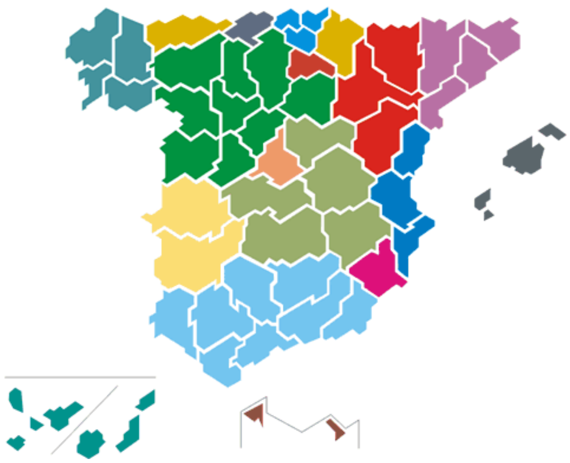
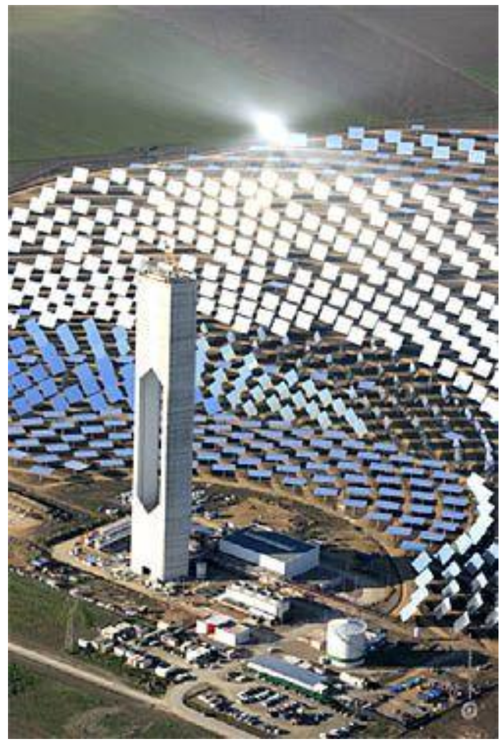
GENI Global Energy Network Institute

Can Spain Reach 100% Renewable Energy by 2020?





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Nigel Williams
Research Associate, Global Energy Network Institute (GENI)
willnj@cox.net

Under the supervision of and edited by
Peter Meisen
President, Global Energy Network Institute (GENI)
www.geni.org
peter@geni.org (619) 595-0139

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Abstract

Spain is a world leader in renewable energies. Their leadership is seen through their implementation of wind and solar power. Spain ranks 4th in the world in wind energy. Also, the country ranks in 2nd place in both photovoltaic solar and thermoelectric solar. In 2010, Spain was able to meet 35% of its electricity demand using renewable energies. The energies with the largest contribution were wind, hydropower, and solar. The 35% was achieved because Spain already had a good foundation for renewable energies to take hold. Despite this and the tremendous progress Spain has made, the majority of the country's electricity is still derived from fossil fuels.

This paper posits that Spain is theoretically capable of obtaining 100% renewable energy by 2020 -- theoretically only because of the logistical issues involved. Also, Spain's slow recovery from the 2008 global recession has caused some reticence about additional spending. Even with the previously mentioned factors though, Spain does have other features that enable them to reach 100% renewable energy. Spain has a well-established foundation. Again, 35% of demand was met with renewable energy. The installed capacity of renewable energy is constantly increasing. Spain's renewable resources provide great potential for the generation of energy. Some policies have been created to promote and facilitate the usage of renewables.

1. The Current Energy Situation

1.1. Energy Demand

1.1a. National Demand

The 2010 national electricity demand for Spain was 275,773 GWh, or about 276 TWh, according to Red Eléctrica de España, the operator of Spain's electricity system[1]. The table below shows how this number was derived.

Figure 1: Table of the National Demand in 2010 (GWh)

	National Total
Hydroelectric	38,653 GWh
Nuclear	61,990 GWh
Coal	25,478 GWh
Fuel/Gas	9,553 GWh
Combined Cycle	68,595 GWh
Ordinary Regime	204,270 GWh
Generation Consumption	- 7,575 GWh
Special Regime	91,866 GWh
Net Production	288,563 GWh
Pump Storage Consumption	- 4,458 GWh
International Exchanges	- 8,333 GWh
Demand in 2010	**275,773 GWh**
Demand in 2009	267,711 GWh

Source: Red Eléctrica de España

Briefly, the terms ordinary and special regime should be defined. The "ordinary regime" includes the more conventional energy sources. This would include nuclear, coal, fuel/gas, hydroelectric above 10 MW of installation, and combined cycle. The "special regime" includes energy sources "*that use co-generation, renewable sources and waste products in facilities with power of no more than 50 MW*"[2]. This also includes, "*Groups which use non-renewable or*

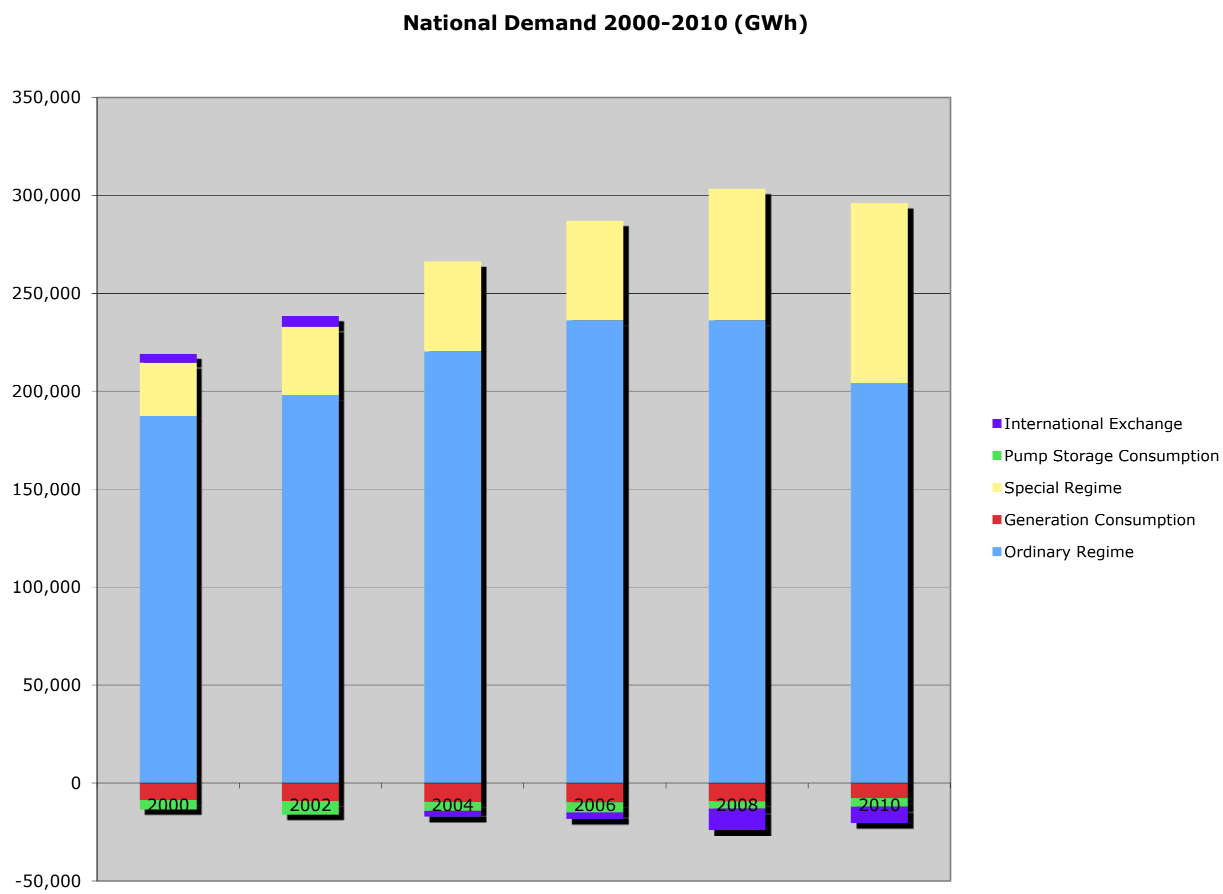
[1] Red Eléctrica de España. 2010 Sistema Eléctrico Español. (Madrid, Spain: Red Eléctrica de España, 2011), 9.
[2] "The Special Regime and the CNE," *Comisión Nacional de Energía*, accessed September 12, 2011, http://www.eng.cne.es/cne/contenido.jsp?id_nodo=411&&&keyword=&auditoria=F

agricultural waste, livestock and service sector waste as primary energy sources, with an installed power lower than or equal to 25 MW, when they entail a high energy yield"[3].

Going back, the ordinary regime covered roughly 66.8% of the total national demand. Of those energies marked under the ordinary regime, combined cycle takes up the majority, it accounts for 23% of national demand. The special regime was 91,866 GWh, 33.2% of the 2010 demand, and the lion's share of that generation came from wind energy.

Figure 2: Evolution of National Demand 2000-2010 (GWh)

Over the years, the special regime has seen the largest increase, while the share the ordinary regime possesses has actually been decreasing.



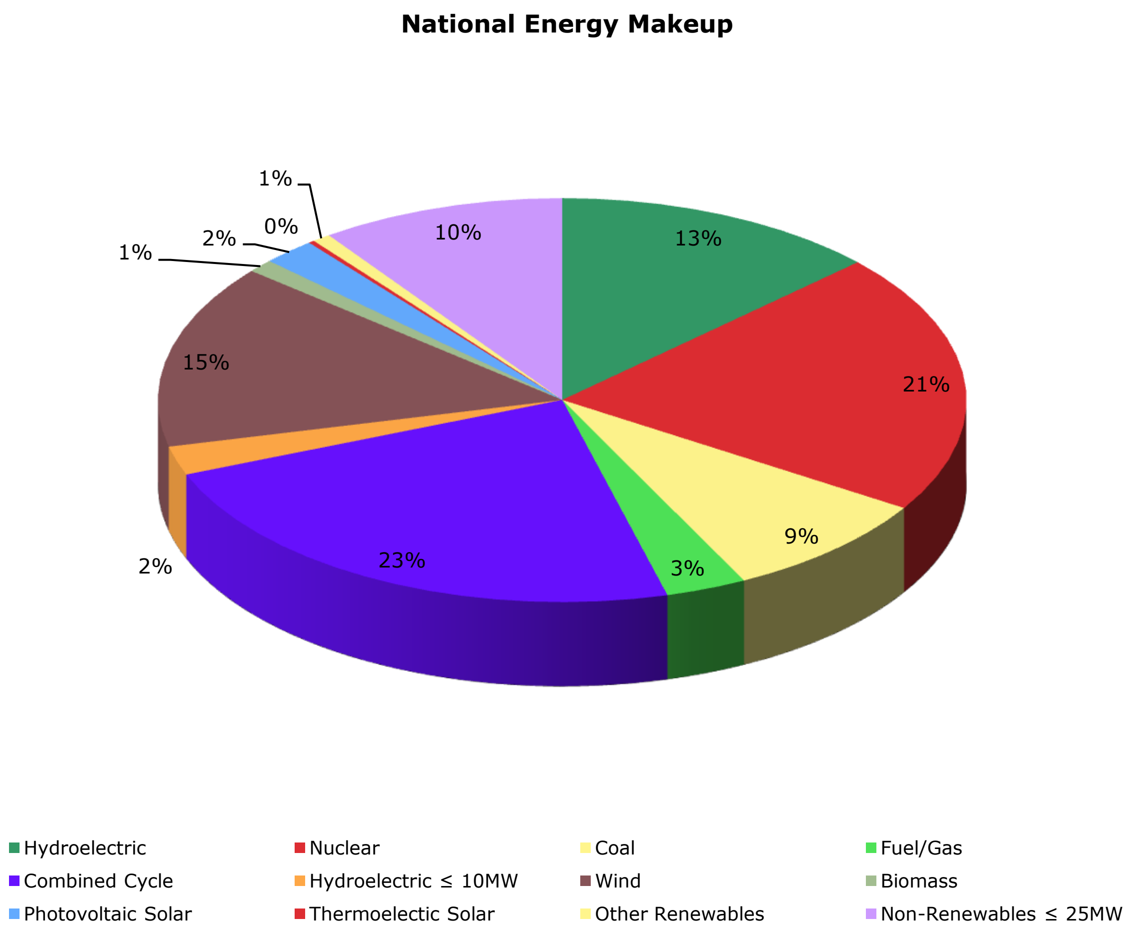
Source: Red Eléctrica de España

[3] "Electric Terminology Index," *Red Eléctrica de España*, accessed September 12, 2011, http://www.ree.es/ingles/ayuda/glosario_electrico.asp

1.1.b. National Energy Makeup

By the end of December 2010, Spain is generating roughly 35% of its electricity from renewable energy sources. The three biggest contributors to this were wind, hydro, and solar. The graph below gives a percentage breakdown of each energy source's contribution to the national demand.

Figure 3: The 2010 National Energy Makeup

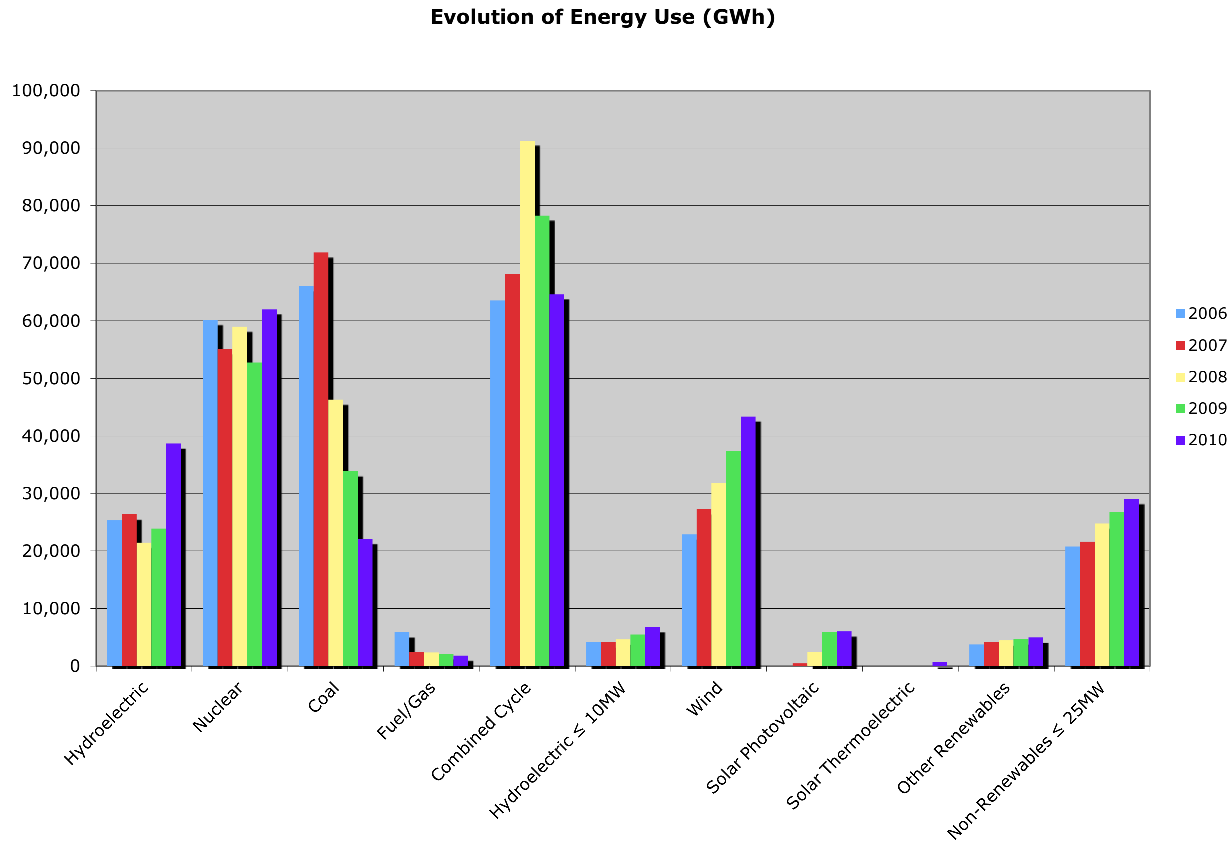


Source: Red Eléctrica de España

Deductions from the generation consumption, international exchange, and the pump consumption are not included in the graph above. The percentages are derived solely from the sum of all energies used.

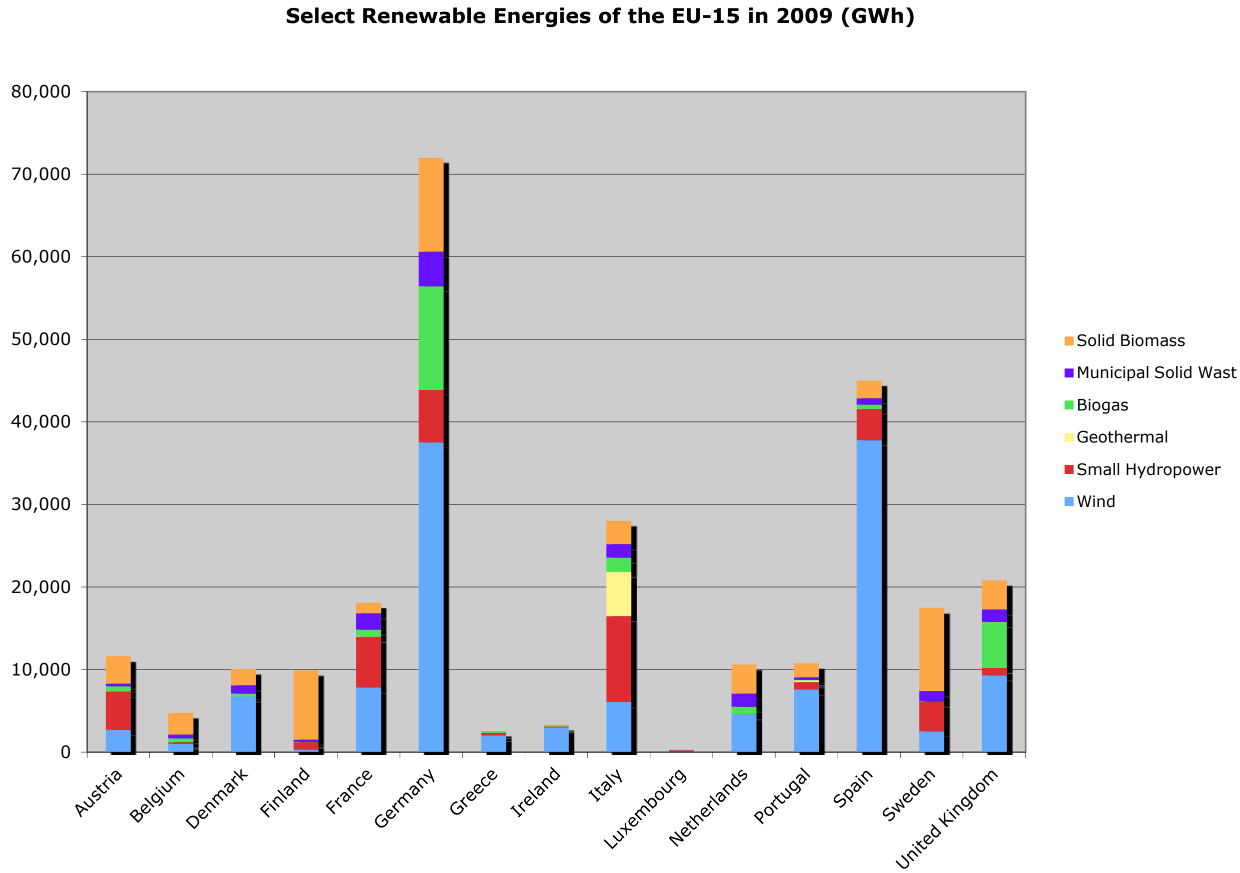
Conventional energy sources still dominate, but renewables are really starting to assert themselves. Figure 4 shows the evolution of the national energy makeup from 2006 to 2010. In 2006 the top four sources were coal, combined cycle, nuclear, and hydroelectric. A few years later, coal saw a dramatic decrease, while wind power surged. 2010's top four altered to combined cycle, nuclear, wind, and hydroelectric.

Figure 4: Energies Used 2006-2010



Source: Red Eléctrica de España

Figure 5: Select Renewable Energies of the EU-15 in 2009
Wind energy has placed Spain among the leaders in EU-15 in regards to renewable electricity



Source: EurObserv'ER

1.1.c. Regional Demand

The table and graph below display the electricity demand by region. The table shows the total demand by region, while the graph shows the breakdown of each region's demand.

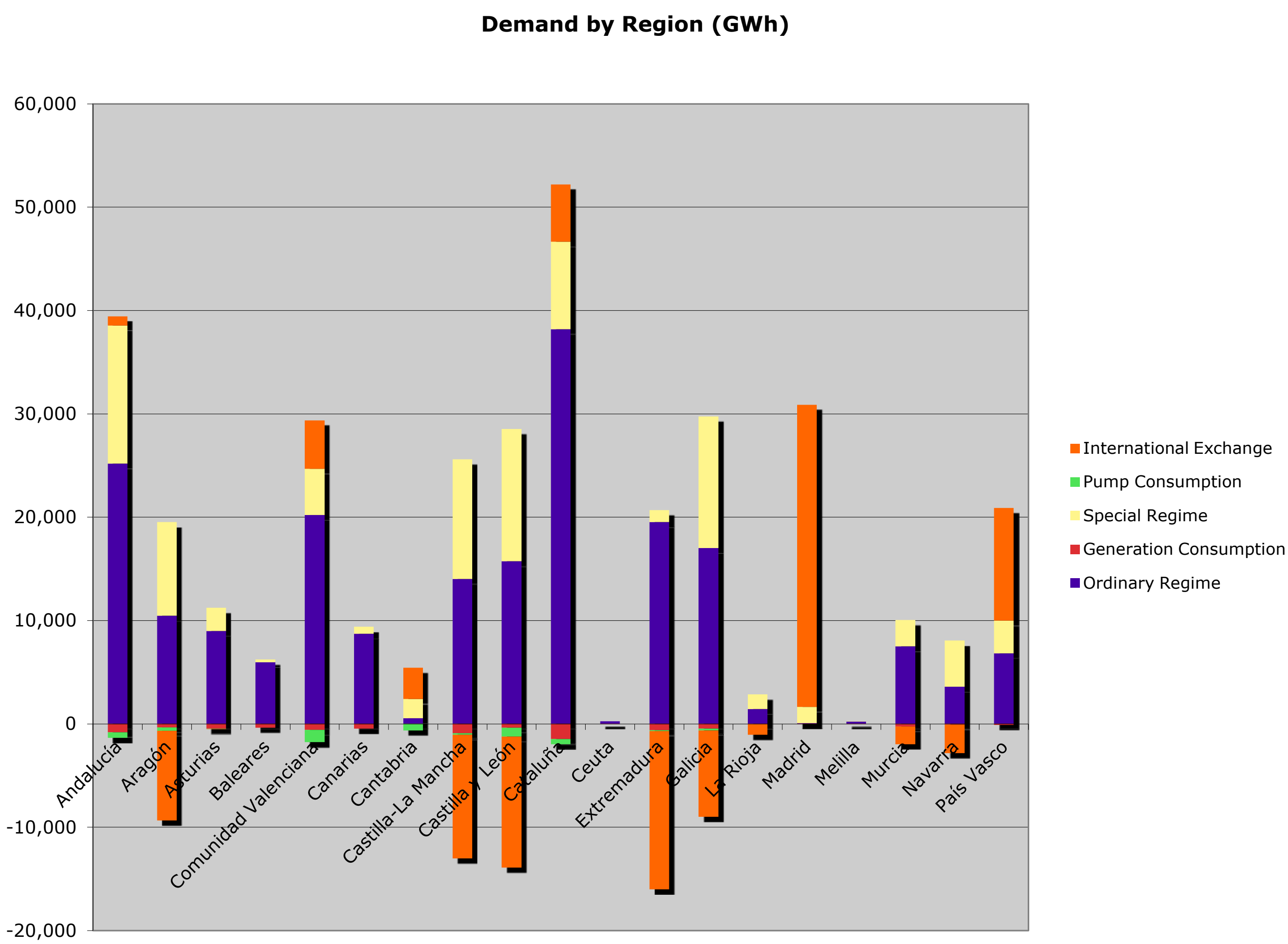
Figure 6: Total Regional Demand in 2010 (GWh)

Region	Demand (GWh)
Andalucía	38,059
Aragón	10,145
Asturias	10,691
Baleares	5,840
Comunidad Valenciana	27,572
Canarias	8,894
Cantabria	4,768
Castilla-La Mancha	12,568
Castilla y León	14,598
Cataluña	50,214

Ceuta	218
Extremadura	4,641
Galicia	20,731
La Rioja	1,766
Madrid	30,874
Melilla	214
Murcia	8,043
Navarra	5,198
País Vasco	20,742
Total	**275,773**

Source: Red Eléctrica de España

Figure 7: Breakdown of Regional Demand (GWh)

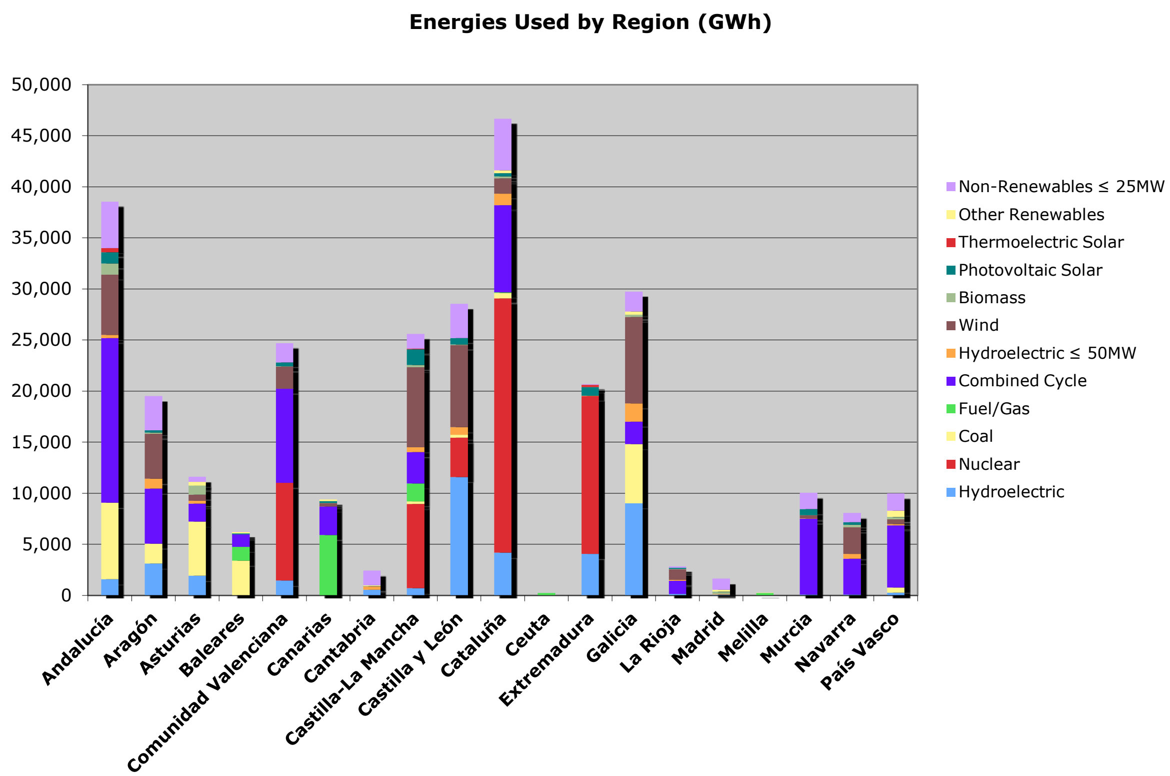


Source: Red Eléctrica de España

The bulk of each regional demand, save for a few exceptions, is from the ordinary regime. This shows that while renewable energies have come a long way there is still a long road ahead. There are some standouts: La Rioja, Navarra, Madrid, and Cantabria are the four regions in the country in which the ordinary regime does not vastly outnumber the special regime. La

Rioja was fairly balanced between both regimes. Navarra, Madrid, and Cantabria were the only regions in Spain to derive more of its energy from the special regime. However, Madrid and Cantabria received a majority of its electricity from international exchanges, thus Navarra was left as the sole region to generate most of its energy from the special regime.

Figure 8: Types of Energy Used by Region (GWh)



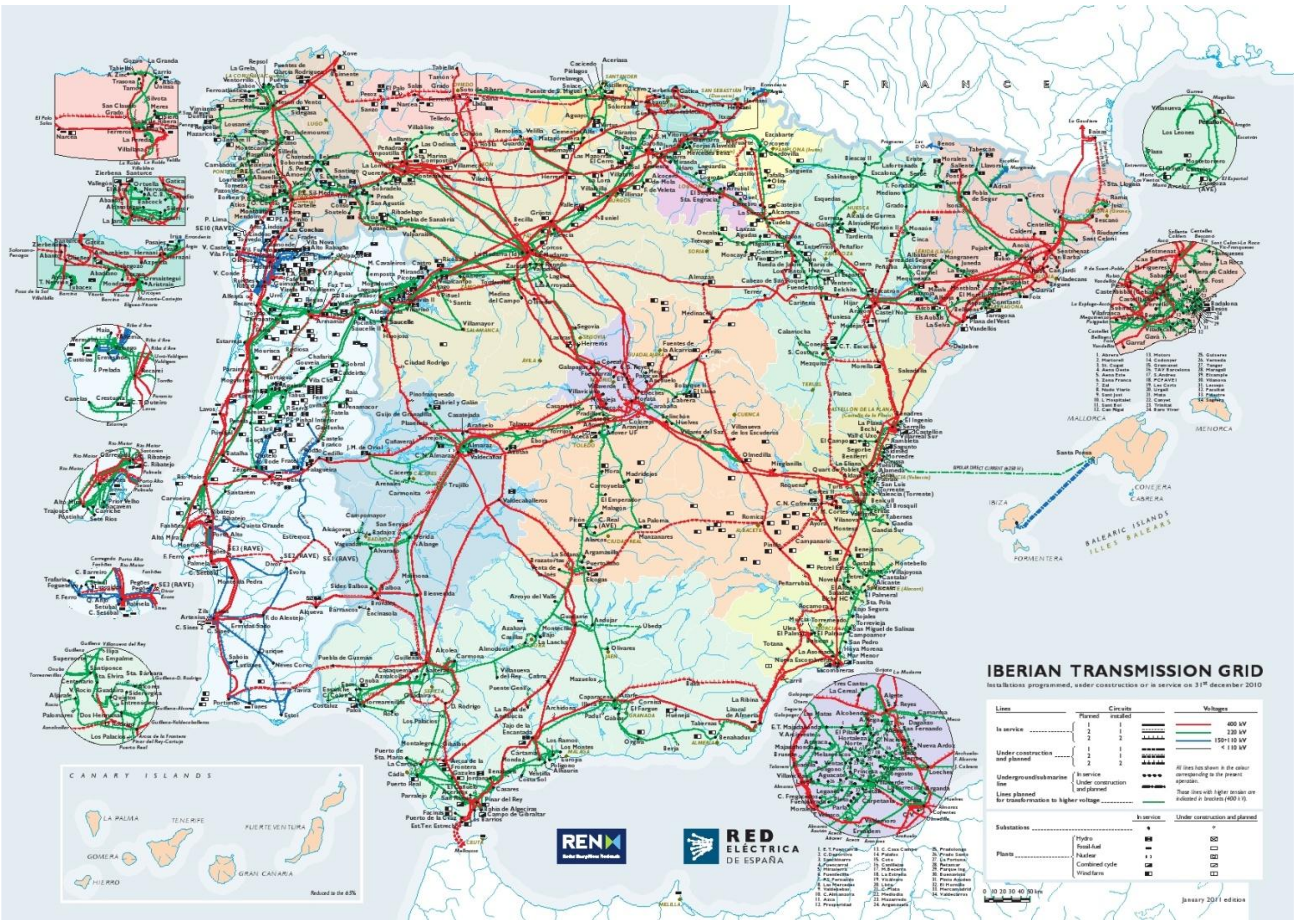
Source: Red Eléctrica de España

1.2. Electricity Transmission

1.2.a. Transmission Grid

Figure 9 is a map of the transmission grid of Spain and Portugal. The voltage of each line is color coordinated. 400 kV lines are in red, green are 220 kV, blue corresponds to lines that are between 110 to 150 kV, and anything less than 110 kV is in black.

Figure 9: Transmission Grid of the Iberian Peninsula

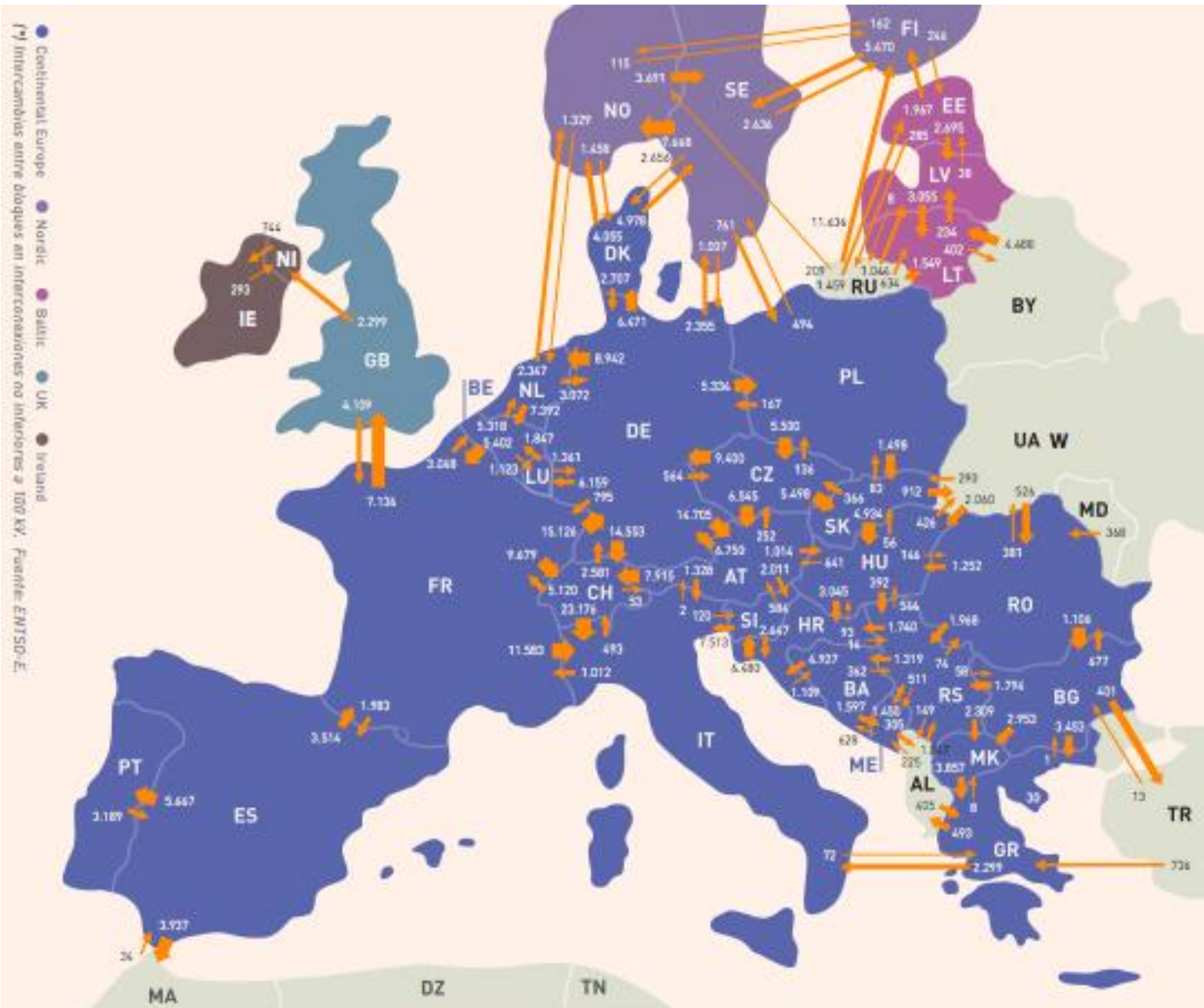


Source: Red Eléctrica de España

1.2.b. International Transmission

Electricity transmission has also been expanding on the in international level. Spain is connected to Portugal, France, Andorra, and Morocco. The largest of these interconnections is between Spain and its neighbor on the peninsula, Portugal. Spain, in 2010, exported more than they had imported; 8,333 GWh more energy was exported abroad than was imported into the country[4].

Figure 10: European Map of Power Exchanges



Source: Red Eléctrica de España

Figure 11: Table of Electricity Imports and Exports

[4] Red Eléctrica de España, 90.

	Imported (GWh)	Exported (GWh)	Balance (GWh)
Portugal	3,189	5,823	-2,634
France	1,983	3,514	-1,531
Morocco	34	3,937	-3,903
Andorra	0	264	-264
Total	**5,206**	**13,539**	**-8,333**

Source: Red Eléctrica de España

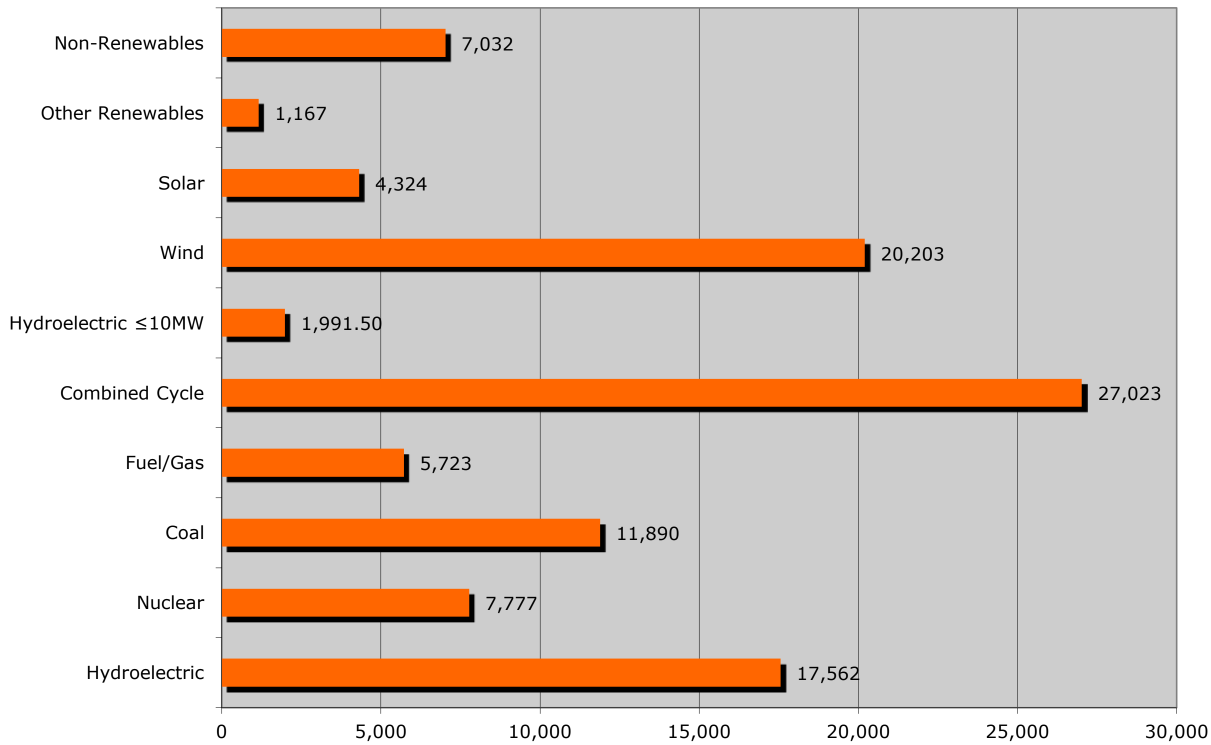
Figure 12: Spanish Map of Power Exchange

Source: Red Eléctrica de España

1.3. Installed Capacity

As of December 2010, Spain reached a total of 104,693 MW of installed capacity[5]. The ordinary regime amongst the peninsular regions was 64,813 MW[6]. The special regime was 34,230 MW[7]. The ordinary regime for the extra-peninsular regions, Melilla, Ceuta, Islas Canarias, and Islas Baleares, was 5,162 MW[8]. The special regime was 488MW[9]. So, a total of 69,975 MW for the ordinary regime, and the special regime was 34,718 MW was installed by the end of 2010.

Figure 13: Installed Capacity by Energy Source (MW)



Source: Red Eléctrica de España

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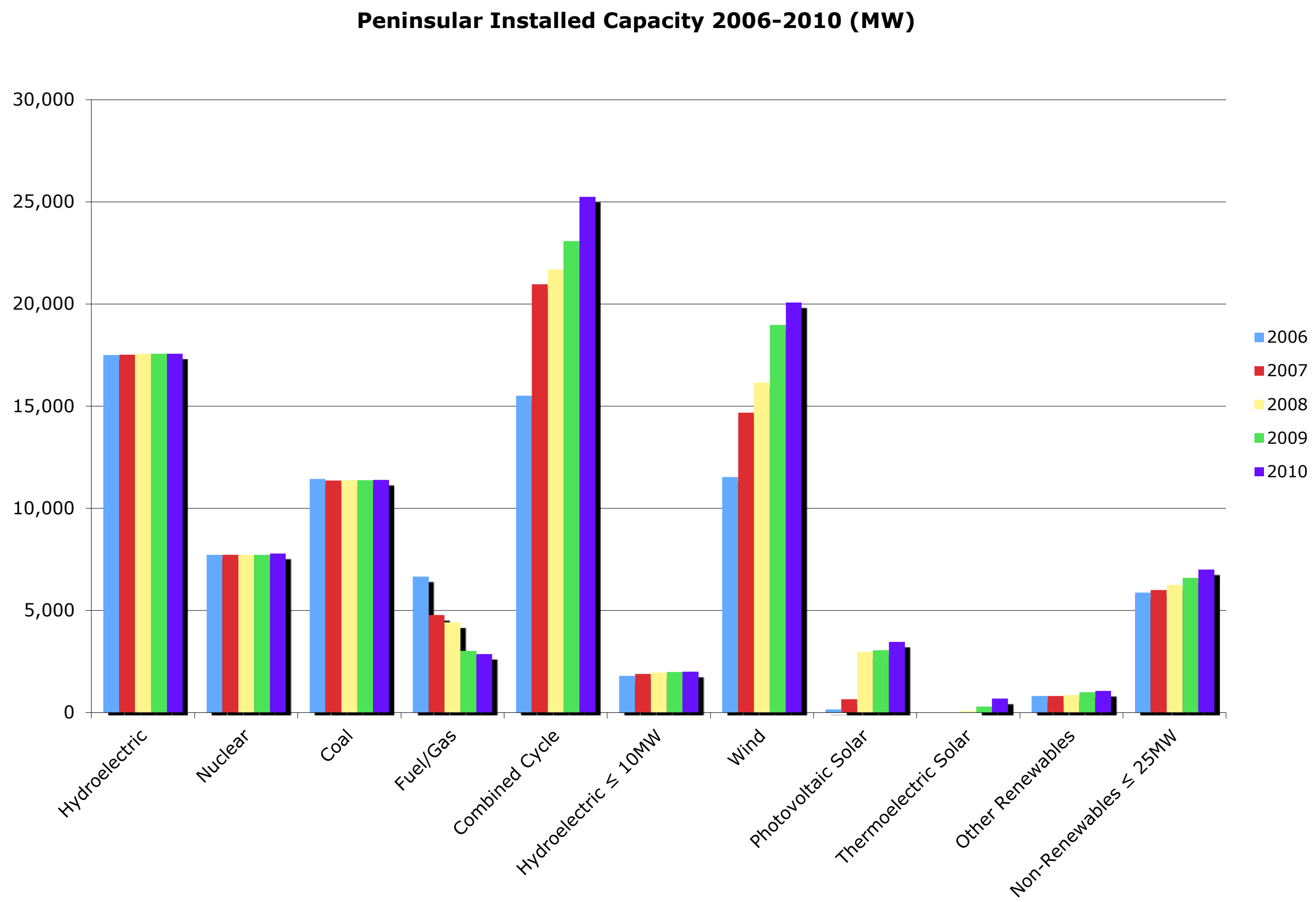
[5] Red Eléctrica de España, 9.
[6] Red Eléctrica de España, 9.
[7] Red Eléctrica de España, 9.
[8] Red Eléctrica de España, 9.
[9] Red Eléctrica de España, 9.

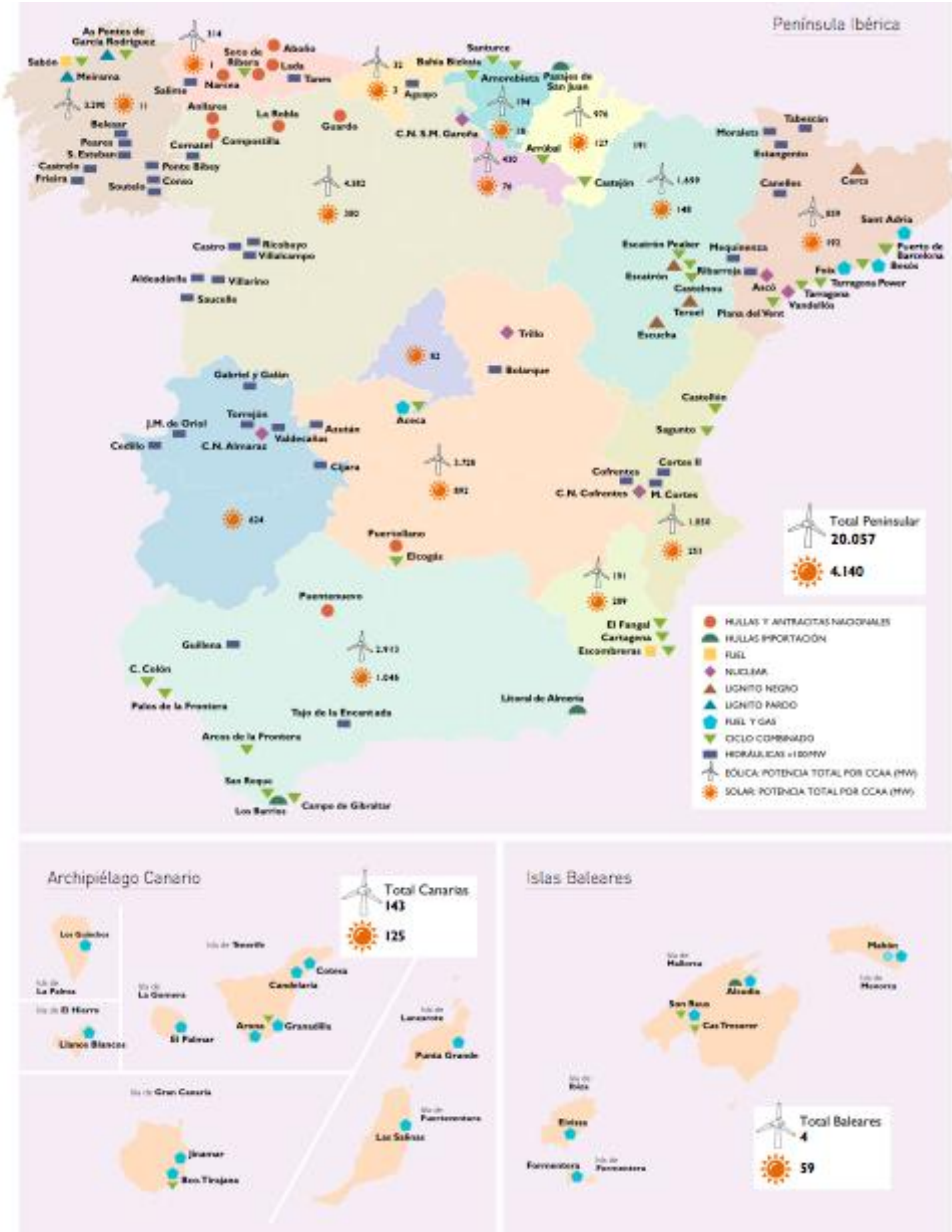
Figure 14: Installed Capacity of Peninsular Regions from 2006-2010
Does not include the extra-peninsular regions of Baleares, Canarias, Ceuta, and Melilla



Source: Red Eléctrica de España

Combined cycle has the largest installation, but wind and hydropower did come in second and third. Some of the most dramatic increases in installed capacity came from renewable energy sources. For example, between 2006 and 2010, wind capacity increased by 8,536 MW. For the most part conventional sources of energy have been relatively stable, without showing any substantial increases or decreases. However combined cycle and fuel/gas are the exceptions. Fuel/gas has made significant decreases, while combined cycle continues showing strong growth.

Figure 15: Map of Major Power Plants Only plants that are categorized under the ordinary regime, wind farms, and solar plants of all types are included on map

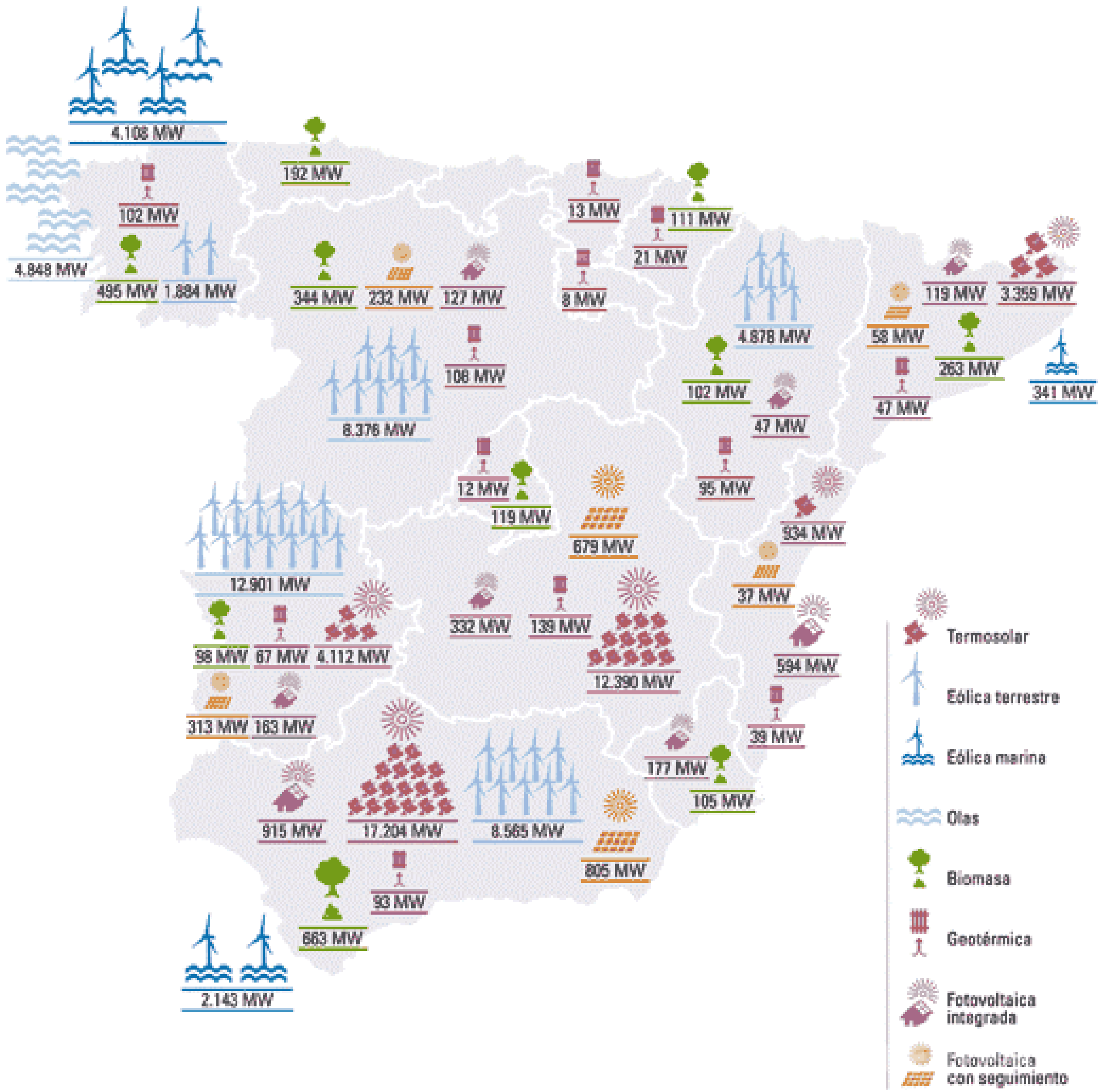


Source: Red Eléctrica de España

1.4. Installed Capacity of Wind and Solar

As mentioned before, the installed capacity of renewable energies has been steadily growing. The largest and most impressive increases in installed capacity have come from the areas of wind and solar power. In fact, Spain is a world leader in both of these energies. Therefore, this section will be solely dedicated to highlighting the capacity of these two particular renewable sources.

Figure 16: Map of Installed Capacity of Renewable Energies

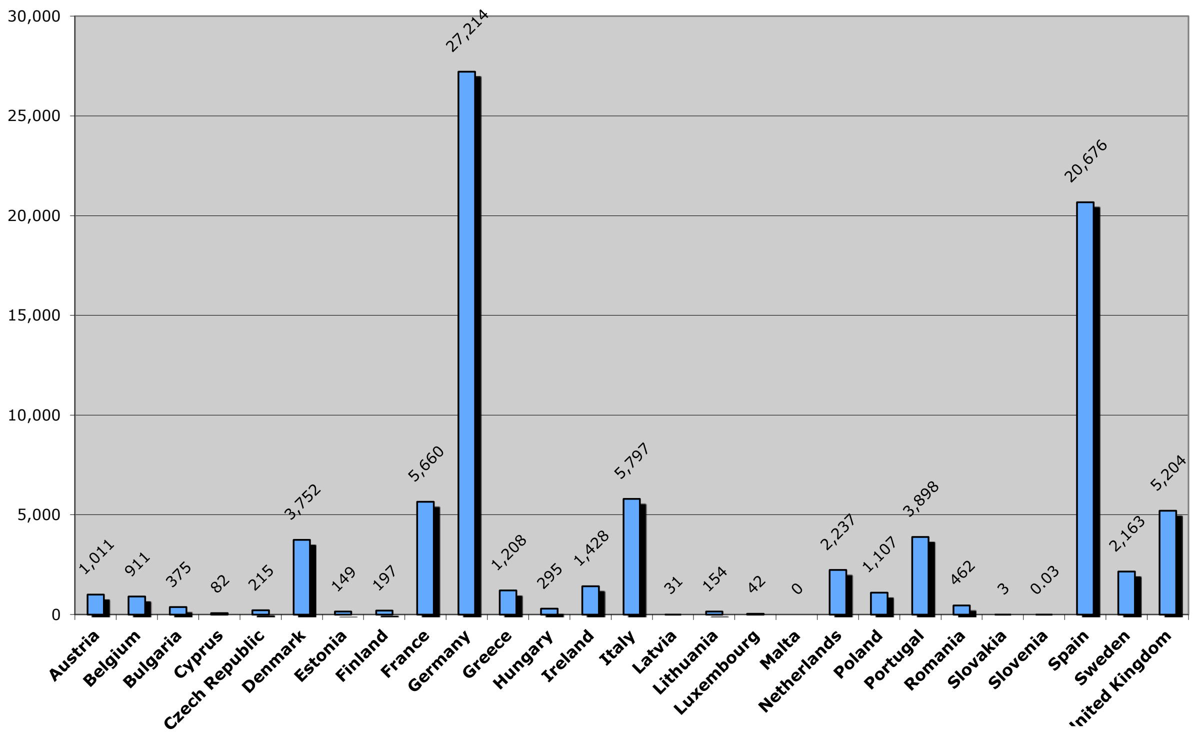


Source: Greenpeace

1.4.a. Wind Capacity

Wind is the fastest growing renewable energy in Spain. The country has become fourth in the world in installed wind capacity, and second in Europe. The European Wind Energy Association estimates that at the end of 2010, wind capacity was 20,676 MW[10]. Spain accounts for 10.5% of the world's 197,039 MW of total installed capacity[11].

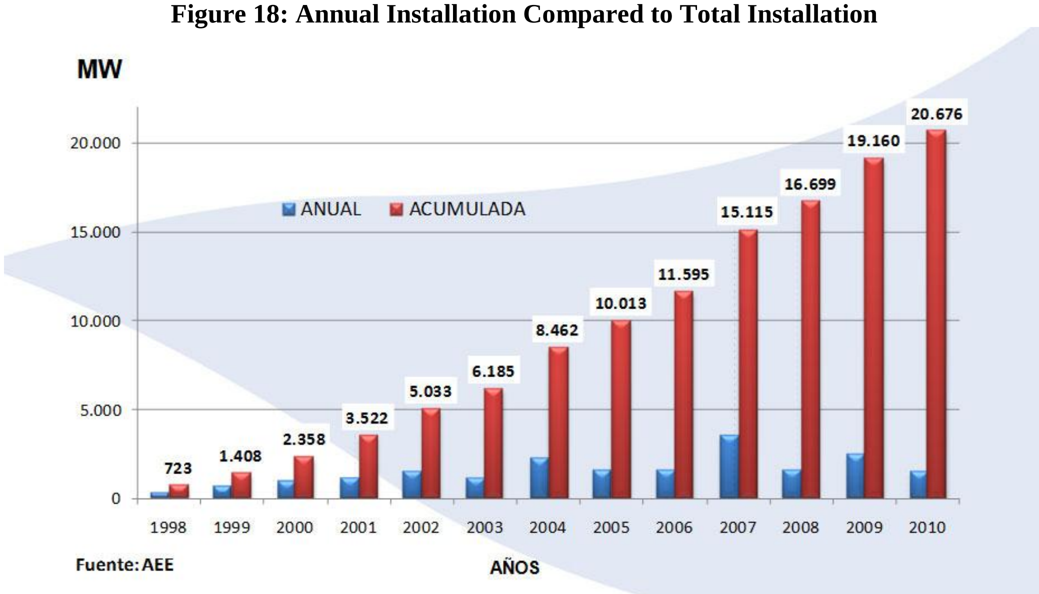
Figure 17: Wind Installed Capacity of EU-27 Countries in 2010 (MW)



Source: The European Wind Energy Association

[10] Global Wind Energy Council. Global Wind Report: Annual Market Update 2010. (Brussels, Belgium: Global Wind Energy Council, 2011). 11.
[11] Global Wind Energy Council, 12.

Figure 18: Annual Installation Compared to Total Installation



Source: Asociación Empresarial Eólica

Spain installed 1,516 MW of wind in 2010; in 2009 the capacity was 19,160 MW[12]. This fact put Spain at the top of the ranking in newly installed capacity in Europe[13]. Germany and France followed with 1,493 MW and 1,086 MW in 2010, respectively[14]. Below is a table showing the installed capacity on the regional level.

[12] Asociación Empresarial Eólica. Wind Power Observatory 2011. (Madrid, Spain: Asociación Empresarial Eólica, 2011). 1.
[13] Global Wind Energy Council, 11.
[14] Global Wind Energy Council

Figure 19: Wind Installed Capacity by Region

REGION	TOTAL INSTALLED CAPACITY AT 31/12/2010	NEW CAPACITY (MW)	% VARIATION 2010/2009	TOTAL WIND FARMS
Castilla y León	4,803.82	917.02	23.59%	204
Castilla-La Mancha	3,709.19	6.00	0.16%	121
Galicia	3,289.33	54.80	1.69%	150
Andalucía	2,979.33	139.41	4.91%	130
Aragón	1,764.01	10.20	0.58%	76
Comunidad Valenciana	986.99	0.00	0.00%	30
Navarra	968.37	6.60	0.69%	45
Cataluña	851.41	326.87	62.32%	33
La Rioja	446.62	0.00	0.00%	14
Asturias	355.95	0.00	0.00%	15
País Vasco	153.25	0.00	0.00%	7
Murcia	189.91	37.60	24.69%	11
Canarias	138.92	0.00	0.00%	47
Cantabria	35.30	17.45	97.76%	3
Baleares	3.65	0.00	0.00%	3

Sources: Asociación Empresarial Eólica

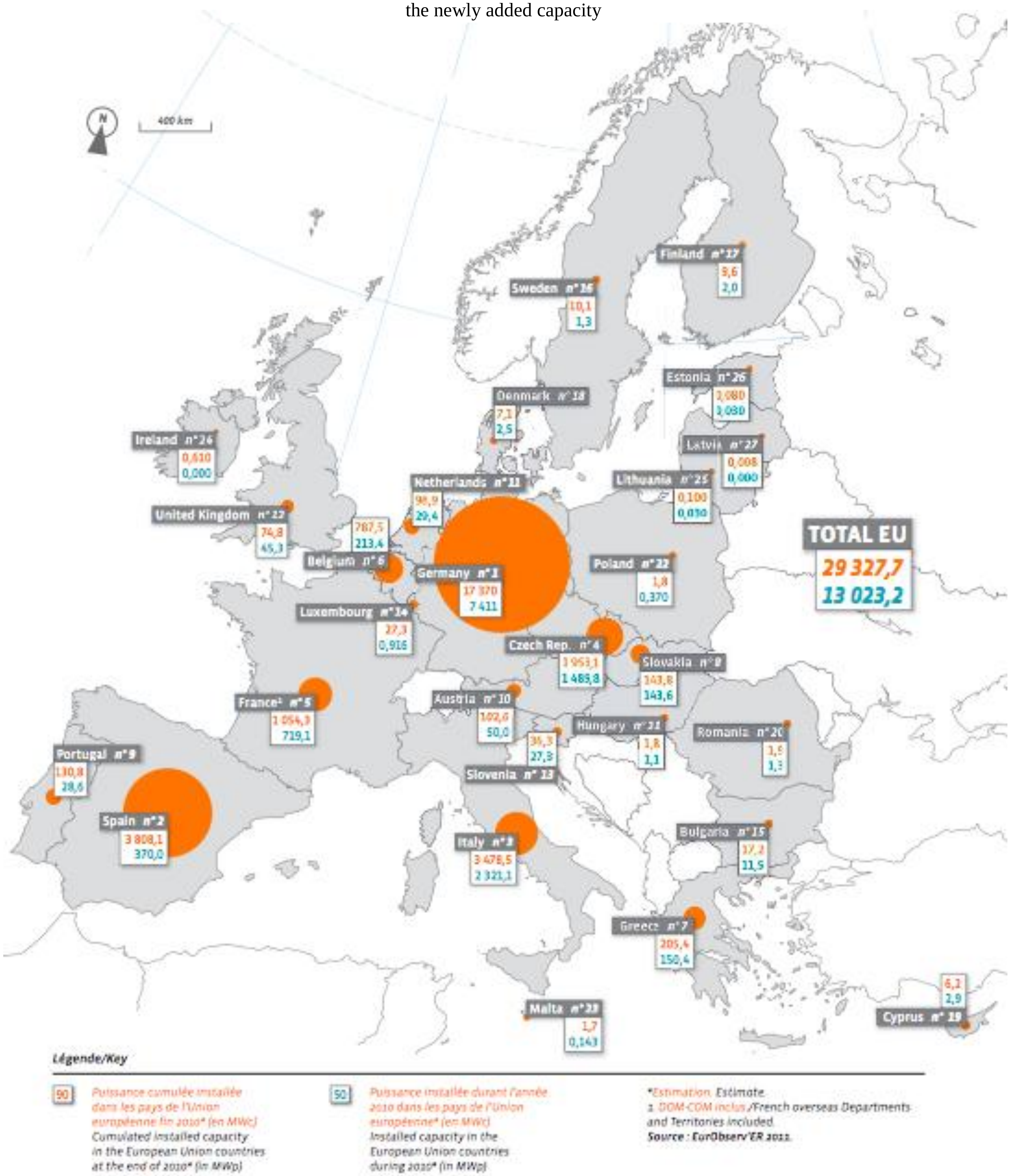
1.4.b. Solar Capacity

Spain ranks second in the world among both photovoltaic and thermoelectric solar power. The installed capacity for photovoltaic solar, in 2010, according to Red Eléctrica de España, was 3,643 MW[15]. EurObserv'ER puts the total slightly higher at 3,808.1 MW[16]. The added installation in 2010 for photovoltaic solar is 407 MW according to Red Eléctrica de España, and 370 MW to EurObserv'ER[17].

[15] Red Eléctrica de España, 116.
[16] EurObserv'ER. Photovoltaic Barometer. (Paris, France: EurObserv'ER, 2011). 153
[17] EurObserv'ER, 153.

Figure 20: European Map of PV Installed Capacity in 2010

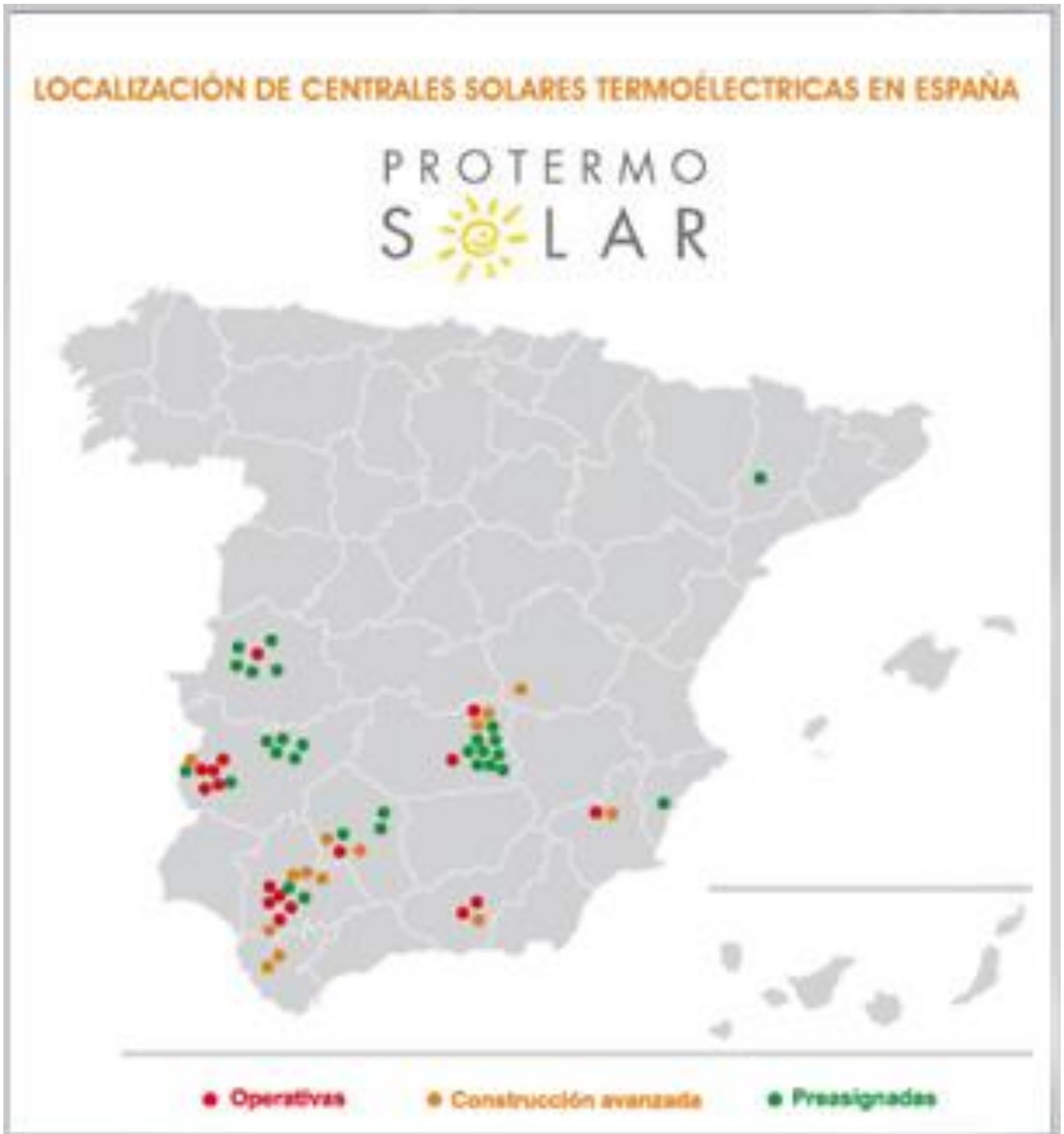
The orange number represents overall capacity and the blue number is the newly added capacity



Source: EurObserv'ER

Currently, there are 852.4 MW of installed capacity of concentrated solar thermal (CST) plants in operation, 1,3022MW are under construction, and 370MW are planned[18]. By 2014, there is an expected 2,525MW of installed capacity, and it is estimated that it will generate 7,298 GWh/year[19].

Figure 21: Map of Concentrated Solar Thermal Locations



Sources: Protermosolar

[18] "Mapa de la Industria Solar Termoélectrica en España," Protermo Solar, accessed September 12, 2011, http://www.protermosolar.com/mapa.html
[19] "Mapa de la Industria Solar Termoélectrica en España."

2. Future Energy Trends

Spain already has a plan for 2020. Spain's National Renewable Energy Action Plan 2011-2020 sets targets uptil the year 2020. The plan is meant to promote the use of renewable energies across all sectors. In the electricity sector, renewables are expected to see a major increase by 2020. However, this plan does not see renewables making up 100%. The purpose of this section will be to get a glimpse at the future energy situation if Spain continues as it has been.

2.1. Projected Demand

Demand for 2020 is expected to rise to 354,882 GWh, or about 355 TWh[20]. Renewables, as a whole, are expected to cover this increase in demand; renewable energies, not including pumped hydroelectric, are expected to cover about 153 TWh[21]. Were this plan to be followed renewable energies would cover roughly 43% of the electricity demand.

Figure 22: Table of 2015 and 2020 Demand

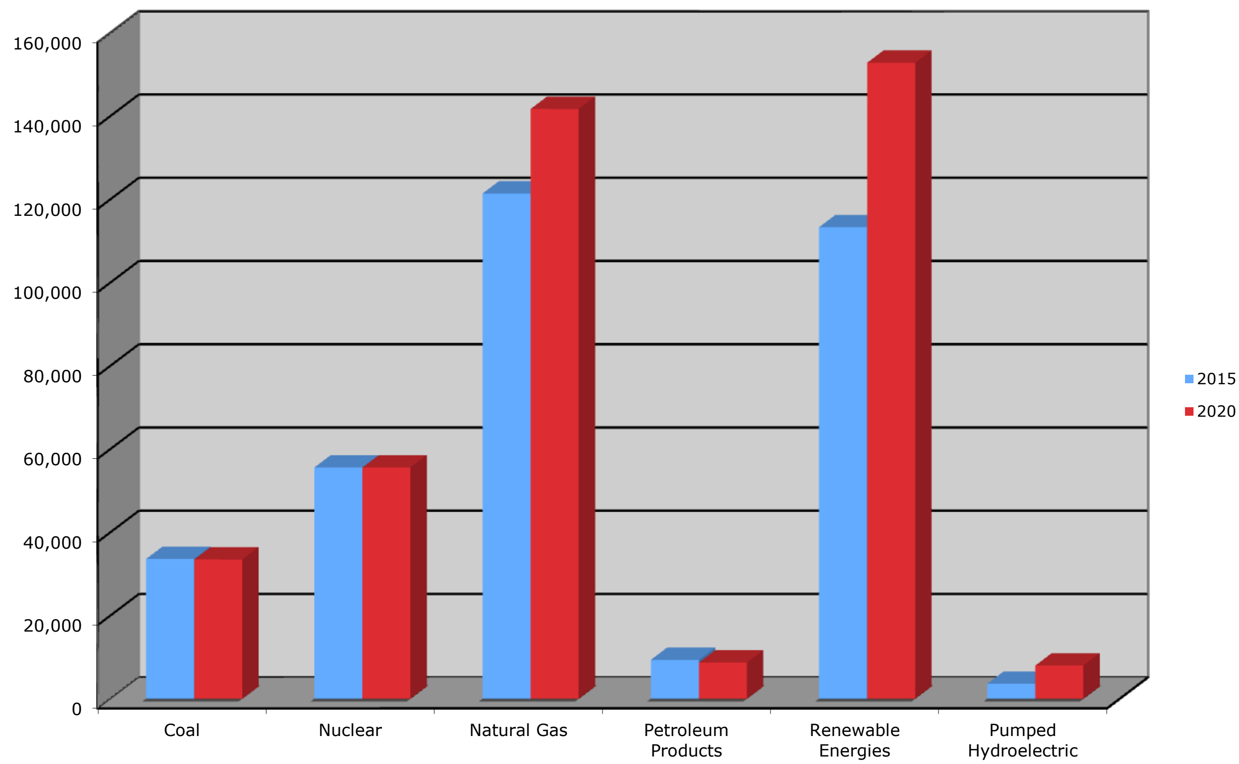
	2015	**2020**
Coal	33,630	33,500
Nuclear	55,600	55,600
Natural Gas	121,419	141,741
Petroleum Products	9,381	8,721
Renewable Energies	113,325	152,835
Pumped Hydroelectric	3,640	8,023
Generation Consumption	- 8,610	- 8,878
Net Generation	331,321	391,542
Pumped Storage Consumption	- 9,396	- 11,462
International Exchange	- 11,285	- 25,199
Demand	**310,640**	**354,882**

Source: National Renewable Energy Action Plan 2011-2020

[20] Ministerio de Industria, Turismo y Comercio, *Spain's National Renewable Energy Action Plan 2011-2020* (2010), 26, http://ec.europa.eu/energy/renewables/transparency_platform/doc/national_renewable_energy_action_plan_spain_en.pdf

[21] Spain's National Renewable Energy Action Plan 2011-2020, 26.

Figure 23: Energy Projections in 2015 and 2020



Source: National Renewable Energy Action Plan 2011-2020

2.2. Projected Contribution of Renewable Energies

Renewable energies, as a whole, are poised to become the main energy source. Looking below the surface, it is seen that wind power is set to remain the largest renewable energy source come 2020. Hydropower and solar power also remain 2nd and 3rd place when it comes to renewables.

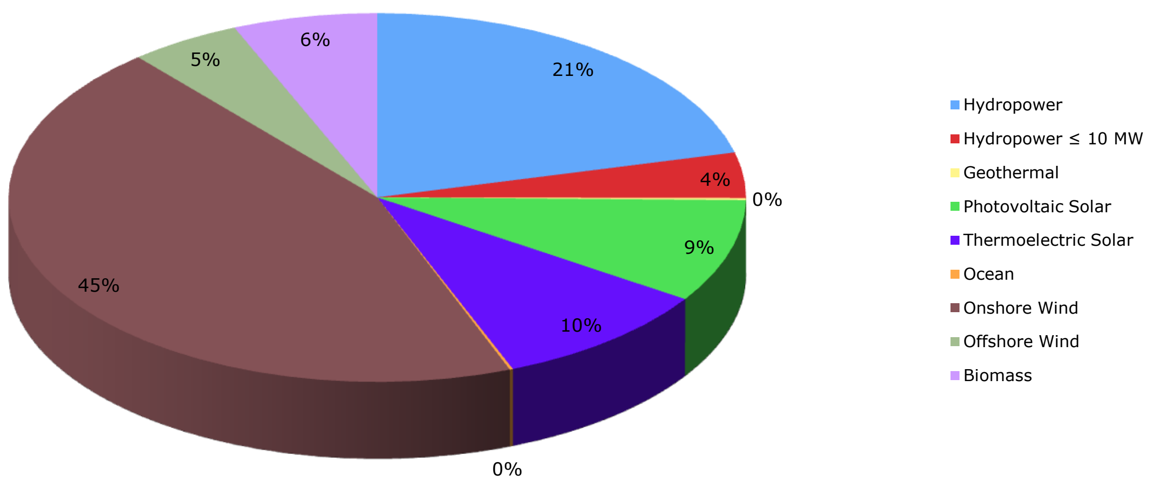
Figure 24: Renewable Energy Projections 2012-2020 (GWh)

	2012	2014	2016	2018	2020
Hydropower	28,676	31,228	32,408	32,844	33,314
Hydropower ≤ 10 MW	6,284	5,331	5,158	5,599	6,280
Geothermal	0	0	0	60	300
Photovoltaic Solar	8,090	9,256	10,565	12,222	14,316
Thermoelectric Solar	4,463	6,867	9,084	11,866	15,353
Ocean	0	0	22	110	220

Onshore Wind	47,312	53,906	59,598	64,925	70,502
Offshore Wind	0	75	975	3,727	7,753
Biomass	4,876	5,499	6,510	7,931	10,017

Source: National Renewable Energy Action Plan 2011-2020

Figure 25: Renewable Energy Output in 2020 (GWh)



Source: National Renewable Energy Action Plan 2011-2020

2.3. Projected Installation

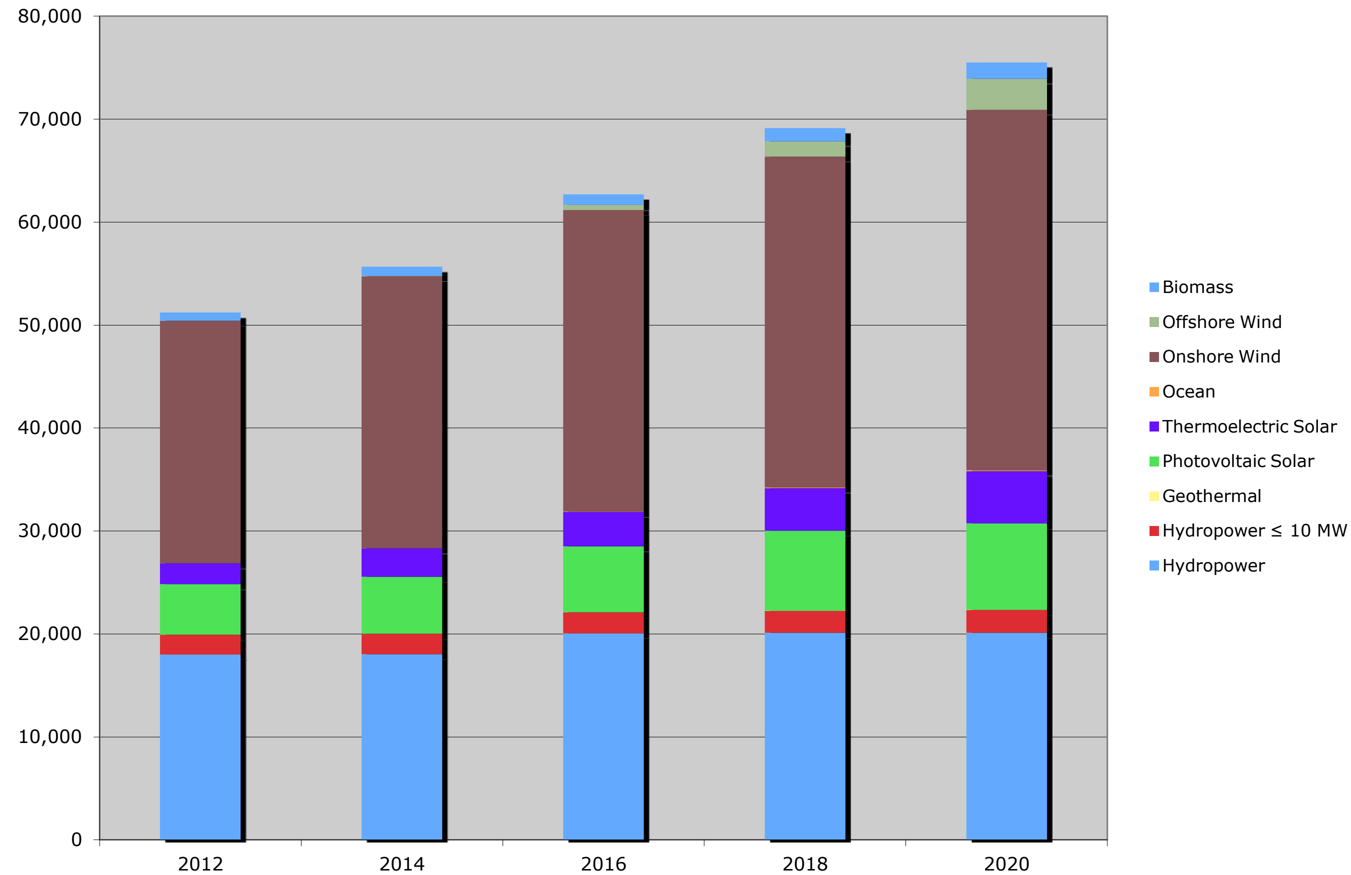
Figure 26: Projected Installed Capacity 2012-2020 (MW)

	2012	2014	2016	2018	2020
Hydropower	17,997	18,017	20,057	20,112	20,117
Hydropower ≤ 10 MW	1,912	1,982	2,052	2,117	2,185
Geothermal	0	0	0	10	50
Photovoltaic Solar	4,921	5,553	6,391	7,780	8,367
Thermoelectric Solar	2,028	2,746	3,361	4,149	5,079

Ocean	0	0	10	50	100
Onshore Wind	23,555	26,416	29,278	32,139	35,000
Offshore Wind	0	50	500	1,500	3,000
Biomass	803	897	1,048	1,265	1,587

Source: National Renewable Energy Action Plan 2011-2020

Figure 27: Installed Capacity 2012-2020 (MW)



Source: National Renewable Energy Action Plan 2011-2020

3. Renewable Energy Potential

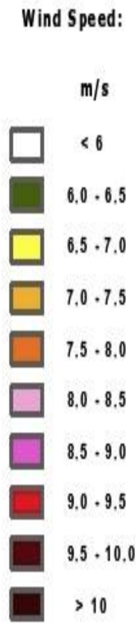
The resources required for an electricity system powered solely from renewable energies are already in place. Some energy sources are more readily available than others. For instance Spain has great potential for solar power, but is lacking in suitable geothermal locations. There have been studies conducted that examines the energy potential that can conceivably generated by a certain source, unfortunately the research is just not yet available for all sources. In lieu of having an estimated potential for some of the energy sources, a map of the most suitable locations will be given for all the sources.

3.1. Wind Potential

It is important to determine what qualifies as an adequate area for wind power. "*Areas with annual average wind speeds around 6.5 m/s and greater at 80-m height are generally considered to have suitable wind resource for wind development*"[22]. The following map shows the best wind resources based on the annual mean wind speed at a height of 80 meters.

Figure 28: Map of Annual Mean Wind Speeds at an 80-meter Height and Key

[22] "80-Meter Wind Map and Wind Resource Potential," U.S. Department of Energy, last modified August 3, 2011, http://www.windpoweringamerica.gov/wind_maps.asp.

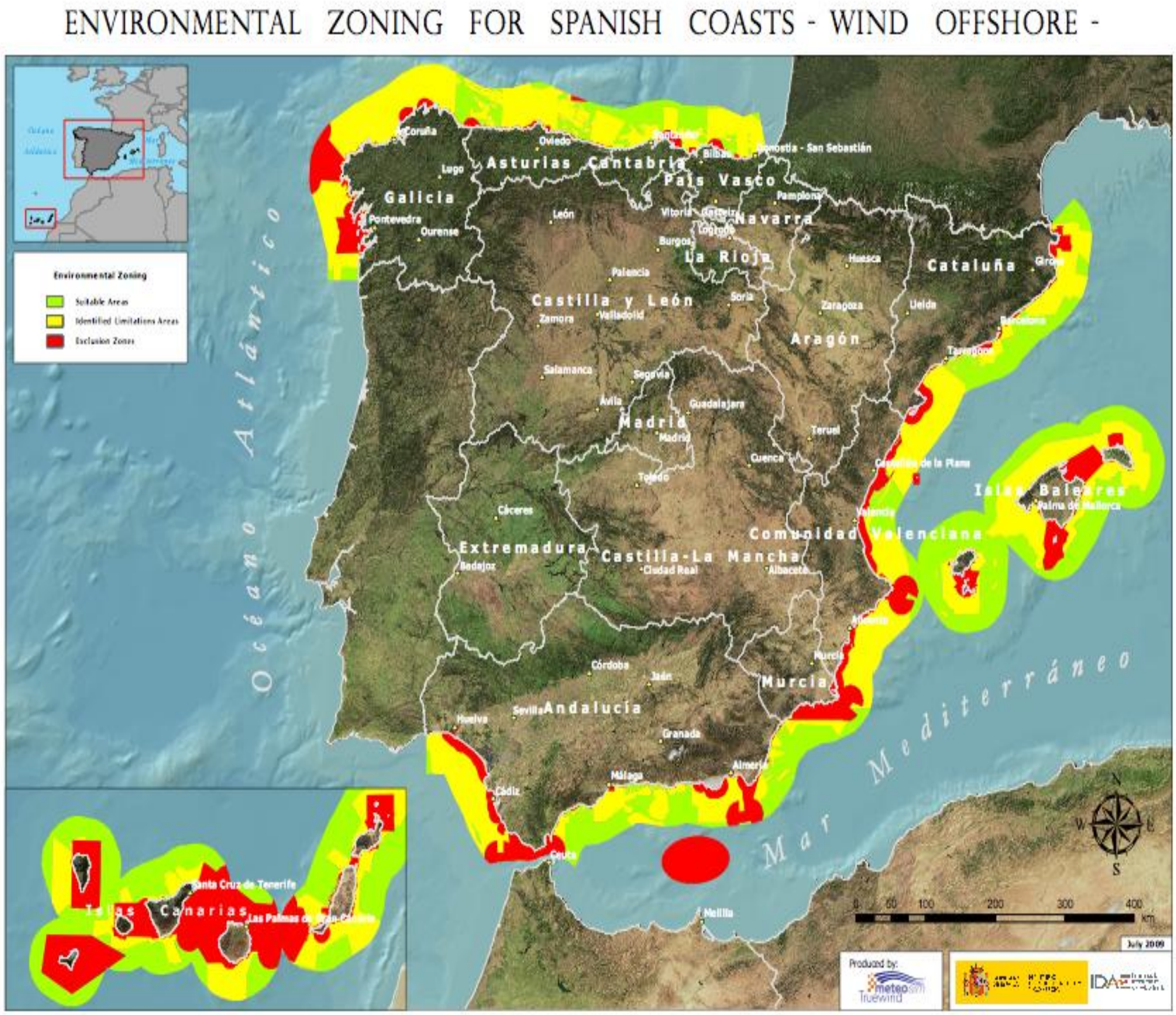


Source: Atlas Eólica

There are pockets of the country that far exceed the 6.5 m/s threshold; the northwest region of Galicia is a great example of this. The southern most tip of Andalucía is also an area with more than enough wind resources for development. Another important note is the wind resource available offshore. Most of the he wind speed offshore well exceeds the 6.5 or greater m/s limit.

As a continuation of the wind resource map above, the map below shows area limitations of offshore wind farms. Areas in green represents suitable areas, yellow corresponds to limited areas, and red represents restricted locations.

Figure 29: Suitable Locations for Offshore Wind Development



Source: Atlas Eólica

According to a study from the University of Zaragoza. The technical potential for onshore wind power was found to be 1,100 TWh/year[23]. Technical potential as defined in the paper is, "*the electricity that can be generated over the whole of the territory during one calendar year, once geographical and technical limitations have been taken into account*"[24]. Basically, the findings are purely the amount of energy that can possibly be generated, and not what is probable or feasible; so, economic and/or social constraints are not considered. The technical potential far exceeds the demand in 2010, which was just less than 300 TWh/year.

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[23] Norberto Fueyo, Yosune Sanz, Carlos Montañés, and César Dopazo, "High Resolution Modelling of the On-shore Technical Wind Energy Potential in Spain," Wind Energy 13 (2010): 725.

[24] Fueyo, "Wind Energy Potential in Spain," 719.

However, in order to reach this level of output, about 50% of the total surface area of Spain would be needed[25]. Naturally, this is not practical. Another aspect that makes this impractical is the low capacity factor; the average capacity factor at the technical potential would be just 12.5%[26]. Most wind farms require 25-35% capacity factor to become viable.

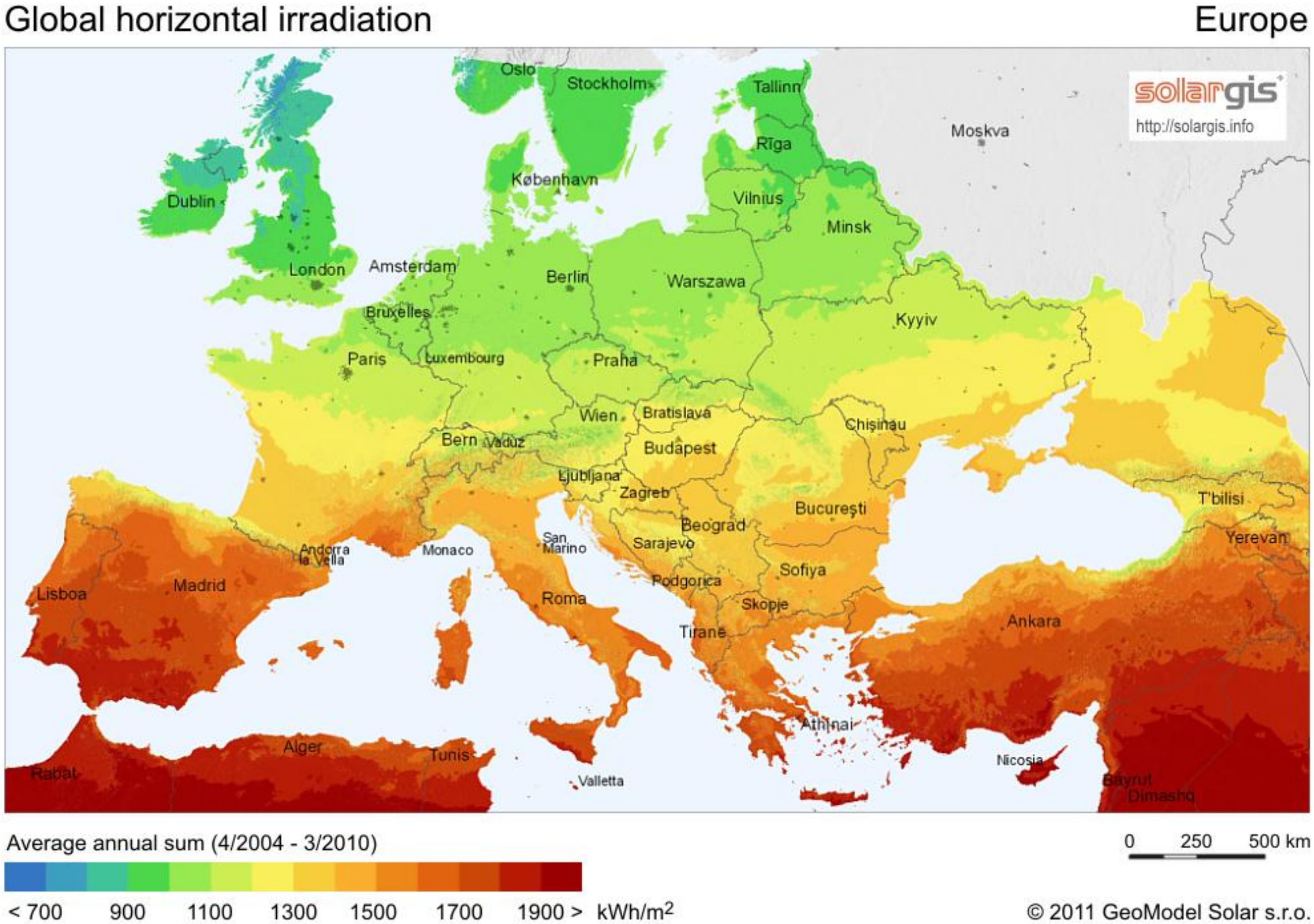
Although the purpose of the study was to determine what was theoretically possible, a more realistic and feasible potential was provided. The researchers put forward a potential of 190 TWh/year for onshore wind energy[27]. This would be achieved with an installed capacity of 70 GW, and a capacity factor of more than 24%[28]. This was determined realistic because this was the capacity factor for the year 2006[29]. In order to generate 190 TWh/year only 3.8% of total surface area is needed, markedly lower than the previously mentioned 50%[30]. Were the potential fully realized, wind would account for about 69% of the electricity demand in 2010, and about 54% of the projected demand in 2020.

3.2. Solar Potential

The solar potential for Spain is amongst the best in Europe, if not the best. Spain and Portugal receive the most annual global horizontal solar irradiance on the European continent. Global horizontal irradiance refers to the total solar irradiance of direct, diffuse and ground reflected radiation; although, "*for all practical purposes global radiation is said to be the sum of direct and diffuse radiation only*", due to the insignificance of ground reflected radiation to the other forms[31].

[25] Fueyo, "Wind Energy Potential in Spain," 725.
[26] Fueyo, "Wind Energy Potential in Spain," 725.
[27] Fueyo, "Wind Energy Potential in Spain," 725.
[28] Fueyo, "Wind Energy Potential in Spain," 725.
[29] Fueyo, "Wind Energy Potential in Spain," 725.
[30] Fueyo, "Wind Energy Potential in Spain," 725.
[31] "Glossary of Solar Radiation Resource Terms," National Renewable Energy Laboratory, accessed September 12, 2011, http://rredc.nrel.gov/solar/glossary/.

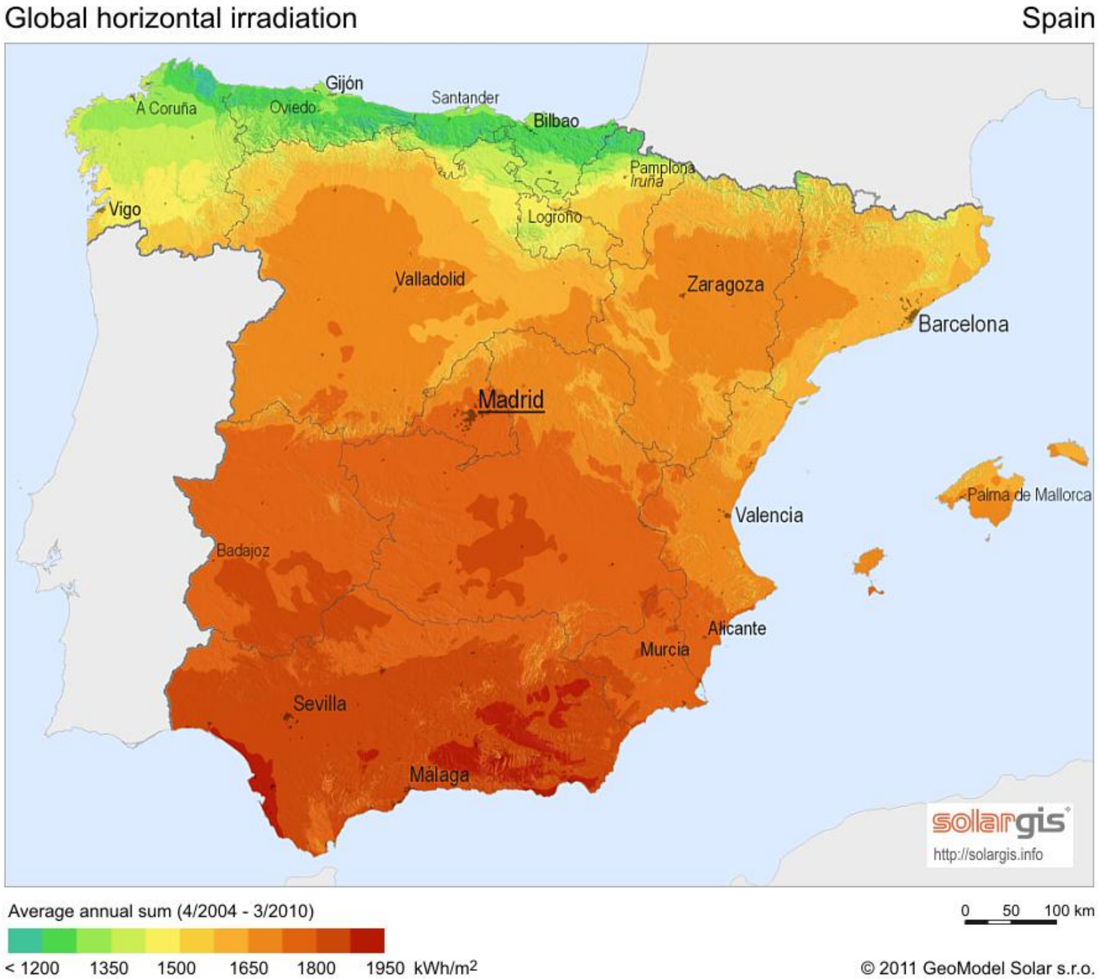
Figure 30: Global Horizontal Irradiation Map of Europe



Source: SolarGIS

A majority of the country falls within the range of 1,600 kW/m2 and 1,950 kW/m2. This can be seen in both the figures above and below. The southern most region of Spain, the Andalusia region, is on the higher end of that range. Whereas, the northern most regions, Asturias, Cantabria, and País Vasco have the lowest amount of annual global horizontal irradiance in Spain.

Figure 31: Global Horizontal Irradiation Map of Spain

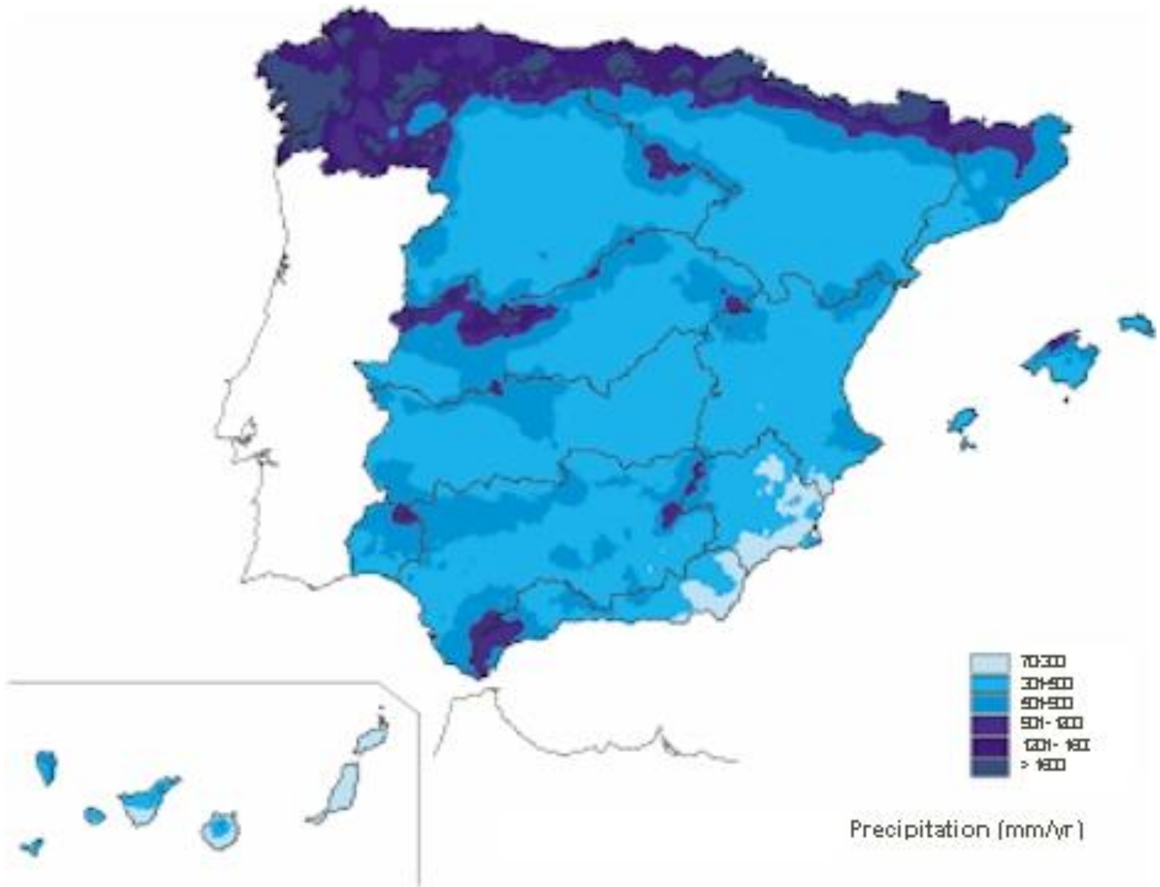


Source: SolarGIS

3.3. Hydropower Potential

Hydropower was one of the three renewable energies that contributed heavily towards Spain generating 35% renewable power in 2010. A good way to measure water supply is by measuring the average annual rainfall. The high average rainfall in the north, particularly the northwestern region, makes it the most suitable in the country for hydropower. This assertion is backed up by figure 15, where it can be seen that a majority of the hydropower plants are in the northern part of the country.

Figure 32: Average Annual Rainfall (in mm/yr)

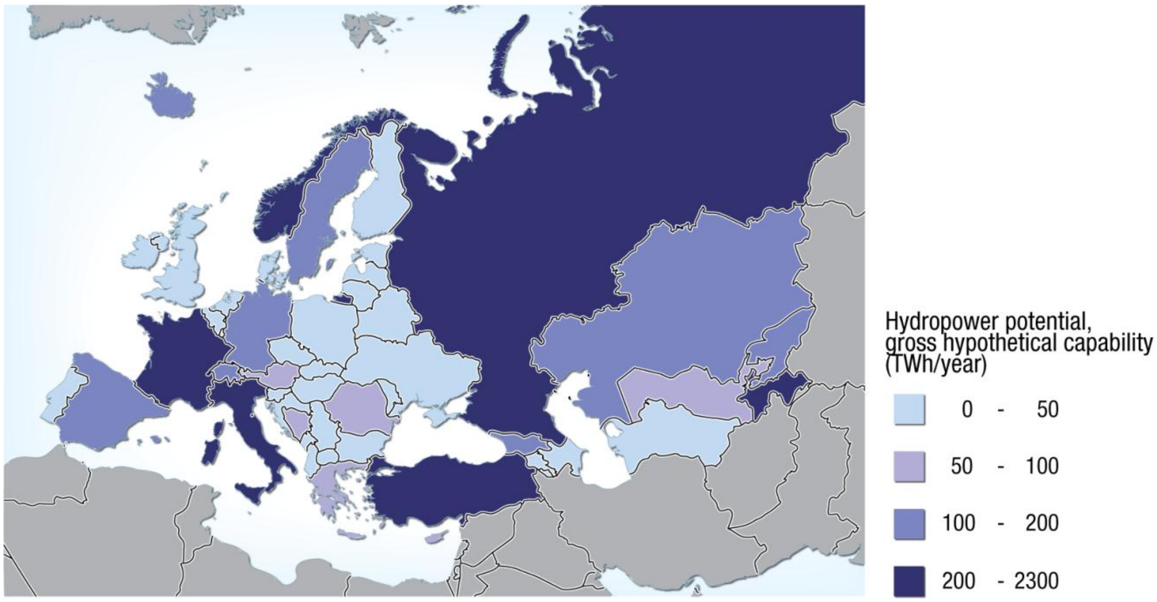


Source: National Technical University of Athens School of Chemical Engineering

Hydropower has great potential to add to the energy sector. Theoretically, hydropower is capable of providing 138 TWh of power; this estimation is after water consumption is taken into account[32].

[32] "Spain," International Small Hydro Atlas, accessed September 12, 2011, http://www.small-hydro.com/index.cfm?Fuseaction=countries.country&Country_ID=72

Figure 33: Theoretical Hydropower Potential of Europe



Source: UNEP/GRIDA

A more realistic potential was estimated at about 64 TWh/year[33]. This would be enough to cover about 23% of the 2010 demand, and 18% of 2020 demand. Already over half of this estimation has been achieved; hydro plants generated 38.6 TWh and small hydro plants (≤ 10 MW) covered 6.8 TWh.

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[33] "Spain."

3.4. Ocean Potential

3.4.a. Wave Potential

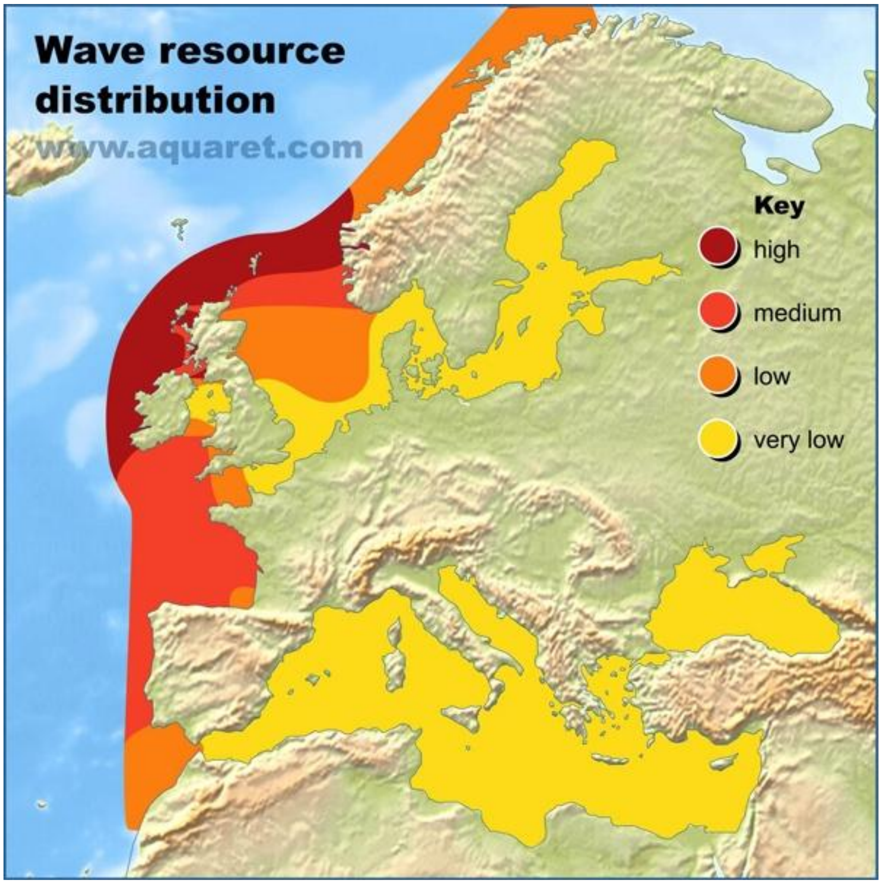
Figure 34: Wave Power Potential

Fuente: IDAE

Source: Xornal de Galicía

Figure 26 shows the wave potential of the World and the inset showing Spain's wave potential. Each number on the map represents kW/linear meter of wave front. So, Spain at different points can generate 46, 55, 50, and 44-kW/linear meter of wave front. A higher number on the map above translates to a higher potential.

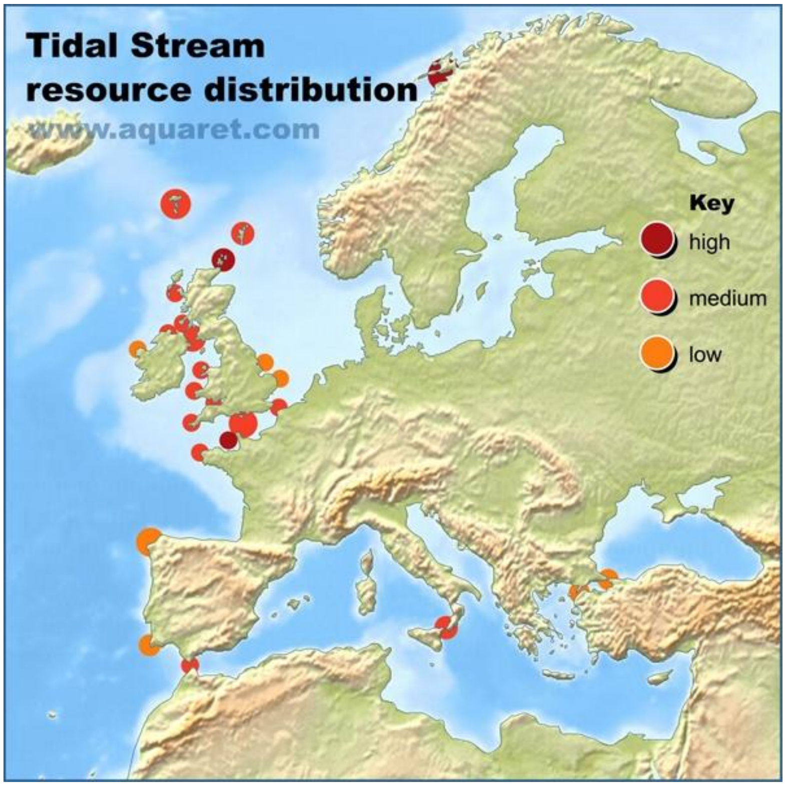
Figure 35: Wave Resource Distribution of Europe
The highest potential for Spain is around the northwest coastal region



Source: Aquaret

3.4.b. Tidal Potential

Figure 36: Tidal Stream Resource Distribution of Europe
The best region for tidal energy is the south of Spain, at the Strait of Gibraltar

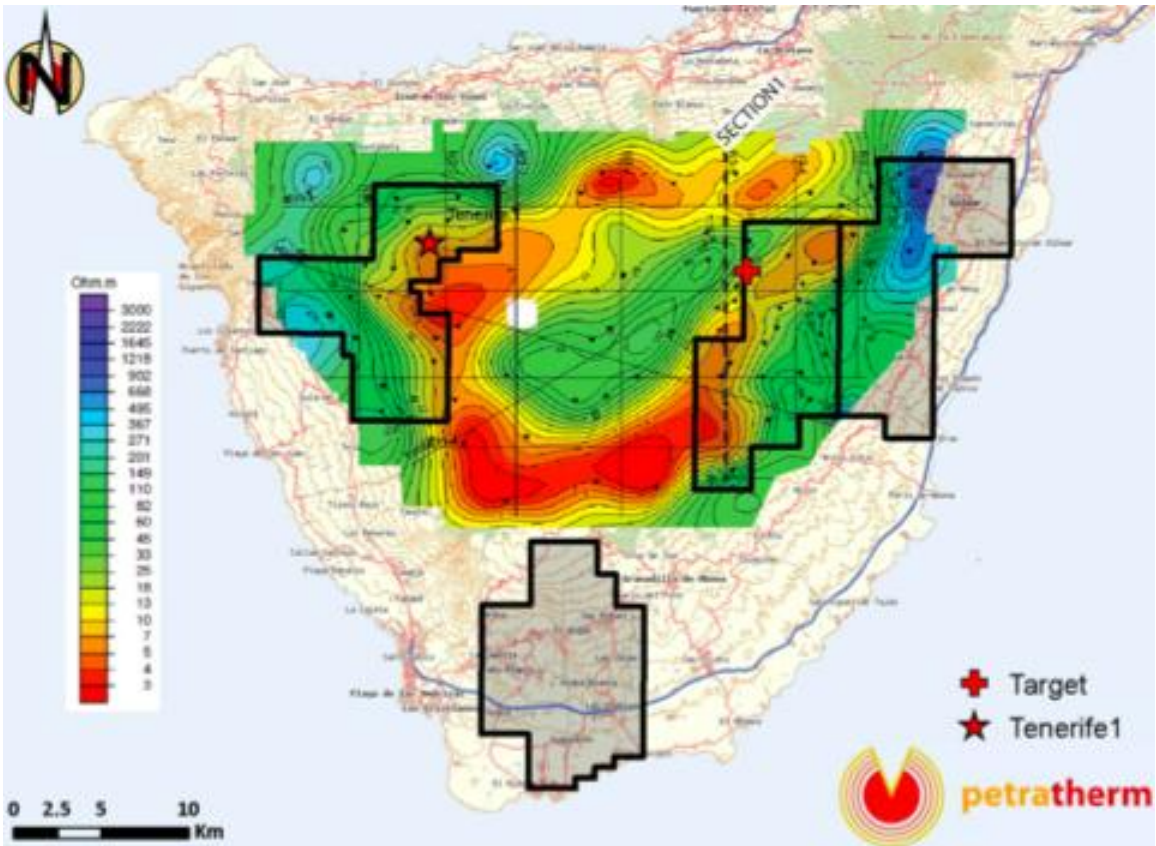


Source: Aquaret

3.5. Geothermal Potential

Geothermal sites with a high enough temperature exist in Canarias (Canary Islands), particularly the islands of Gran Canaria and Tenerife. Below is a thermal map of Tenerife.

Figure 37: Map of Geothermal Locations in Tenerife

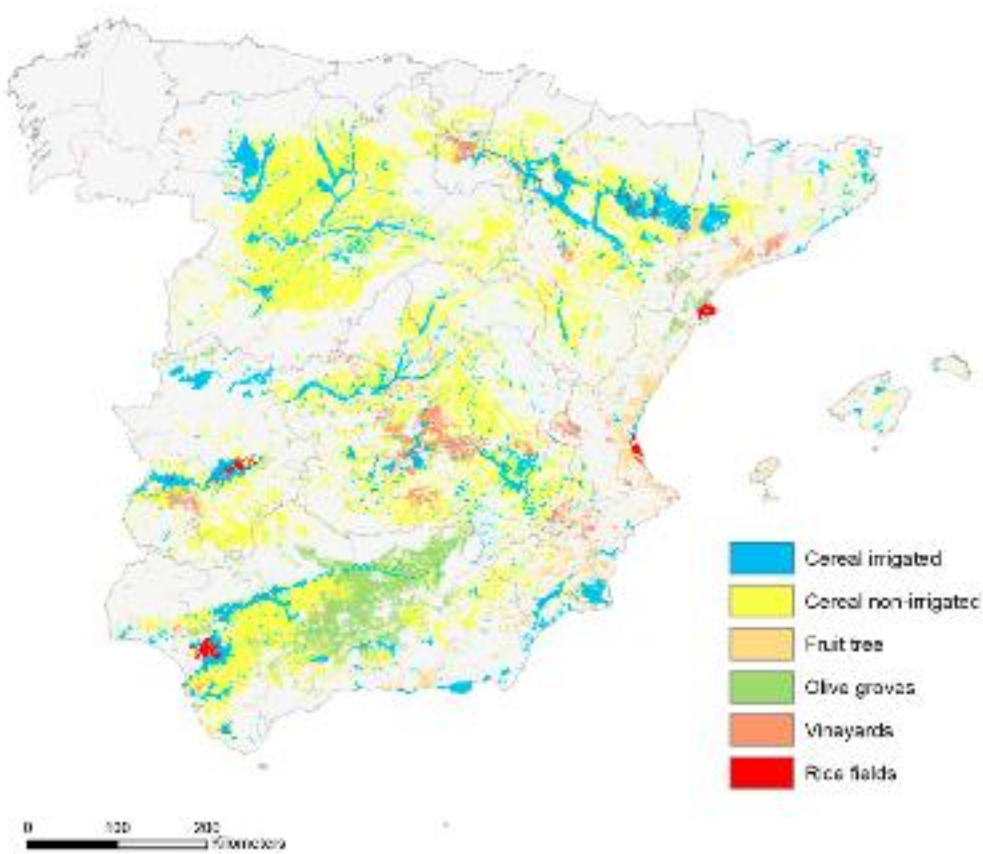


Source: Petratherm

3.6 Biomass and Biogas Potential

A study from the University of Zaragoza sought to find the energy potential of agro-industrial residue. The sources of residue used in the study involved olive mills, wineries, forestry residue, nut processing, rice mills, wastewater from meat processing from meat processing and dairies, and breweries[34].

Figure 38: Agro-Forestry Map



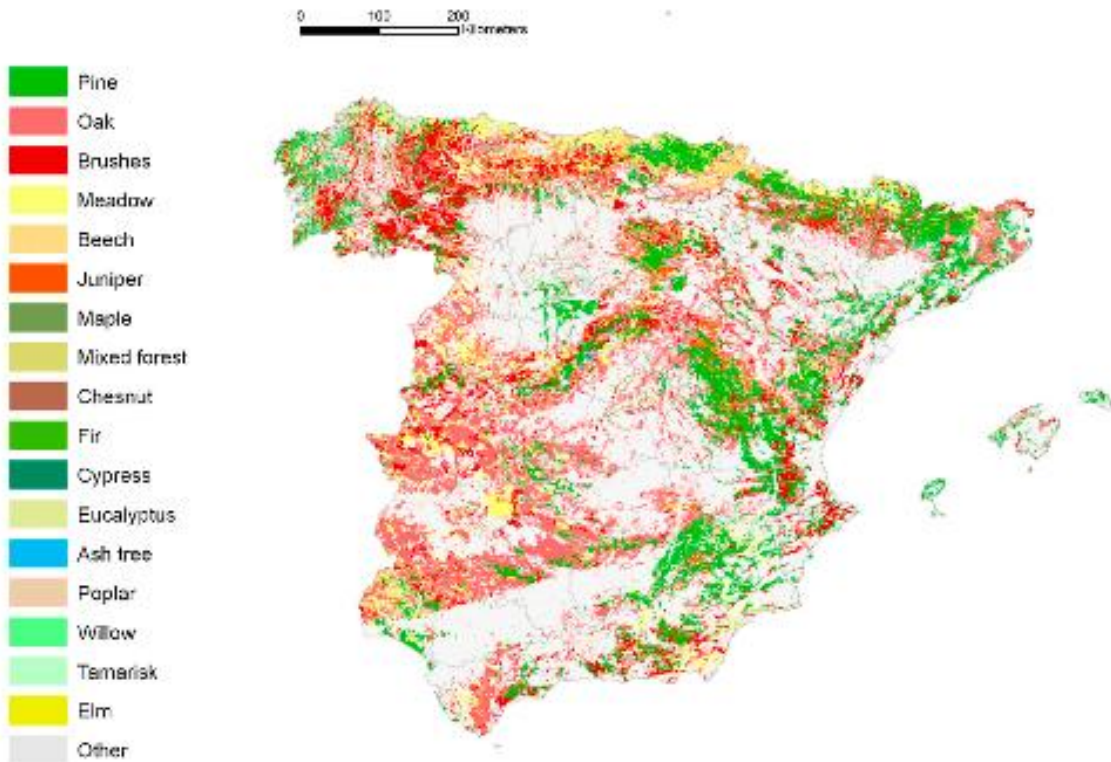
Source: The Potential for Electricity Generation from Crops and Forestry Residues in Spain

The energy potential for forestry and agricultural residues is split between technical limits and economic potential. First, the technical limit, which takes into consideration the location of resources and "*the technical characteristics (including performance) of the equipment used for transforming the resource into electrical energy*"[35]. It was found that the technical limit was 32.7 TWh/year[36]. Economic potential, which takes the generation costs into account, leads to a

[34] Antonio Gómez, Marcos Rodrigues, Carlos Montañés, Cesar Dopazo, and Norberto Fueyo. "The Potential for Electricity Generation from Crop and Forestry Residues in Spain," *Biomass And Bioenergy* 34: 706.
[35] Gómez et. al, "Electricity Generation from Crop and Forestry Residues," 706.
[36] Gómez et. al, "Electricity Generation from Crop and Forestry Residues," 718.

significantly lower potential, 12.87 TWh/year[37]. An important note is that as time progresses and newer technologies are developed that generation costs may go down, thus increasing the amount of potential this source can generate. The potential, looking at it from the technical limit or the economic potential, can be anywhere from 12% of 2010 demand to about 5%. The technical limit and economic potential would amount to 9% and 3% of expected 2020 demand.

Figure 39: Forestry Map



Source: The Potential for Electricity Generation from Crops and Forestry Residues in Spain

Another study conducted at the University of Zaragoza was done in order to determine the energy potential of municipal solid waste, animal waste, and sewage sludge. The potential from all 3 sources can range from 8.13 to 20.95 TWh/year, depending on the particular method of production[38]. That is between 3 and 7.5% 0f 2010 demand, and 2 to 6% of 2020 demand.

The production types are by incineration, landfill gas, and anaerobic digestion. Landfill gas refers to the biogas collected from waste degrading in landfills. Anaerobic digestion "*reproduces the natural process of degradation of the organic matter in the landfill, but using reactors under controlled operating conditions*"[39]. The production method assumed for animal waste and sewage sludge is anaerobic digestion, and the potential is 5.44 TWh/year and

[37] Gómez et. al, "Electricity Generation from Crop and Forestry Residues," 718.
[38] Antonio Gómez, Javier Zubizarreta, Marcos Rodrigues, César Dopazo, and Norberto Fueyo, "Potential and Cost of Electricity Generation from Human and Animal Waste in Spain," *Renewable Energy* 35: 504.
[39] Gómez et. al, "Potential and Cost of Electricity Generation," 499.

0.49 TWh/year respectively[40]. For municipal solid waste the potential is "*4.02 TWh/year for landfill gas, 15.02 TWh/y for incineration and 2.20 TWh/y for anaerobic digestion*"[41].

On the lower end, aggregating wind, biomass, and hydropower, is 275 TWh. Basically this is suffiecient to cover the entire 2010 demand. Again, this is considering 8.13 TWh from waste, the 12.87 economic potential of agro-forestry residue, the 64 TWh of hydropower, and 190 TWh/year for wind. On the higher end, considering 20.95 TWh/year for waste, the potential for onshore wind, hydro, and biomass is 287.82 TWh/year. This would cover 81% of 2020 demand, and this is not even taking into account the potential of solar, offshore wind, ocean, and geothermal.

4. Average Cost of Plants

Whether a country can even afford a plant is a major factor in reaching 100% renewable energy. Spain has yet to shake off the effects of the 2008 economic crisis, however it does remain the 12th largest economy in the world. The 2010 gross domestic product (GDP), at current prices is 1,062.6 billion euros (1,536,732,120,000 USD). The projection is set to increase to 1,230.7 billion euros (1,779,838,340,000 USD) in 2014. The goal for this section will be to demonstrate a brief overview of the price of an average plant for each respective renewable energy source. With the average cost of a plant and the resource potential in mind, the amount necessary for reaching 100% can be deduced.

The subsequent sections will cover the investment, operation and maintenance, and generation costs by energy source. All costs are given in both U.S. dollars and euros. Costs are derived from various energy reports from the International Energy Agency (IEA), so costs are based off a global average, and are not necessarily specific to Spain.

[40] Gómez et. al, "Potential and Cost of Electricity Generation," 504.
[41] Gómez et. al, "Potential and Cost of Electricity Generation," 503.

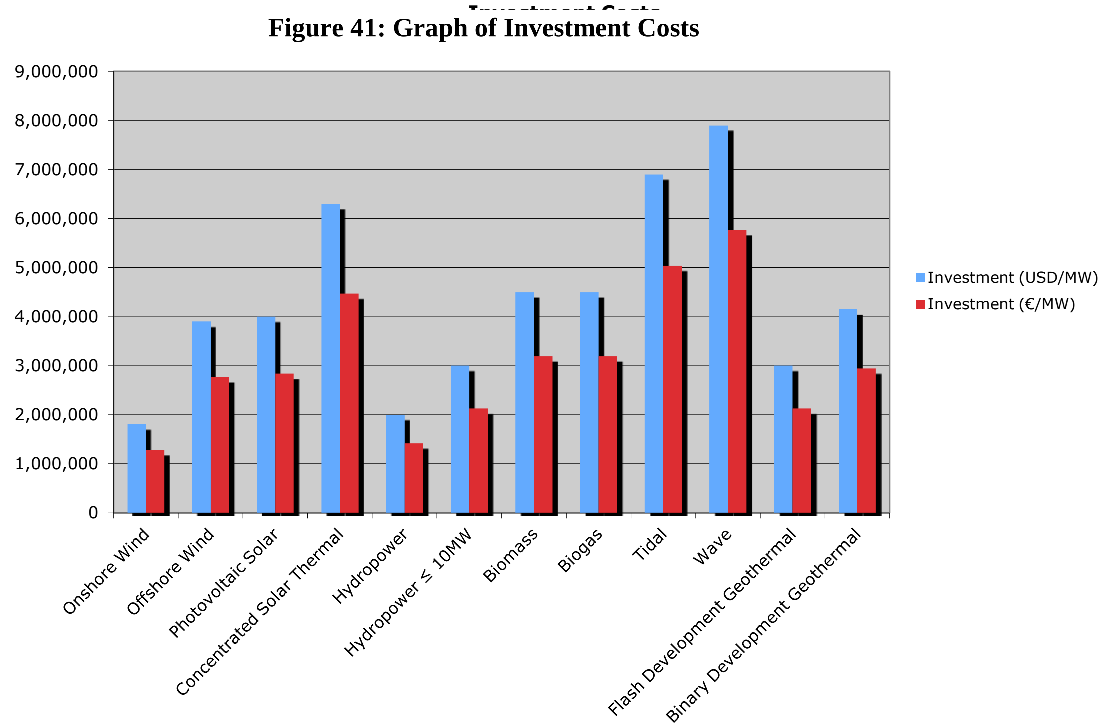
4.1 Investment Costs

Figure 40: Table of Investment Costs by Energy Source
Costs are in both USD/MW and €/MW

	Investment (USD/MW)	Investment (€/MW)
Onshore Wind	1,450,000 – 2,160,000	1,028,450.25 – 1,531,969.20
Offshore Wind	3,100,000 – 4,700,000	2,198,659.50 – 3,333,451.50
Photovoltaic Solar	4,000,000	2,836,980
Concentrated Solar Thermal	4,200,000 – 8,400,000	2,978,829 – 5,957,658
Hydropower	2,000,000	1,418,490
Small Hydropower ≤ 10MW	2,000,000 – 4,000,000	1,418,490 – 2,836,980
Biomass	3,000,000 – 6,000,000	2,127,735 – 4,255,470
Biogas	3,700,000 – 5,300,000	2,624,206.50 – 3,758,998.50
Tidal	6,000,000 – 7,800,000	4,378,602 – 5,692,182.60
Wave	6,800,000 – 9,000,000	4,962,415.60 – 6,567,903
Geothermal Flash Development	2,000,000 – 4,000,000	1,418,490 – 2,836,980
Geothermal Binary Development	2,400,000 – 5,900,000	1,702,188 – 4,184,545.50

Source: IEA

Figure 41: Graph of Investment Costs



Data from IEA

4.2. Operation and Maintenance Costs

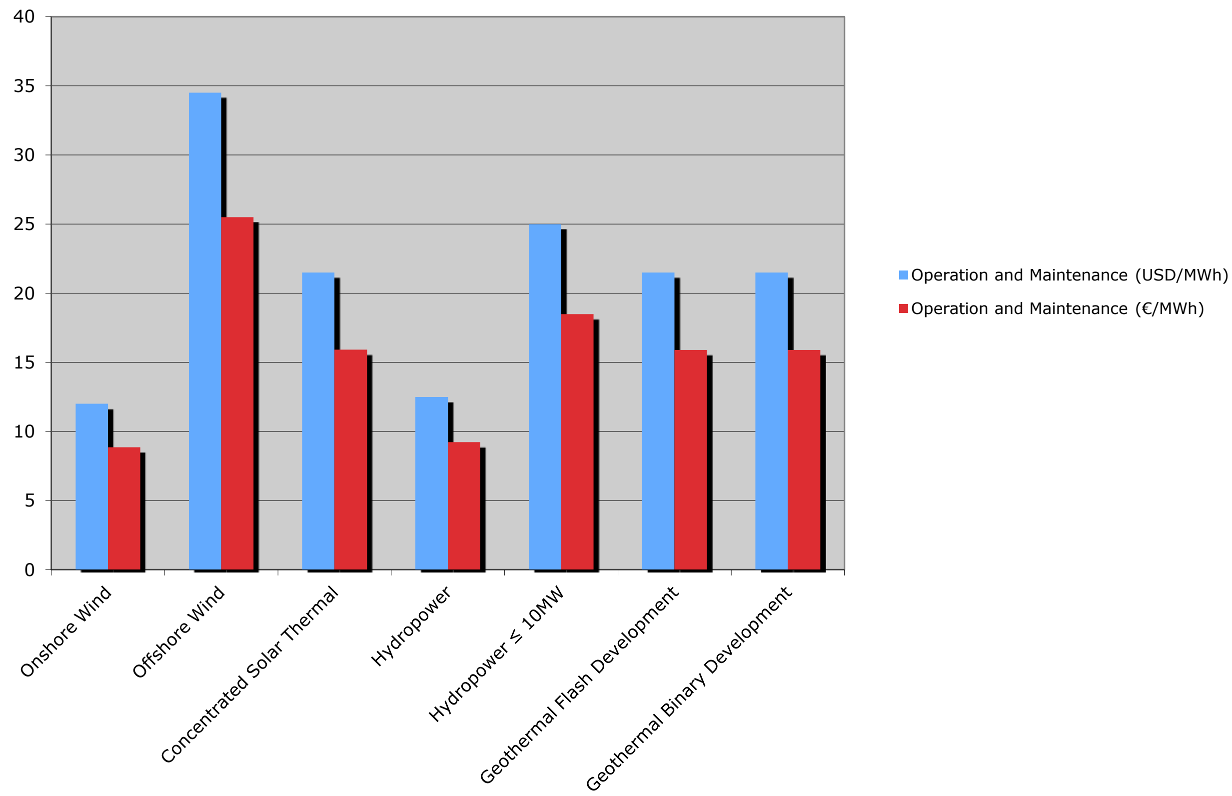
Figure 42: Table of Operation and Maintenance Costs
Costs are in both USD/MWh and €/MWh

	Operation & Maintenance (USD/MWh)	**Operation & Maintenance (€/MWh)**
Onshore Wind	12	8.87
Offshore Wind	21 – 48	15.52 – 35.47
Photovoltaic Solar		
Concentrated Solar Thermal	13 – 30	9.67 – 22.17
Hydropower	5 – 20	3.70 – 14.78
Small Hydropower ≤ 10MW	10 – 40	7.39 – 29.56
Biomass		
Biogas		
Tidal		
Wave		
Geothermal Flash Development	19 – 24	14.04 – 17.73
Geothermal Binary Development	19 – 24	14.04 – 17.73

Data from IEA

The operation and maintenance costs for photovoltaic solar are about 1% of investment cost every year[42]. Biomass and biogas have an operation and maintenance cost of USD 100/kW (€73.89/kW) and USD 300/kW (€221.66/kW) respectively[43]. The costs for tidal and wave are about USD 150/kW (€109.47/kW) and USD 200/kW (€145.95/kW)[44]. Operation and maintenance costs are annual costs.

Figure 43: Graph of Operation and Maintenance Costs
Costs are in both USD/MWh and €/MWh



Source: IEA

[42] International Energy Agency, Technology Roadmap: Solar Photovoltaic Energy (Paris: International Energy Agency, 2010,) 9.
[43] "Energy Technology Systems Analysis Programme: Biomass for Heat and Power," International Energy Agency, accessed September 13, 2011, http://www.etsap.org/E-techDS/PDF/E05-Biomass%20for%20HP-GS-AD-gct.pdf
[44] "Energy Technology Systems Analysis Programme: Marine Energy," International Energy Agency, accessed September 13, 2011, http://www.etsap.org/E-techDS/PDF/E08-Ocean%20Energy_GSgct_Ana_LCPL_rev30Nov2010.pdf

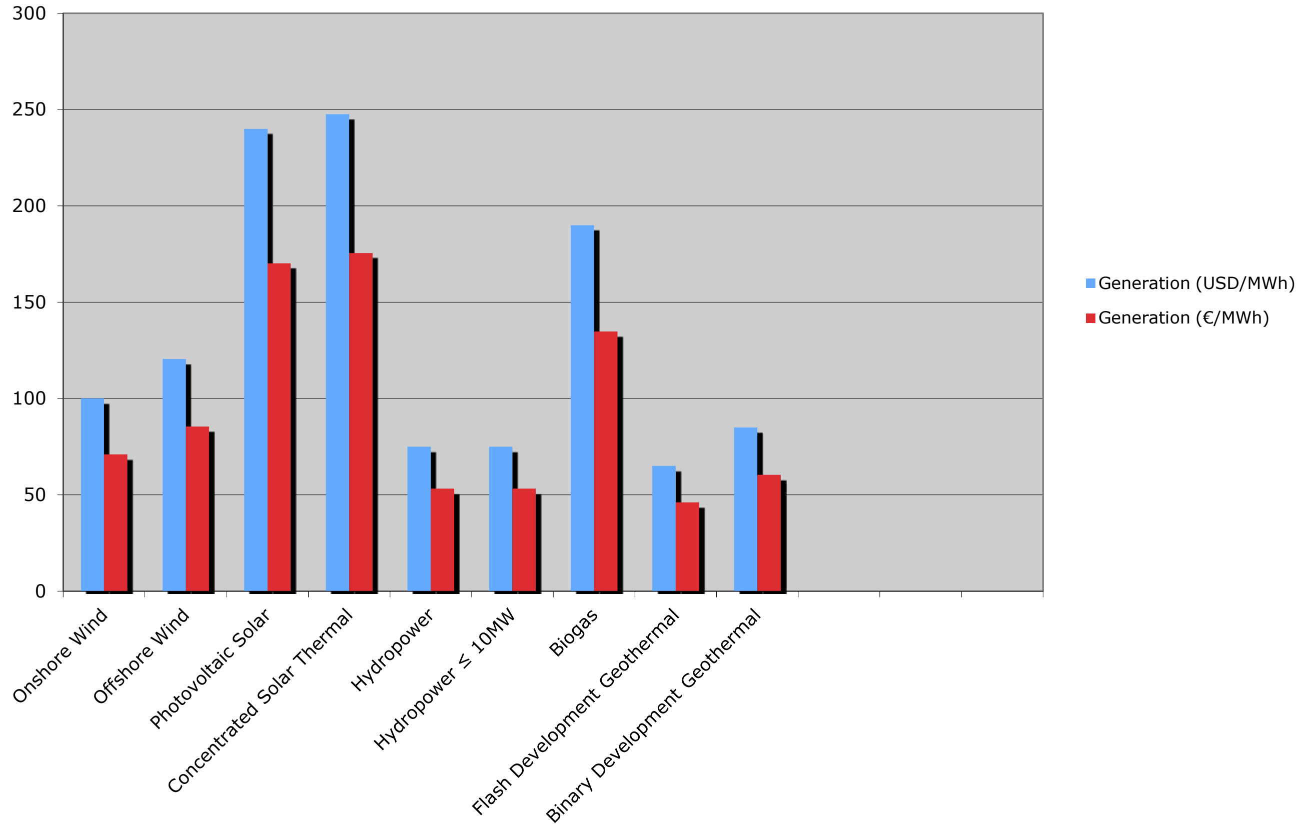
4.3. Generation Costs

Figure 44: Table of Generation Costs
Costs are in both USD/MWh and €/MWh

	Generation (USD/MWh)	Generation (€/MWh)
Onshore Wind	70 – 130	49.65 – 92.20
Offshore Wind	110 – 131	78.02 – 92.91
Photovoltaic Solar	240	170.22
Concentrated Solar Thermal	200 – 295	141.85 – 209.23
Hydropower	50 – 100	35.46 – 70.92
Small Hydropower ≤ 10MW	50 – 100	35.46 – 70.92
Biomass	n/a	n/a
Biogas	190	134.76
Tidal	n/a	n/a
Wave	n/a	n/a
Geothermal Flash Development	50 – 80	35.46 – 56.74
Geothermal Binary Development	60 – 110	42.56 – 78.02

Source: IEA

Figure 45: Graph of Generation Cost
Costs are in both USD/MWh and €/MWh



Source: IEA

5. Renewable Energy Companies

Many Spanish companies have already taken the initiative to disseminate renewable energies to Spain and the rest of the world. Many companies have driven Spain's renewable sector, but four companies in particular: Abengoa, Acciona Energía, Gamesa, and Iberdrola are notable for their vast installations of renewable energies in Spain and across the world. What is also notable regarding these four countries is that they have brought in success in regards to both domestic and international project development.

5.1. Abengoa

In Abengoa's mission statement, they describe themselves as a "*technology company that applies innovative solutions for sustainability in the environmental and energy sectors*"[45]. Areas of focus for Abengoa include concentrated solar power, biofuels, desalination, and ocean energy. Due to the nature of this paper, and the fact that ocean energy is not yet fully explored,

[45] "Our Commitment," Abengoa, accessed September 12, 2011, http://www.abengoa.es/corp/web/en/compania/nuestro_compromiso/index.html

Abengoa's contribution to solar will be what is discussed in this particular section. At the moment, Abengoa has 343 MW of installed solar plants. About 193 MW of that is installed in Spain, and 150 MW is in Algeria[46]. A further 780 MW of capacity is under construction in Spain, the US, the United Arab Emirates, Mexico, and Chile[47]. There are offices in all the previously mentioned nations plus India, China, Australia, Italy, and South Africa[48]. Much of the technology Abengoa uses are parabolic troughs, solar towers, and photovoltaic systems.

Figure 46: PS-10 in Seville, Spain
The first commercial solar power tower in the world

Source: Abengoa Solar

5.2. Acciona Energía

Acciona Energía "*presents itself to the market as a global operator in clean energy*"[49]. The company owns 7,904 MW of installed capacity[50]. The largest portion of that comes in the form of wind power, 6,614 MW, or 84%[51]. 912 MW, 12%, is from hydropower[52]. Concentrated solar power, photovoltaic, biomass, and solar thermal make up the rest of Acciona Energía's

[46] "Operating Facilities," Abengoa Solar, accessed September 12, 2011, http://www.abengoasolar.com/corp/web/en/nuestras_plantas/plantas_en_operacion/
[47] "Plants Under Construction," Abengoa Solar, accessed September 12, 2011, http://www.abengoasolar.com/corp/web/en/nuestras_plantas/plantas_en_construccion/
[48] "Offices," Abengoa Solar, accessed September 12, 2011, http://www.abengoasolar.com/corp/web/en/nuestras_plantas/oficinas/
[49] "The Company," Acciona Energy, accessed September 13, 2011, http://www.acciona-energia.com/about_us/the_company.aspx
[50] "Capacity," Acciona Energy, accessed September 13, 2011, http://www.acciona-energia.com/about_us/energy-data/capacity.aspx
[51] "Capacity"
[52] "Capacity"

renewable installed capacity[53]. Co-generation has amounted to 9 MW[54]. On top of all that an additional 1,555 MW was installed by the company for others[55]. Again, the bulk of that is wind power, 1,472 MW of the 1,555 MW[56]. In 2010, Acciona generated 18,574 GWh from renewable sources[57]. This was a 37% increase from 2009, which saw 13,569 GWh of of energy generated[58]. So far, as of the 30th of June, Acciona generated 9,219 GWh from renewable sources[59]. 73% of this capacity is in Spain, and the rest is in the US, South Korea, Mexico, Greece, Portual, Germany, Italy, Hungary, Canada, India, and Australia[60]. During the first half of 2011, the net revenue of Acciona Energía amounted to €809 million[61].

Figure 47: Lasarra Hydropower Station in Aragón, Spain

Image from Acciona Energía

5.3. Gamesa

Gamesa is a manufacturing company of wind turbines and plants[62]. The company has about 22,000 MW of installation in 30 countries, with 14,000 MW under construction[63]. Gamesa has offices, manufacturing plants, and wind farms in Europe, Northern Africa, Asia, North

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53 "Capacity"
54 "Capacity"
55 "Capacity"
56 "Capacity"
57 "Production," Acciona Energy, accessed September 13, 2011, http://www.acciona-energia.com/about_us/energy-data/production.aspx
58 "Production"
59 "Production"
60 "Capacity"
61 "In Figures," Acciona Energy, accessed September 13, 2011, http://www.acciona-energia.com/about_us/in-figures.aspx
62 "Gamesa," accessed September 12, 2011, http://www.gamesacorp.com/en/gamesaen/
63 "Gamesa."

America, and South America[64]. Net profits of €50 million were brought in during the year 2010[65].

Figure 48: Gamesa G136-4.5 MW Turbine

Source: Gamesa

5.4. Iberdrola

Iberdrola is another energy company of Spain. Iberdrola had an installed capacity of 12,530 MW operational, and a produced 25,400 million kWh in 2010[66]. 3,500 MW is expected to be installed between 2011 and 2014. Iberdrola is a world leader in wind energy; wind power is a large part of its renewable business. Iberdrola's Renewable Energy Business is in a number of European countries, Mexico, the United States, Brazil, and China[67]. If all of Iberdrola's activities: like their headquarters, distribution, and engineering and construction is included, then the number of involved countries drastically increases. Net profits of Iberdrola's renewable business amounted to €360 million[68].

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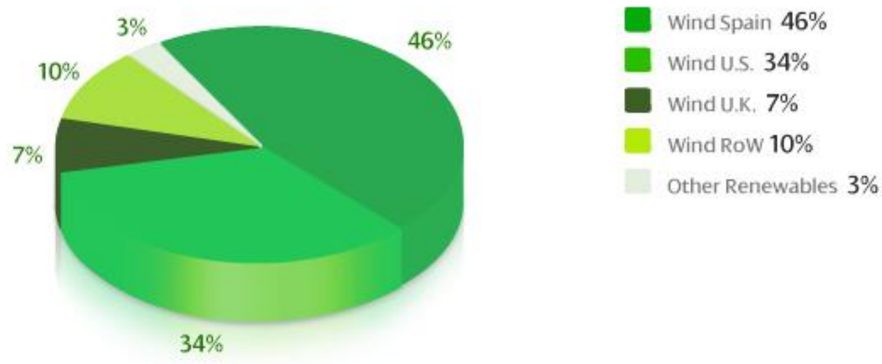
64 "Gamesa."
65 "Gamesa."
66 "Renewable Energy Business," Iberdrola, accessed September 12, 2011, http://www.iberdrola.es/webibd/corporativa/iberdrola?IDPAG=ENWEBCONLINRENOVABLES&codCache=13158581089641936
67 "Lines of Business," Iberdrola, accessed September 12, 2011, http://www.iberdrola.es/webibd/corporativa/iberdrola?IDPAG=ENWEBCONLINEA&codCache=13158583129539728
68 "Renewable Energy Business"

Figure 49: Iberdrola's Renewable Capacity in 2010



Source: Iberdrola

6. Policy

A reason for Spain's current success with renewable energies, and a reason it is believed that Spain is capable of obtaining 100% renewables, is because of policies enacted to promote the usage of renewable energy. This section will summarize just a few notable policies that have contributed to the dissemination of renewables into the energy system.

6.1. Royal Decree 436/2004

A system where producers can sell their electricity production or surplus to distributors or just sell on the market is laid out in this royal decree[69]. If the producer decides to sell to a distributor, the producer would get a regulated rate[70]. If sold to the market, a "*negotiated market price, plus an incentive for participating and a premium*"[71]. Producers of solar thermoelectric would receive improved incentives and premiums.

6.2. Royal Decree 314/2006

The Royal Decree 314/2006 is also known as the technical building code. A number of mandates are made in this particular royal decree. One aspect of the law is that new and refurbished buildings in the tertiary sector must have photovoltaic panels[72].

6.3. Royal Decree 661/2007

The Royal Decree 661/2007 is a 2007 law that regulates electricity generation in the special regime[73]. Electricity generated from renewable sources, plants with an installed capacity

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[69] "Spanish Legislation", Comisión Nacional de Energía, accessed September 13, 2011, http://www.eng.cne.es/cne/contenido.jsp?id_nodo=409&&&keyword=&auditoria=F
[70] "Spanish Legislation"
[71] "Spanish Legislation"
[72] "Spanish Legislation"

of less than 50 MW, co-generation, and from the incineration of waste are all regulated under the special regime.

6.4. Feed-in Tariff (FiT)

Spain utilizes feed-in tariffs in order to promote renewable energy sources. Feed-in tariffs are what energy producers are paid "*for each unit of electricity fed into the grid, and generally oblige power companies to purchase all electricity from eligible producers in their service area over a long period of time -- usually 15 to 20 years*". Plants with an installed capacity ≤ 50 MW are capable of receiving feed-in tariffs[74]. Two types of tariffs are available, guaranteed and variable tariffs. Guaranteed tariffs are the minimum tariff that the country gives out[75]. Variable tariffs are tariffs based on things like the season[76]. Biomass and hydroelectric producers are able to choose a variable tariff over a guaranteed tariff[77]. If electricity is generated from renewable energy sources that are above 50 MW and are not a photovoltaic system, then the producer can choose between a guaranteed tariff and a bonus "*on top of the price achieved in the free market*"[78]. The tariff prices were decided in the Royal Decree 661/2007. The tariffs for photovoltaic were updated in Royal Decree 1578/2008.

Figure 50: Table of Feed in Tariffs

	Tariffs
Wind	• For 20 years: 7.9084 €cent/kWh • After 20 years: 6.6094 €cent/kWh
Solar	PV • For 25 years: 13.4585 – 28.8821 €cent/kWh Thermoelectric • For25 years: 29.0916 €cent/kWh • After 25 years: 23.2731 €cent/kWh
Hydroelectric	• For 25 years: 8.4237 €cent/kWh • After 25 years: 7.5814 €cent/kWh
Biomass	• For 15 years: 7.0284 – 17.1596 €cent/kWh • After 15 years: 7.0284 – 12.7362 €cent/kWh
Biogas	• For 15 years: 8.6311 – 14.1141 €cent/kWh • After 15 years: 7.0306 €cent/kWh
Geothermal	• For 20 years: 7.441 €cent/kWh • After 20 years: 7.0306 €cent/kWh

[73] "Spanish Legislation"
[74] "Feed-in Tariff (Régime Especial)," RES Legal, last modified July 18, 2011, http://www.res-legal.de/en/search-for-countries/spain/single/land/spanien/instrument/price-regulation-regimen-especial/ueberblick/foerderung.html?bmu%5BlastShow%5D=5&cHash=15e242e566eb2c4b0c37d56be95c8218
[75] "Feed-in Tariff (Régime Especial)"
[76] "Feed-in Tariff (Régime Especial)"
[77] "Feed-in Tariff (Régime Especial)"
[78] "Feed-in Tariff (Régime Especial)"

Data from RES Legal

6.5. Directive 2009/28/EC

Directive 2009/28/EC, a directive from the European Parliament, does a number of things. Broadly, the goal of this directive is to promote the usage of renewable energies and provides a basis for this. A goal for member states, the 20-20-20 goal, has been set to provide a target for 2020[79]. The 20-20-20 goal states the 20% of greenhouse gas emissions must be cut, 20% increase of renewables in the energy system, and 20% decrease in energy consumption by the year 2020[80]. Member states are directed to establish national energy action plans[81]. The energy action plans promote renewable energy and "*set the share of energy from renewable sources consumed in transport, as well as in the production of electricity and heating*"[82].

6.6. National Renewable Energy Action Plan (NREAP) 2011-2020

As dictated by Directive 2009/28/EC, Spain enacted a national renewable energy action plan of their own. The plan provides targets up until the year 2020, and provides ways to reach those targets.

Conclusion

It is the opinion of this researcher that Spain is theoretically capable of powering 100% of their electricity system with renewable energies by the year 2020. Theoretically is used as a qualifier, because of the logistical problems constructing and operating new plants pose, and the political and economic variables that may arise. Again, this paper posits that it is possible due to some key factors.

First, Spain already has a strong foundation in regards to renewable energies. In the year 2010, Spain generated 35% of its electricity from renewable sources, chief among them were wind and hydropower. While, conventional, fossil fuel based, sources are still predominant, their dominance is increasingly being challenged by renewables.

Renewable energies are seeing dramatic increases in installed capacity in short amounts of time. Wind and solar are capacity is probably the most telling. Spain is both a European and world leader in wind, photovoltaic solar, and concentrated solar power capacity. Spain is fourth in the world in wind power behind China, the United States, and Germany. Spain has the second largest installation of photovoltaic. The world's first commercial solar tower, PS-10, was built in Spain.

Second, and probably the most important reason, is that Spain already has the resources to generate more than enough clean electricity. Wind, hydroelectric, and biomass, alone has the potential to generate more electricity than the 2010 demand. Using just those three sources can

[79] "Promotion of the Use of Energy from Renewable Sources," Europa, last modified July 9, 2010, http://europa.eu/legislation_summaries/energy/renewable_energy/en0009_en.htm
[80] "EU Climate Package Explained" BBC News, April 9, 2010, accessed September 13, 2011, http://news.bbc.co.uk/2/hi/7765094.stm
[81] "Promotion of the Use of Energy from Renewable Sources"
[82] "Promotion of the Use of Energy from Renewable Sources"

also cover over 80% of the projected 2020 demand. Again, that does not even include solar, geothermal, offshore wind, and ocean power.

Finally, there have been many policies enacted over the years that have helped promote the use of renewable energies, so there is strong framework in place to help reach 100%. It is for these three main reasons, that Spain can theoretically reach 100% renewable energy by 2020.

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