-800 €/kW.

3.7.2.2 Operation and maintenance cost

O&M costs entails again a great challenge, when it comes to identify its currents values and future evolution. From IRENA's reports, the only information found is the value for O&M costs in the USA in 2015, between 9.4 and 16.9 €/(kW*year).

In PER 2011-2020, the O&M costs for fixed, ground based modules are considered to be 47 €/kW in 2010.

3.7.2.3 Levelized cost of electricity reduction potential

Solar PV's LCOE was reduced around 58% between 2010 and 2015 and is predicted to decrease another 59% until 2025. That means it would change, on weighted average, from 0.12 €/kWh (2015) to 0.051 €/kWh (2025).

Record prices in 2015 were set for projects to come in the following years, with values as low as 0.045€/kWh (Peru) or 0.042€/kWh (Mexico).

4. SIMULATION OF POWER PLANTS

In this section, the results of the pre-design of the power plants will be presented, together with all the assumptions and calculations that were needed to obtain such results.

One first approach will disregard the support that these technologies have in both countries, to see whether they are already competitive without any kind of help. Then, with a second approach, the impact of the current supporting systems to renewable energies will be considered, to see how much these systems influence the profitability of such projects.

4.1 No support approach

4.1.1 Wind power station in Malmslätt (Sweden)

Table 4.1 shows the incomes for the wind power station in Malmslätt, which were calculated using the method explained in *2. Methodology*.

TABLE 4.1: INCOMES FOR THE WIND POWER STATION IN MALMSLÄTT

	Price €/MWh	Electricity (MWh)	Incomes (€)
Jan	32.39	20544.93	665499.7984
Feb	39.85	14117.91	562616.2508
Mar	44.83	17756.39	796078.0127
Apr	38.89	15006.20	583548.7911
May	32.74	11355.95	371748.1666
Jun	44.21	13742.71	607512.0667
Jul	52.40	10663.04	558726.6933
Aug	53.30	6363.13	339176.5123
Sep	56.77	10532.68	597940.3882
Oct	53.25	20146.86	1072779.101
Nov	46.91	17162.28	805161.17
Dec	52.08	19815.74	1032014.907
total	45.64	177207.81	7992801.858

Source: Own preparation with data from Nord Pool, SMHI and Vestas

With the considered costs (from *2. Methodology*)

a. Fixed O&M cost: 1,250,000 €/year
b. Variable O&M cost: 354,415 €/year
c. Installed cost: 73,500,000 €

Earnings and payback time.

d. The earnings per year would be: 6,388,386 €
e. Which leads to a payback time of 11.5 years

4.1.2 Wind power station in Valencia (Spain)

Table 4.2 shows the incomes for the wind power station in Valencia.

TABLE 4.2: INCOMES FOR THE WIND POWER STATION IN VALENCIA

	Price €/Mwh	Electricity (MWh)	Incomes (€)
Jan	61.86	16663.91	1030767.842
Feb	53.78	10227.94	550107.6255
Mar	48.69	13496.82	657211.8439
Apr	49.98	12757.74	637570.6986
May	54.85	9126.76	500640.5879
Jun	58.44	7202.96	420952.1252
Jul	61.86	6936.72	429082.9806
Aug	64.31	8572.77	551347.059
Sep	71.25	6726.75	479300.7333
Oct	65.07	12008.71	781453.0128
Nov	62.81	12641.75	793973.1474
Dec	61.65	6936.72	427615.8596
total	59.55	128634.04	7260023.516

Source: Own preparation with data from REE, Valencia's port and Vestas

Which give the following values:

a. Fixed O&M cost: 2,000,000 €/year
b. Variable O&M cost: 257,268 €/year
c. Installed cost: 65,000,000 €

That leads to the final results:

a. Earnings per year: 5,002,755 €
b. Payback time of 13 years

4.1.3 Solar PV power station in Norrköping (Sweden)

Table 4.3 shows the incomes for the solar PV station in Norrköping.

TABLE 4.3: INCOMES PER MONTH FOR THE SOLAR PV STATION IN NORRKÖPING

	Price €/Mwh	Electricity (MWh)	Incomes (€)
Jan	35.02	2000.22	70039.78
Feb	42.21	2476.56	104530.01
Mar	48.35	5336.63	258042.99
Apr	40.38	5834.72	235578.97
May	35.01	6955.09	243477.80
Jun	45.34	6119.76	277450.27
Jul	53.30	6655.42	354756.89
Aug	56.77	5715.61	324475.07
Sep	53.25	5069.99	269966.35
Oct	46.91	3194.61	149873.93
Nov	52.08	1533.83	79882.64
Dec	54.19	1085.97	58843.59
total	46.90	51978.40	2426918.28

Source: Own preparation from PVSyst outputs and Nord Pool's data

Finally, the earnings per year become 1,426,918 € and the payback time is 28 years.

4.1.4 Solar PV power station in Valencia (Spain)

Table 4.4 shows the incomes for the solar PV station in Valencia

TABLE 4.4: INCOMES PER MONTH FOR THE SOLAR PV STATION IN VALENCIA

	Price €/Mwh	Electricity (MWh)	Incomes (€)
Jan	63.70	5351.86	340928.37
Feb	53.66	6181.63	331723.04
Mar	48.98	7393.64	362104.06
Apr	50.47	7254.28	366125.32
May	55.51	7244.04	402118.70
Jun	59.15	7133.42	421927.11
Jul	62.85	7509.41	472000.36
Aug	65.94	7288.79	480604.13
Sep	72.89	6545.45	477129.88
Oct	67.04	6386.78	428147.76
Nov	63.70	5323.11	339085.78
Dec	63.70	4553.26	290045.38
total	60.63	78165.69	4711939.91

Source: Own preparation with PVSyst's outputs and REE's data

Finally, the solar PV power station in Valencia would earn 3,711,940 € per year, which leads to a payback time of 10.8 years.

4.2 Approach with support

From all the different methods to support renewable energies explained in points *3.2.6 Support for renewables in Spain* and *3.3.6 Support for renewables in Sweden*, here only the electricity certificates system and the investment subsidy in the Spanish system are considered.

4.2.1 Power Stations in Sweden

With the new incomes and keeping the previous costs, the situation for both power stations has changed:

Tables 4.5 and *4.6* show new incomes of the solar PV and wind power stations in Sweden, adding the electricity certificate incomes.

TABLE 4.5: INCOMES PER MONTH FOR THE SOLAR PV STATION IN NORRKÖPING (WITH ELECTRICITY CERTIFICATES)

	Elect. Price €/Mwh	Electricity (MWh)	Sold Certificates	Cert. price (€/cert.)	Incomes (€)
Jan	35.02	2000.22	1180	7.87	79331.16
Feb	42.21	2476.56	1461	9.72	118732.57
Mar	48.35	5336.63	3149	9.43	287729.36
Apr	40.38	5834.72	3442	14.09	284097.32
May	35.01	6955.09	4104	17.11	313677.22
Jun	45.34	6119.76	3611	14.77	330795.61
Jul	53.30	6655.42	3927	19.15	429946.90
Aug	56.77	5715.61	3372	26.24	412975.28
Sep	53.25	5069.99	2991	22.65	337711.93
Oct	46.91	3194.61	1885	14.58	177354.63
Nov	52.08	1533.83	905	16.57	94880.15
Dec	54.19	1085.97	641	15.84	68994.91
total	46.90	51978.40	30667	15.67	2936227.05

Source: own preparation with data from Nord Pool, SKM and PVSyst

TABLE 4.6: INCOMES FOR THE WIND POWER STATION IN MALMSLÄTT (WITH ELECTRICITY CERTIFICATES)

	Elect. Price €/MWh	Electricity (MWh)	Sold Certificates	Cert. price (€/cert.)	Incomes (€)
Jan	32.39	20544.93267	12122	7.87	760934.9
Feb	39.85	14117.90724	8330	9.72	643579.6
Mar	44.83	17756.3869	10476	9.43	894852.5
Apr	38.89	15006.19954	8854	14.09	708332.2
May	32.74	11355.94537	6700	17.11	486366.5
Jun	44.21	13742.70818	8108	14.77	727305.8
Jul	52.40	10663.04316	6291	19.15	679193.0
Aug	53.30	6363.126035	3754	26.24	437702.9
Sep	56.77	10532.67881	6214	22.65	738678.9
Oct	53.25	20146.86249	11887	14.58	1246086.4
Nov	46.91	17162.28002	10126	16.57	972971.1
Dec	52.08	19815.73702	11691	15.84	1217246.9
total	45.64	177207.8074	104553	15.67	9513250.9

Source: Own preparation with data from Nord Pool, SMHI, SKM and Vestas

- Solar PV in Norrköping:
  - New earnings per year: 1,936,227 €
  - New payback time: 20.7 years
- Wind farm in Malmslätt:
  - New earnings per year: 7,908,835 €
  - New payback time: 9.3 years.

4.2.2 Power Stations in Spain

Using the subsidies showed in *2.2.5 Adding the support policies to the analysis* the new payback times are:

- For the wind power station: 12.5 years

- For the solar PV power station: 10.24 years

4.3 Summarize of the results

In this section, the most important results of the different simulations are presented together, so that the results can be compared easily.

TABLE 4.7 SUMMARIZE OF THE SIMULATION'S RESULTS

		Installed cost (€)	O&M cost (€/year)	Incomes (€/year)	Earnings (€/year)	Payback time (years)
Without Support	Wind Malmslätt	73,500,000	1,604,415	7,992,801	6,388,386	11.5
	Wind Valencia	65,000,000	2,257,268	7,260,023	5,002,755	13
	Solar PV Norrköping	40,000,000	1,000,000	2,426,918	1,426,918	28
	Solar PV Valencia	40,000,000	1,000,000	4,711,939	3,711,939	10.8
With Support	Wind Malmslätt	73,500,000	1,604,415	9,513,250	7,908,835	9.3
	Wind Valencia	62,615,800	2,257,268	7,260,023	5,002,755	12.5
	Solar PV Norrköping	40,000,000	1,000,000	2,936,227	1,936,227	20.7
	Solar PV Valencia	38,017,700	1,000,000	4,711,939	3,711,939	10.24

These results will be commented later, in the discussion part.

5. DISCUSSION

The aim of this chapter is to present a discussion on the contents of chapters 3 and 4, analyzing the present state of both countries in energy matters and its room for improvement.

5.1 Current development of renewable energies

Given the global energy balance presented in *Figure 3.1*, (section *3.1.1 Global Energy Balance*), it seems evident that most of the countries still base their economies in fossil fuels.

Conventional renewable energies, like hydropower or biomass, have a larger share in this energy balance than non-conventional renewable energies, like wind power or ocean power. One reason that would explain this is the fact that technologies like wind power or solar PV have started to become profitable during the last years, while other technologies like ocean power or geothermal power have not reached the necessary level of development to be profitable by themselves, in general.

However, as *Figure 3.5* (section *3.1.2*) shows, the exponential growth of solar PV and wind power has more than doubled the renewable power capacity within 10 years.

Looking at *Figure 3.3* (section *3.1.1*), probably the sector with the biggest room for improvement is the transport sector, where renewable energies only account for 3% of total energy use. This problem could be solved by increasing the share of biofuels and electric vehicles. On the other hand, the heating sector, which is the most energy-consuming, also could be improved by increasing the share of biomass in an energy-efficient way.

The conclusion in this section could be that renewable energies are growing faster than expected, especially in the electricity sector, but there is still a huge room for improvement, especially in the transport sector.

5.2Energy balance, installed capacity and electricity generation in Sweden and Spain

Starting from the Spanish case, there is a great room for improvement. First of all, it is completely pointless to have a system based on fossil fuels in Spain, since its reserves are almost non-existent. 99.9% of oil, natural gas and coal that are used in Spain have to be imported, and that makes the country extremely vulnerable to changes in their prices. Moreover, this system is very pollutant and unsustainable, and it is destined to be over sooner or later, when global fossil fuel reserves start to run out.

The largest improvement potential is clearly in the sector with the highest energy use: transport. With an almost inexistent presence of biofuels and a relatively small electricity use, oil is the most important source of energy in the transport sector (see *Figure 3.6* in section *3.2.1 Energy Balance in Spain*). In a country with so much agriculture and livestock activity, it would make sense to invest in the development of biofuels, with the possibility to save a great amount of polluting gases and make the Spanish' economy more independent.

On the other hand, a transition to the model of an electric vehicle, together with a renewable or nuclear based electricity generation, could also lead to more sustainable energy consumption in the transport sector.

Regarding the installed capacity, Spain is still the first and the fifth country in the world in CSP and wind power installed capacity, respectively. It also used to be one of the leaders in solar PV systems, but maybe due to its sudden legislation change, it lost that position some years ago. This is probably one of the most important issues to discuss in the Spanish' energy system, since it is one of the countries in Europe with the highest solar resource, and PV technology seems to have acquired an enough level of development to become profitable in many cases.

Another issue to discuss is how to manage the valley demand, which until now has been met with nuclear power mainly. One possibility could be to rebuild the currently existent nuclear power stations as they get too old to keep working (that will happen no later than the next 5-10 years).

There is also a great installed capacity of combined cycle (the biggest installed capacity in Spain). It offers a high-efficient solution to meet peaks of demand, which might not be satisfied only with renewable energies. For example, in peaks of demand at nights, when there is no solar PV generation, if they happen when there is no much wind and when reservoirs are not plenty enough to meet such peaks, the best solution to satisfy them is to use all those combined cycle power stations. A better long-term solution could be to install biomass power plants, that could start to produce electricity during these peak loads too. This could be done as electricity generation with biomass gets cheaper.

Regarding the Swedish energy system, thanks to *Figure 3.13* in section *3.3.1 Energy balance in Sweden,* the evolution of the Swedish model can be observed. It is flashy to see how in 40 years a fossil fuel-based model has been transformed into a nuclear and renewable energies-based model. If the main source of energy for Sweden was oil in the 70s and 80s, the growth of biofuels, the development of nuclear powers and the installation of hydroelectric and wind power stations have managed to reduce the oil consumption to less than half, and this was done while the total energy consumption was growing. However, Sweden still has a big room for improvement, with a larger than 150 TWh oil and coal consumption in 2016.

The sector with the greatest improvement potentials is, again, the transport sector. More than 75% of total energy consumption in transport comes from oil use, while the rest belongs to biofuels. New investments and polices to support biofuels could increase their share in this field. Meanwhile, electric vehicle companies still need to work on attracting more customers to perform what seems to be an unavoidable transition to a new electricity-based transport model.

Residential and service sector is quite well optimized from the point of view of energy supply. Half of its total energy use comes from electricity and more than one fourth is district heating, which normally uses wastes to produce heat. Biofuels have the biggest share of the remaining energy consumption, that is completed with oil and natural gas. In this sector, maybe the best way of making a progress is to work on the demand, that is, to reduce energy consumption through the performance of energy audits.

Finally, the industrial sector is based mainly on electricity and biofuels, which together account for two thirds of the total energy use. The rest is a mix of oil, natural gas, district heating and other fuels. This leaves a considerable margin to invest in renewable energies, although it seems that many companies have already done such investments, to use transform their wastes into their own sources of energy. That would explain the large share of the biofuels in this sector.

Regarding the distribution of the electricity generation, nuclear power and hydropower work together to meet more than 80% of the demand. Their power capacity is enough to satisfy valley and base demand. A relevant growth in wind power in the last 10 years has achieved to get a share of 10% of total electricity production. While the remaining 10% was provided by CHP. Peak demand is satisfied also with hydropower, although some wind turbines and conventional power stations could produce electricity, if needed.

5.3 Support policies

Starting with the Spanish case, the first thing to say is that all the sudden changes in legislation could have had a negative effect on the development of the renewable energies, because it can create a state of uncertainty that would not help to attract investors to this sector.

However, it cannot be denied that renewable energies in Spain grew fast between 2007 and 2013 (when the legislation was more favorable, see *3.2.6 Support systems for renewables*). *Figure 3.26*, from *3.5.1 Solar Resource in Spain* shows how, the solar PV's contribution to the electricity production started being relevant in 2007, growing from 0% to 3% in 6 years. Such development was stopped in 2013, with the already mentioned change in legislation. *Figure 3.28*, from *3.5.2 Wind Resource in Spain* also shows the same tendency before and after 2013.

In the late years, with the progress in costs, these technologies are becoming more and more profitable by themselves, not depending on subsidies or bonuses, but on the spot market price and maybe the fossil fuel prices.

Another interesting subject to discuss could be what consequences these policies have had on the final price for the small customers, and whether it has been beneficial or detrimental for them. Nevertheless, this is not a matter to be addressed in this report.

Regarding the Swedish case, checking the evolution of installed capacity in *Figure 3.17* (*3.3.5 Installed Power Capacity in Sweden*), the evolution of the quota obligations in *Figure 3.19* and the evolution of certificates' price in *Table 3.4* (*3.3.6 Support systems for renewables*) it seems that there is an interrelationship. The growth of wind power's installed capacity became noticeable among 2009-2010. Those years had the highest average prices for the certificates (293 and 295 SEK, respectively) and, moreover, a maximum was reached in the quota obligations in 2010. This demonstrates the effect of the electricity certificates on the wind power development.

Quota obligations are expected to reach their peak in 2020, and then decrease slightly until their final extinction in 2035, when they should be no longer needed. Therefore, this system has succeeded in its aim, although its effect might be not as clear as in the Spanish case. One last compelling subject to discuss could be which model has had the higher costs on the final customers and which one was more cost-effective. This matter, still, is also out of the limits of this report.

5.4 Analysis of the simulations

This section will analyze the results of the simulations of the power stations and what other results could have been obtained if different assumptions would have been made.

It must be considered that every earning or payback time calculated is based on the current electricity and certificates price, in addition to the most recent costs data founded. A slight change in any considered price or a considerable change in the costs will have a huge impact on such results.

However, the process of applying a new hypothesis and then re-calculating everything is very quickly, since every operation is programmed so that one change in input data produces instant changes in the output results.

5.4.1 Power stations in Spain

5.4.1.1 Solar PV power station

This power station would have an approximate payback time of 10.77 years without any subsidy for the investment and 10.24 years with it. The earnings per year would be the same, around 3.72 M€.

10 years is a quite reasonable payback time for a project of this size. With an expected useful life of 25 years, the total earnings could be around 52.8 M€ in the first case and 54.8 M€ in

the second one. Even if the selected costs would have been too optimistic, this project still has room to be feasible.

The subsidy does not make a big difference, since it only affects slightly the investment.

As a conclusion, a deeper study on this project is likely to offer similar profitability results, and that would mean that middle and large-scale solar PV projects are already profitable in Spain, at least in a location with a similar or better solar resource than this one. As it can be observed in *3.5.1 Solar Resource in Spain* such locations are plentiful. This means that, at least apparently, there is no reason to deny the huge potential of growth that PV technology has in Spain.

5.4.1.2 Wind power station

In this case, the payback time would be around 13 years without the subsidy and around 12.5 years with it. As it could be expected, a higher investment requires a higher payback time, but earnings are also larger, since this power station would have a higher capacity factor. The earnings would be around 5 M€ per year in both cases.

Considering 25 years of technical lifetime, total earnings could be 60 M€ without the subsidy and 62.5 M€ with it.

In this case the subsidy does not make a noticeable difference either.

To sum up, even if projects like this could be attractive for an investor, in a country like Spain, with more than 23 GW of installed capacity and not especially remarkable wind resource, the best locations are normally used already. Maybe the future investments will focus on installing new and more bigger turbines in the old onshore wind farms or in exploring the possibilities in offshore locations, when such technology gets cheaper or when some truly supportive policies motivate new investments.

5.4.2 Power stations in Sweden

5.4.2.1 Solar PV power station

This power station would have a payback time of 28 years if the electricity certificate system would not exist in Sweden and 20.6 years in the contrary case (in the current existent system). Being a longer period of time than the useful life itself, the value of the payback time for the first case automatically leads to discard the project.

In the second case, the value is lower than the useful life, and that means that Swedish policies do have a big impact in these projects, but 20.6 years is still way too high to consider this project profitable. Moreover, adding the uncertainty of what will happen with the certificates system, this project becomes even less attractive for any investor.

The problem here resides in the resource. This location, even if it is not one of the worst ones in Sweden, does not offer enough solar resource to make the project profitable.

It could be said that in other locations with better resource, like in Visby, a project like that might be feasible, but the shortage of similar projects in Sweden indicates that there are better options.

Anyway, small-scale projects, which are not considered in this report, with the additional subsidy that the Swedish government offers, may be a good option for some householders or companies.

5.4.2.2 Wind power station

Ignoring the effect of the electricity certificates, the payback time of this power station would be around 11.5 years, while considering it, it becomes 9.3 years. This last value is the lowest of all ones, even if the investment is the highest. The earnings for the first and the second case would be 6.4 M€ and 7.9 M€, respectively. Both cases reflect good profitability, and the Swedish support policy influences them very positively.

There are two reasons to explain such results.

Firstly, the location has very good resource, way better than the Spanish location, so that the amount of energy that the same wind turbines produce is also larger. Secondly, as it can be observed in *Figure 3.16*, in *3.3.3 Price evolution in the spot market*, the average price of electricity in Sweden has raised considerably in the last years. Thereby, considering these last prices to do the calculations, the results show a better profitability than if other prices would have been chosen.

To sum up, if electricity prices continue raising this way, it is likely that companies start thinking of investing more money in wind power in Sweden.

5.4 Final conclusions

This point will address the research questions from *1.3 Research questions*, trying to give coherent and justified answers.

First of all, after analyzing Swedish and Spanish energy balances, it seems obvious that the Spanish energy system is more strongly based on fossil fuels, although it could no be said that Swedish energy system is completely independent on them either.

None of these countries has relevant oil, natural gas or coal reserves, so changing this model into another one based on renewable energies and (maybe) nuclear power is recommendable.

For example, in both cases the transport sector is still clearly based on oil, so promoting biofuels and electric cars might be a very good measure to improve both situations.

However, in other sectors, the Spanish case presents a larger room for improvement, since oil and especially natural gas are some of the main sources of energy in the residential-service sector and in the industrial sector. Using biomass instead of fossil fuels or using more electricity could make a big difference in this field too.

There are two parameters that powerfully influence the possibility to do this in a cost-effective way. First one is technology research. The main obstacle of biomass, biofuels and electricity in front of the fossil fuels is the profitability, especially in the two first cases. Thereby, as long as technology research keeps on reducing these costs, such changes should be done soon. Moreover, in the case of electric cars, a reasonable hypothesis is that when batteries development reaches the possibility of doing long trips without having to stop to charge them, in a cost-effective way, more and more people might start buying electric vehicles and, consequently, reduce oil consumption of countries like Spain and Sweden. This will not only mean a change of energy carriers, but also huge net energy savings, since electric engines have much higher efficiency than thermal motors.

The second one is the evolution of fossil fuel prices. If these prices are increased, then alternative solutions will be more profitable and, thereby, more likely to be carried out. And unfortunately, if such prices were decreased, then these environment-friendly solutions might become less profitable than fossil fuels and, therefore, less likely to be carried out.

Regarding the profitability of wind power, both theoretical and practical approaches seem to confirm it in both countries. However, Sweden has currently a larger underused wind resource than Spain, where wind power is the second most widespread technology in electricity production. Therefore, wind power projects may have higher profitability in Sweden than in Spain.

On the other hand, the profitability of utility-scale solar PV projects is not so clear. In Spain, with the available solar resource and the already low costs, that are expected to keep on decreasing, is unquestionable confirmed, at least under good project-design and maintenance conditions. Nevertheless, the Swedish case is debatable. The almost absence of larger than 1MW solar PV power stations is a good sign of their profitability in Sweden. Even if considering the effect of the electricity certificates, it seems hard to find a location in Sweden with good enough solar resource to install a large power station there, at least with current costs. Maybe in some years, with some advances in efficiency and in costs, such projects could become profitable in Sweden too.

Regarding the effect of the support policies, the Swedish model is currently way more helpful to stimulate renewable energies development than the Spanish one. The latter used to work very well in the past, but after being changed, figures show how solar PV's and wind power's growth was strongly slowed down. The previous model's sustainability could also be questioned, anyway.

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APPENDIX 1: Vestas V90 1.8 MW information

V90-1.8/2.0 MW
Facts and figures

POWER REGULATION	pitch regulated with variable speed

OPERATING DATA

Rated power	IEC IIA - 50 Hz: 1,800 kW IEC IIA - 60 Hz: 1,815 kW IEC IIIA - 50 Hz: 2,000 kW
Cut-in wind speed	4.0 m/s
Rated wind speed	12 m/s
Cut-out wind speed	25 m/s
Wind class	IEC IIA (V90-1.8 MW) IEC IIIA (V90-2.0 MW)
Operating temperature range	standard turbine: -20°C to 40°C low temperature turbine: -30°C to 40°C

SOUND POWER MODES

Mode 0: Max sound power level:	104 dB(A)
Mode 1: Max sound power level:	103 dB(A)
Mode 2: Max sound power level:	101 dB(A)
Mode 3: Max sound power level:	104 dB(A)*

*) low noise at low wind

ROTOR

Rotor diameter	90 m
Swept area	6,362 m^2
Nominal revolution	14.5 rpm
Operational interval	9.3 – 16.6 rpm
Air brake	full blade feathering with 3 pitch cylinders

ELECTRICAL

Frequency	50/60 Hz
Generator type	4-pole (50 Hz)/6-pole (60 Hz) doubly fed generator, slip rings
Nominal output	50 Hz: 1,800 kW / 2,000 kW 60 Hz: 1,815 kW

GEARBOX

Type	two planetary stages and one helical stage

TOWER

Type	tubular steel tower
Hub heights	
V90-1.8 MW - 50 Hz	80 m, 95 m and 105 m (IEC IIA)
V90-1.8 MW - 60 Hz	80 m and 95 m (IEC IIA)
V90-2.0 MW	80 m, 95 m, 105 m and 125 m (IEC IIIA)
V90-2.0 MW	95 m, 105 m and 125 m (DIBt II)

BLADE DIMENSIONS

Length	44 m
Max. chord	3.5 m

NACELLE DIMENSIONS

Height for transport	4 m
Height installed (incl. CoolerTop®)	5.4 m
Length	10.4 m
Width	3.4 m

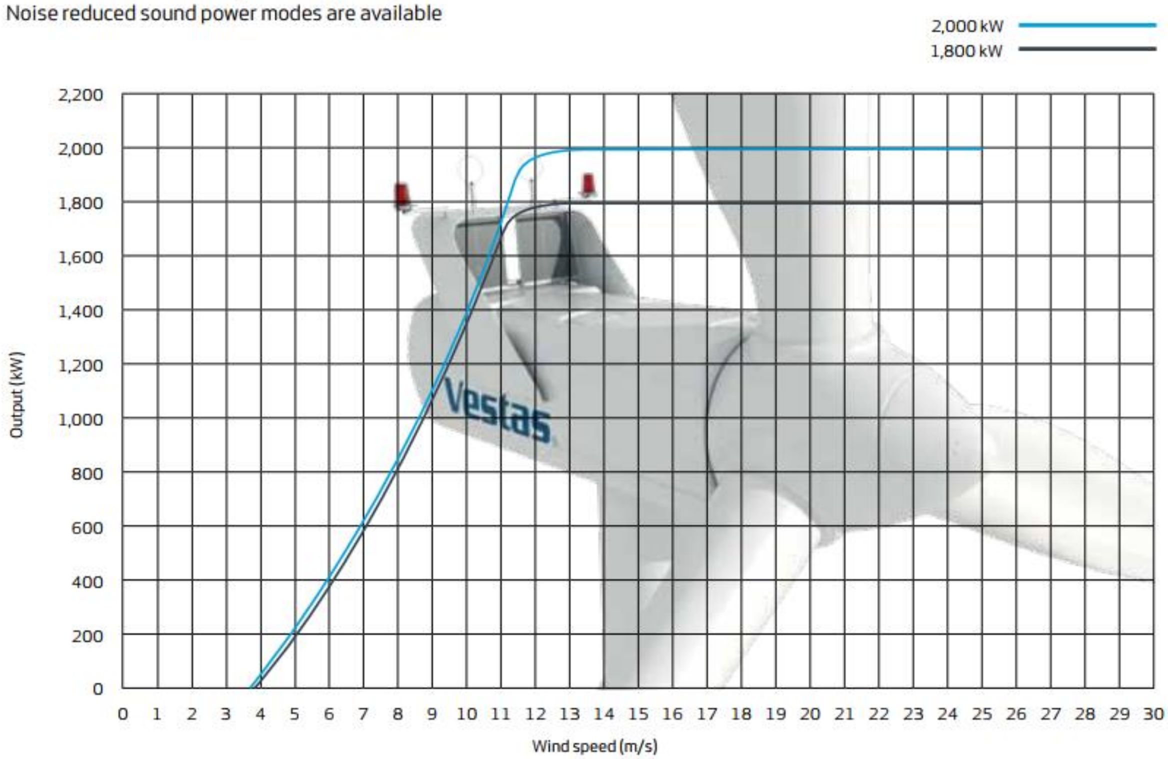
HUB DIMENSIONS

Max. diameter	3.3 m
Max. width	4 m
Length	4.2 m

Max. weight per unit for transportation	70 metric tonnes

POWER CURVE V90-1.8/2.0 MW (50 Hz)

Noise reduced sound power modes are available



APPENDIX 2: Wind Speed data from Valencia's port

Official data from Valencia's port at 20 m height.

Interval	Count	Interval	Count	Frequency
<1	22766	0	22766	0.11
<2	45962	1-2	23196	0.11
<3	84851	2-3	38889	0.18
<4	119077	3-4	34226	0.16
<5	145402	4-5	26325	0.12
<6	165588	5-6	20186	0.10
<7	181128	6-7	15540	0.07
<8	191834	7-8	10706	0.05
<9	199415	8-9	7581	0.04
<10	204587	9-10	5172	0.02
<11	207731	10-11	3144	0.01
<12	209647	11-12	1916	0.01
<13	210730	12-13	1083	0.01
<14	211395	13-14	665	0.00
<15	211801	14-15	406	0.00
<16	212015	15-16	214	0.00
<17	212126	16-17	111	0.00
<18	212204	17-18	78	0.00
<19	212254	18-19	50	0.00
<20	212295	19-20	41	0.00

APPENDIX 3: OUTPUT DATA FROM PVSYST (next sheet)

PVSYST V6.79		01/06/19	Page 1/1

Grid system presizing

Geographical Site	**Norrkoping/Kungsang**	Country	**Sweden**
Situation	Latitude 58.58° N	Longitude	16.25° E
Time defined as	Legal Time Time zone UT+1	Altitude	5 m
Collector Plane Orientation	Tilt 60°	Azimuth	0°

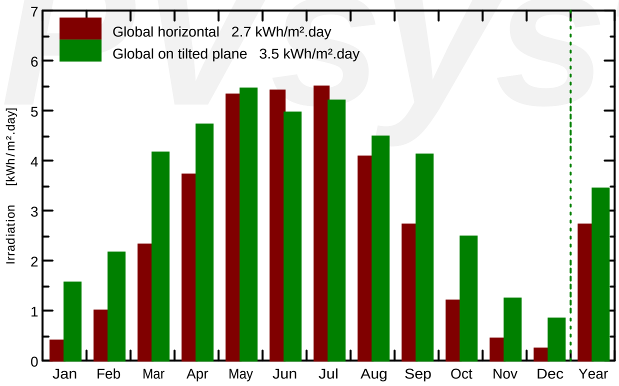
PV-field installation main features

Module type	Standard
Technology	Monocrystalline cells
Mounting method	Ground based
Back ventilation properties	Free standing

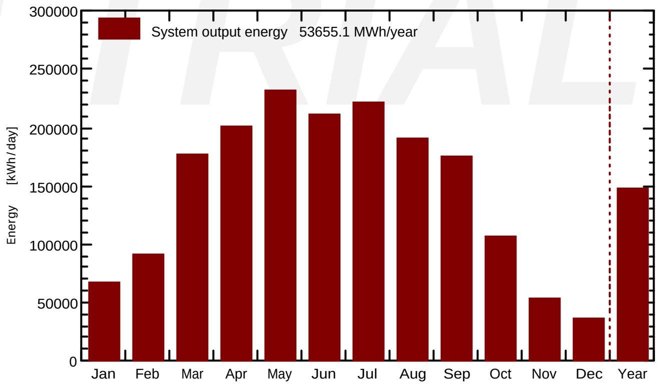
System characteristics and pre-sizing evaluation

PV-field nominal power (STC)	Pnom	50000 kWp		
Collector area	Acoll	312500 m²		
Annual energy yield	Eyear	53655 MWh	Specific yield	1073 kWh/kWp
Economic gross evaluation	Investment	*86699 EUR	Energy price	0.09 EUR/kWh

Meteo and incident energy



System output



	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh
Jan.	0.42	1.57	66605	2064741
Feb.	1.01	2.15	91302	2556447
Mar.	2.33	4.18	177703	5508780
Apr.	3.72	4.73	200764	6022933
May	5.33	5.45	231595	7179444
June	5.42	4.96	210573	6317176
July	5.49	5.22	221617	6870113
Aug.	4.10	4.48	190322	5899980
Sep.	2.72	4.11	174451	5233534
Oct.	1.19	2.51	106376	3297665
Nov.	0.44	1.24	52777	1583306
Dec.	0.23	0.85	36161	1120998
Year	2.71	3.46	147000	53655116

Grid system presizing

Geographical Site — **Valencia** — Country **Spain**

Situation — Latitude 39.48° N — Longitude -0.38° W
Time defined as — Legal Time — Time zone UT+1 — Altitude 13 m

Collector Plane Orientation — Tilt 45° — Azimuth 0°

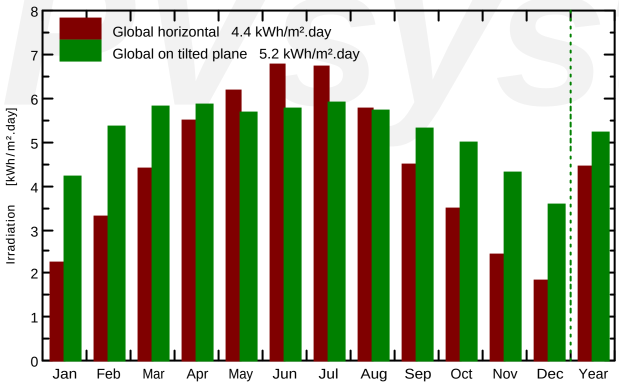
PV-field installation main features

Module type	Standard
Technology	Monocrystalline cells
Mounting method	Ground based
Back ventilation properties	No ventilation

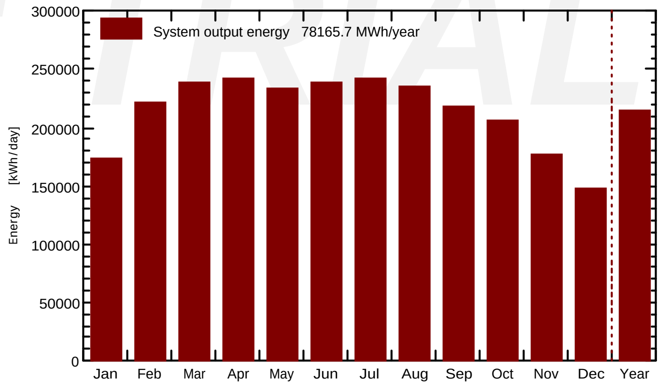
System characteristics and pre-sizing evaluation

PV-field nominal power (STC)	Pnom	50000	kWp			
Collector area	Acoll	312500	m²			
Annual energy yield	Eyear	78166	MWh	Specific yield	1563	kWh/kWp
Economic gross evaluation	Investment	*86699	EUR	Energy price	0.06	EUR/kWh

Meteo and incident energy



System output



	Gl. horiz.	Coll. Plane	System output	System output
	kWh/m².day	kWh/m².day	kWh/day	kWh
Jan.	2.25	4.20	172641	5351858
Feb.	3.30	5.37	220773	6181634
Mar.	4.38	5.80	238505	7393643
Apr.	5.49	5.88	241809	7254284
May	6.20	5.68	233679	7244043
June	6.77	5.78	237781	7133418
July	6.72	5.89	242239	7509413
Aug.	5.76	5.72	235122	7288792
Sep.	4.48	5.30	218182	6545452
Oct.	3.46	5.01	206025	6386782
Nov.	2.42	4.31	177437	5323112
Dec.	1.84	3.57	146879	4553255
Year	4.43	5.21	214153	78165686

PVsyst TRIAL