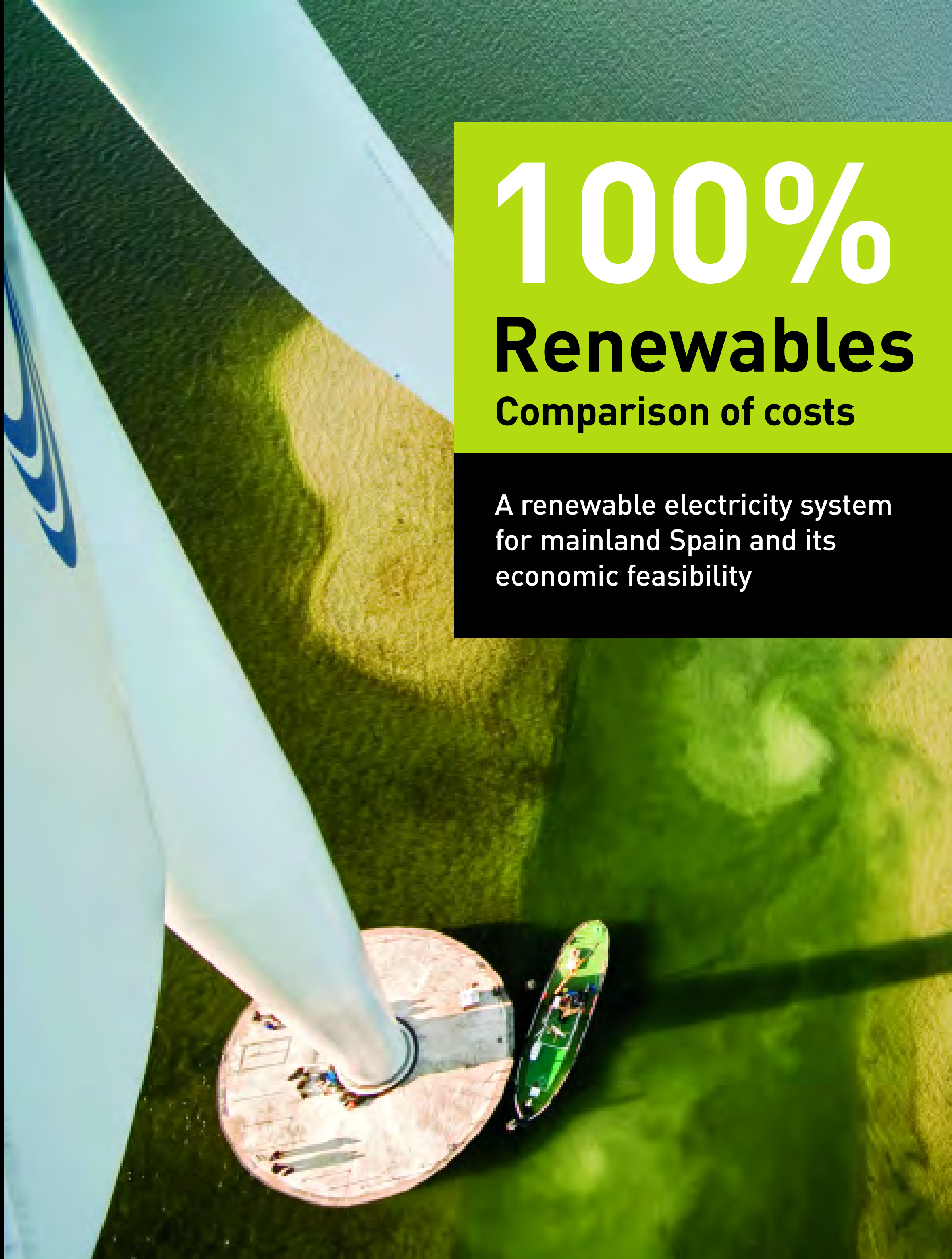
SUMMARY OF COSTS

100% Renewables

Comparison of costs

A renewable electricity system for mainland Spain and its economic feasibility



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Summary document, drawn up by Alicia Cantero and José Luis García Ortega, from the report entitled "100% Renewables. A renewable electricity system for mainland Spain and its economic feasibility

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PRESENTATION

The report *"100% Renewables. A renewable electricity system for mainland Spain and its economic feasibility"* presents extensive information on costs for the different technologies, renewable and non-renewable, both at present and around 2050. The analysis includes detailed information on the cost structure for each technology – incorporating the environmental costs arising from its use – and the evolution of these with generation volume. All the information is presented on a province by province basis.

The cost analysis it presents is very important since it enables us to compare for the first time using the same parameters, renewable and non-renewable technologies; and by using clear hypotheses it traces the cost trends of the different technologies around 2050. The main findings are presented in this summary.

Will a generation system based on renewables cost more?

The cost argument is the first used to reject the renewables option. Renewable technologies appear to be more expensive, however the arguments employed are not adequate for comparing the different technological options. With a view to developing energy planning that enables us to progress towards sustainability, the important comparisons are the ones carried out which assume that all technologies, renewable or non-renewable, have reached industrial maturity, and that all costs associated with the use of the technology are properly internalized.

In this document we show the main findings of the cost analysis which compares different technologies using the same parameters, at present and around 2050 by which time all the technologies we decide to include in our energy system will for certain have reached their industrial maturity.

All the information presented in maps, which allows us to locate the quality of the sites on a province by province basis, providing one scenario for the current situation and another projected to 2050. Furthermore, in order to carry out a comparison between technologies, the costs of the different technologies considered in the study are presented jointly.

We also indicate for each autonomous community, on a province by province basis, those technologies which match the best technical categories and the cost of electricity for each of them projected to 2050.

This document provides us with an analysis of a cost analysis which is detailed enough for us to compare the different technologies using the same parameters. However, to define the cost of a generation system, **it is not just enough to know the cost of each of the technologies individually,** because this may vary substantially according to the combination of technologies employed to meet demand. **The report "100% Renewables. Summary of Conclusions" tackles this issue.**

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INDICATORS USED

The parameters used to develop the study's cost analysis are the following:

- **Levelized Electricity Cost (LEC).** It is the main indicator, it groups the investment costs and those of operation and maintenance over the life cycle of the technology. It is expressed in $c€/kWh_e$ (cost of a kilowatt hour electricity)
- **Interest from money.** i = 8%.
- **Inflation rate.** f = 2,6%[1].
- **Disposal costs of CO2 (CECO2).** It is expressed in $€/Tm\text{-}CO_2$. (euro per tonne of CO_2).

To calculate it a combined cycle power station has been taken as the benchmark technology operating with natural gas[2], at 2003 values, with an electricity cost of 4 $c€/kWh_e$. So that if a technology shows a positive value for CO2 disposal costs, it means that the cost of the electricity generated with this technology is greater than that generated by a combined cycle plant. Whilst if it shows a negative value the cost of electricity generated using this technology would be lower.

For example, if a technology by the year 2050 has a CE_{CO2} = -11 $€/Tm\text{-}CO_2$, it would mean that the cost of electricity using this technology would be less than that generated with the benchmark technology (combined cycle in 2003), and would involve a saving of 11 € per ton of CO_2.

The values for this parameter must not be understood in absolute terms but relative between technologies.

[1] *This value was adopted at the beginning of the project (2003). Given subsequent developments the inflation rate has undergone, it was modified to f = 3.5 %. In the report findings both values are presented.*

[2] *Combined cycle power stations have been taken as the benchmark technology, because it is the technology which uses the fossil fuel which emits the least CO_2.*

3

MAIN RESULTS

3.1. Combined cycle and Nuclear

Thermal and nuclear power stations

Firstly, and in order to have a comparison standard, we present the main findings of the cost analysis carried out for a combined cycle thermal power station fired with natural gas and for a nuclear power station.

These technologies, have already reached their industrial maturity so the expected cost development will be triggered by an increase due to: fuel increase and depletion, reduction in production volume (through sharing the market with other technologies) and internalization of environmental costs.

Coal-fired power stations have not been considered in this study because of their high emissions and low power cycle performance. Neither have we considered coal gasification technologies because their performance will always be much lower than those of a combined cycle gas turbine, which "a priori" would make up for the fuel price difference. Besides they would maintain higher specific emissions of CO_2.

Combined cycle thermal

The cost of electricity generated by a combined cycle power station employing natural gas as its fuel has been analysed as well as its development over time.

The cost of electricity generated by this type of power station is conditioned by a series of factors related to:

- **Fuel cost:** an increase in fuel cost is expected as finite reserves run out. Furthermore this cost is subject to considerable fluctuation associated with the social and political situation at the time.
- **The operating mode of the power station:** to keep the benchmark cost (4 c€/kWh$_e$) it would be necessary to operate it many hours a year, that is, to use high capacity factors[3].
- **Operating and maintenance costs:** within which the evaluation of external factors such as CO_2 emission costs are included.

[3] *Capacity factor: quotient between useful energy generated and the maximum that could be generated by operating at maximum power throughout the whole year.*

3.1

Bearing in mind these factors and even in the case that it made sense to put forward a scenario in which electricity demand in 2050 was met by **combined cycle power stations** fired by natural gas, the costs of electricity generated with this technology would be considerably higher than those the majority of renewable technologies would provide us with. Scarce fuel cost increases on which greater demand would be placed, and the internalization of environmental impacts associated with the use of this fuel, would lead to electricity costs projected to 2050 **in excess of 15 c€/kWh$_e$.**

Nuclear

Nuclear fission technology has many arguments which advise against it use from the sustainability point of view: high costs when including safety requirements, energy resource limitation, waste management, operating safety, prevention against attack, prevention of nuclear arms proliferation, limitation of technology transfer and regulation difficulties. Fusion technology, setting aside the possible problems associated with it, will not be available as a useful tool within the period we have to solve the climate change problem.

If we focus exclusively on fission technology, costs of electricity generated by a nuclear power station will be conditioned by a series of factors related to:

- **Investment costs.** Despite the great uncertainty over current investment costs for nuclear power stations, it is unlikely that by 2050 they will remain below 3000 €/kW$_e$ to comply with the required safety requirements.

- **Operating and Maintenance Costs.** There is little information relating to all the concepts included in this factor. From information available it may be concluded that these costs cannot be situated below 7 c€/kWh$_e$. With current exploitation rates these costs are more important than the cost of the fuel itself.

- **Operation mode of the system.** In a system with a high penetration of renewables, it would be necessary for power stations to operate in regulation mode and not operating at maximum output, as they do at present. Even assuming that a nuclear power station could technically carry out this regulation, the final effect would be a reduction of the capacity factor, and consequently a cost increase.

- **Price of fuel.** Given that it is a scarce fuel, in the case of high nuclear implementation, nuclear fuel would increase in cost as demand went up.

- **Interest from loan.** Long construction periods and associtated uncertainty would lead to loans with high interest rates.

Bearing in mind these factors, and despite the great uncertainty surrounding this technology, we could expect that it would lead to **a nuclear electricity cost by 2050 in the order of 20 c€/kWh$_e$**, considerably higher than electricity costs using many renewable technologies around this time.

3.2. Costs by renewable technologies

We present the cost information for the different renewable technologies in data maps on a province by province basis. The technologies considered are those described in the first report of the project entitled "Renewables 2050. A report on the potential of renewable energies in mainland Spain".

For each technology we present two scenarios, one using the current cost structure and another for 2050, and in each of them the average values by province[4] for electricity and CO_2 disposal costs are shown.

The energy performance on which these maps are based are those of current power station operation modes, that is, at maximum output.

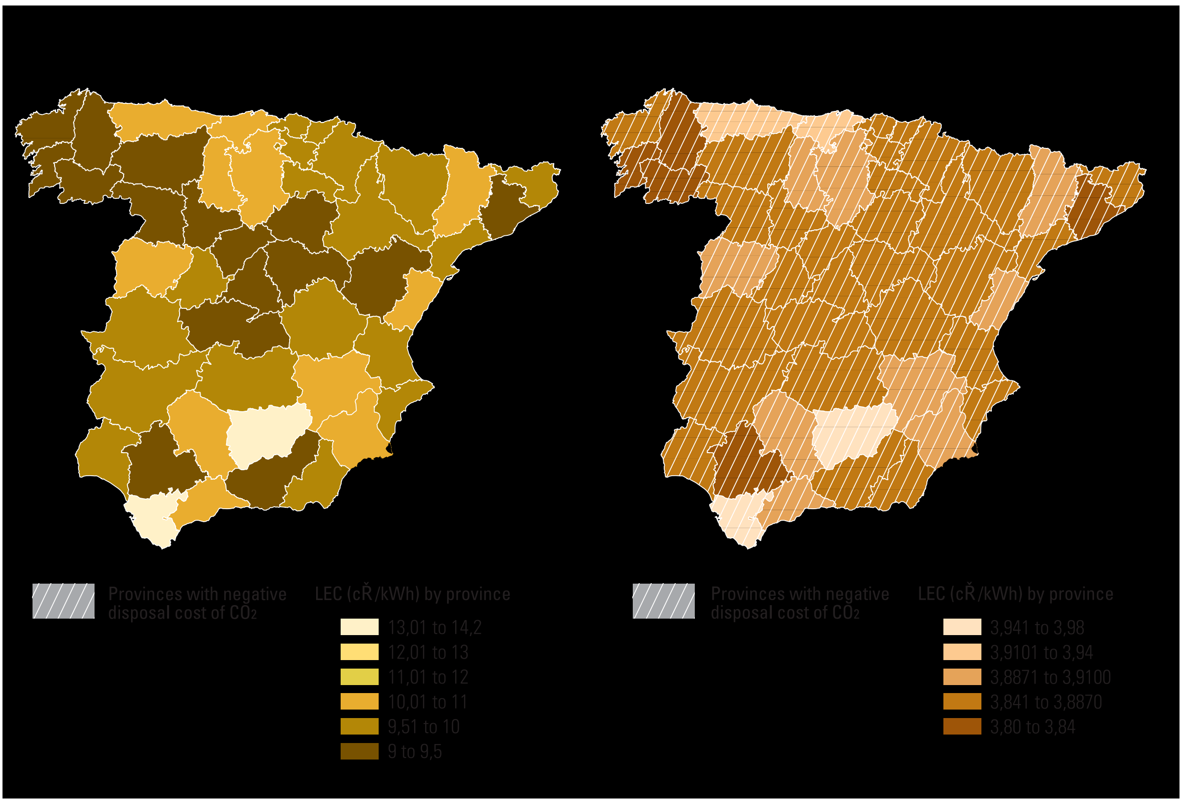
[4] *A single climate record for each province has been adopted, there being sites in each province with better or worse characteristics than the average value adopted. So, it may turn out that a province has the best sites for one technology, does not appear on the map in the best category, since it is taken as representative of the provincial average.*

GEOTHERMAL

In dry rock geothermal technology the costs are split into two components: for drilling and for above ground work. For the development of the calculations of the drilling costs it is assumed that, using current technology, good geothermal sites which can be accessed are scarce.

By the year 2050 the development of new drilling techniques will enable us to exploit all the sites at a reasonable cost, even if they are of a low thermal gradient.

Geothermal. Provincial distribution of the cost of electricity (LEC) and CO_2 disposal. *(i = 8%, f = 2.6% and N = 40 years)*



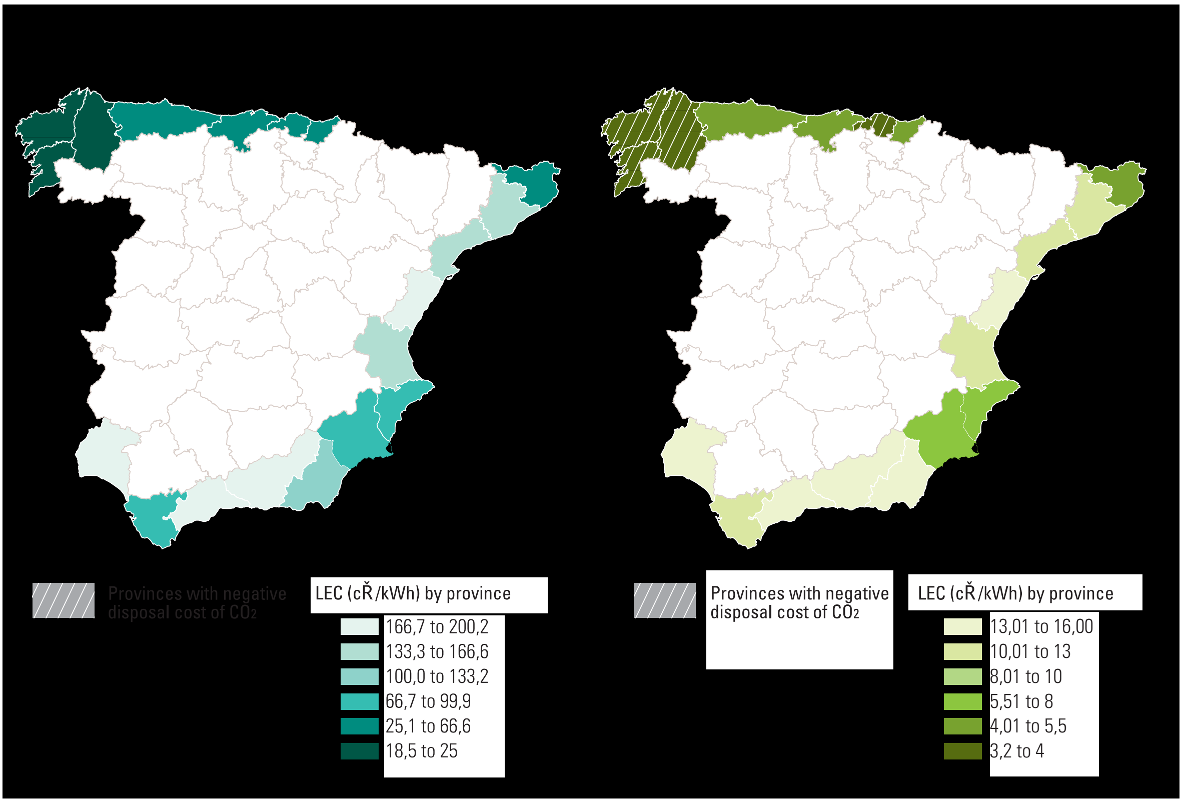
Under the current medium cost structure, the cost of electricity fluctuates, in the different provinces, between a minimum cost of 9.03 c€/kWh$_e$, and a maximum of 14.20 c€/kWh$_e$. These costs exceed those of a combined cycle power station in 2003, so all the cost values for CO_2 disposal are positive.

Under the projected cost structure for the year 2050, the medium cost of electricity fluctuates between 3.81 and 3.96 c€/kWh$_e$, so the cost values for CO_2 disposal shows a negative value in all provinces. The reduction of the drilling cost leads by 2050 to a very homogeneous provincial distribution for electricity costs. These costs, in all the provinces, are significantly lower than those of any scenario using nuclear and thermal by the year 2050.

WAVE

Wave power technology is in its early stages for commercial use, which brings about certain difficulties when assessing its costs. This technology's lack of commercial maturity leads to a significantly lower evaluation of its potential than what might be expected by 2050, so the costs in 2050 have been assessed by taking into account two scenarios: one assuming that the technology has reached its maturity and another in which it is considered that the technology continues at the same stage of commercial immaturity. The data that are presented in the maps assume in 2050 an improvement in the capacity factors with respect to current technology.

Wave power. Provincial distribution of the cost of electricity (LEC) and CO_2 disposal. *(i = 8%, f = 2.6% and N = 40 years)*



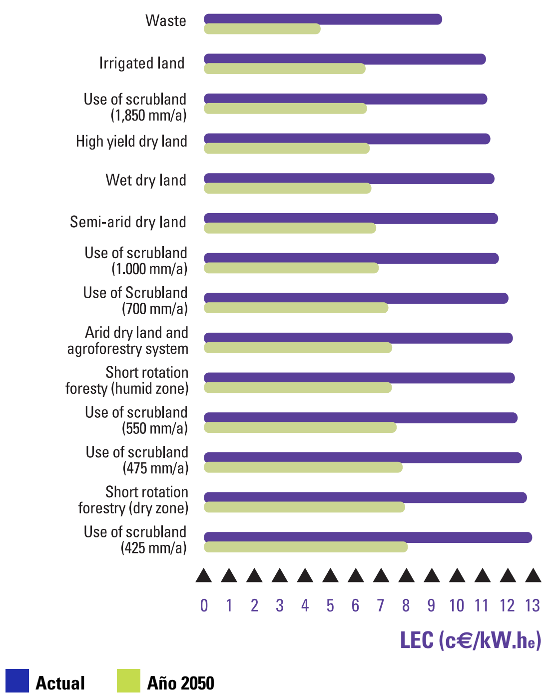
Using the current cost structure, wave power technology, provides us with electricity medium costs which fluctuate between 18.99 c€/kWh$_e$ and 187.58 c€/kWh$_e$ for the different provinces. In the year 2050, it provides us with electricity medium costs with values between 3.34 c€/kWh$_e$ and 15.36 c€/kWh$_e$. As we can see, these costs are below those projected in a scenario using nuclear and thermal in the majority of provinces, resulting a lot lower in the provinces with better tidal resources, such as Corunna, Lugo or Pontevedra.

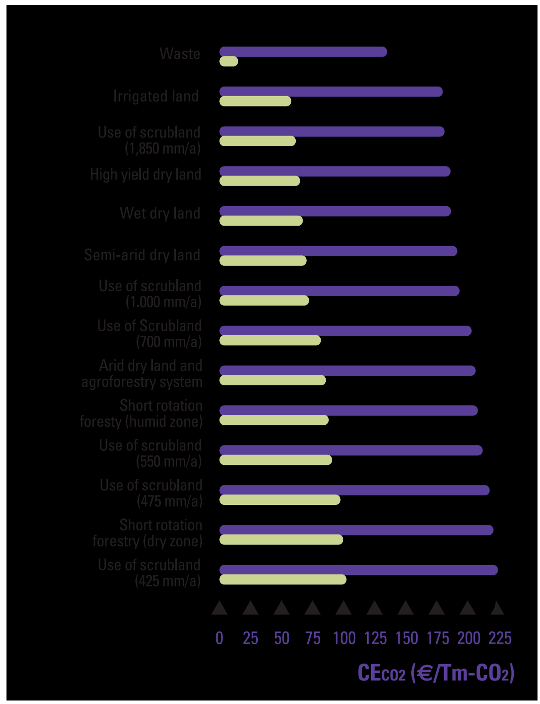
In these provinces, in 2050, negative CO_2 disposal costs would also be reached. Assuming that we consider that in 2050 wave power technology is at its current stage, electricity costs would reach values between 5.6 c€/kWh$_e$ and 50 c€/kWh$_e$. In this case only the Atlantic sites would provide competitive costs for wave power technology.

BIOMASS

Biomass cost structure has three different components which would progress differently: Investment (gas turbine, gassifiier and biomass silo), operating and maintenance costs, and costs associated to fuel (residual, energy crops, short rotation forestry crops and scrubland). It is noteworthy the effect that the fuel employed has on the electricity cost from biomass. So the technology cost is not determined by its geographical situation but by the type of fuel used. In the following graphs we present the current cost and the one in 2050, of electricity generated with biomass according to the type of fuel used. The same data are presented for CO_2 emission costs.

Biomass Electricity. (LEC) and CO_2 disposal (CE_{CO2}) cost using biomass[5] technology according to fuel type. *(i = 8 %, f = 3.5%).*





As we can see from the graph on the current cost structure, electricity costs vary from 9.38 c€/kWhe to 12.84 c€/kWhe according to the type of fuel. By the year 2050 a reduction in the cost of electricity will take place linked to its industrial maturity, and electricity costs range from 4.60 and 8,06 c€/kWhe. CO2 disposal costs show positive values, because in all cases electricity costs show values higher than the benchmark (combined cycle power station at 2003 costs).

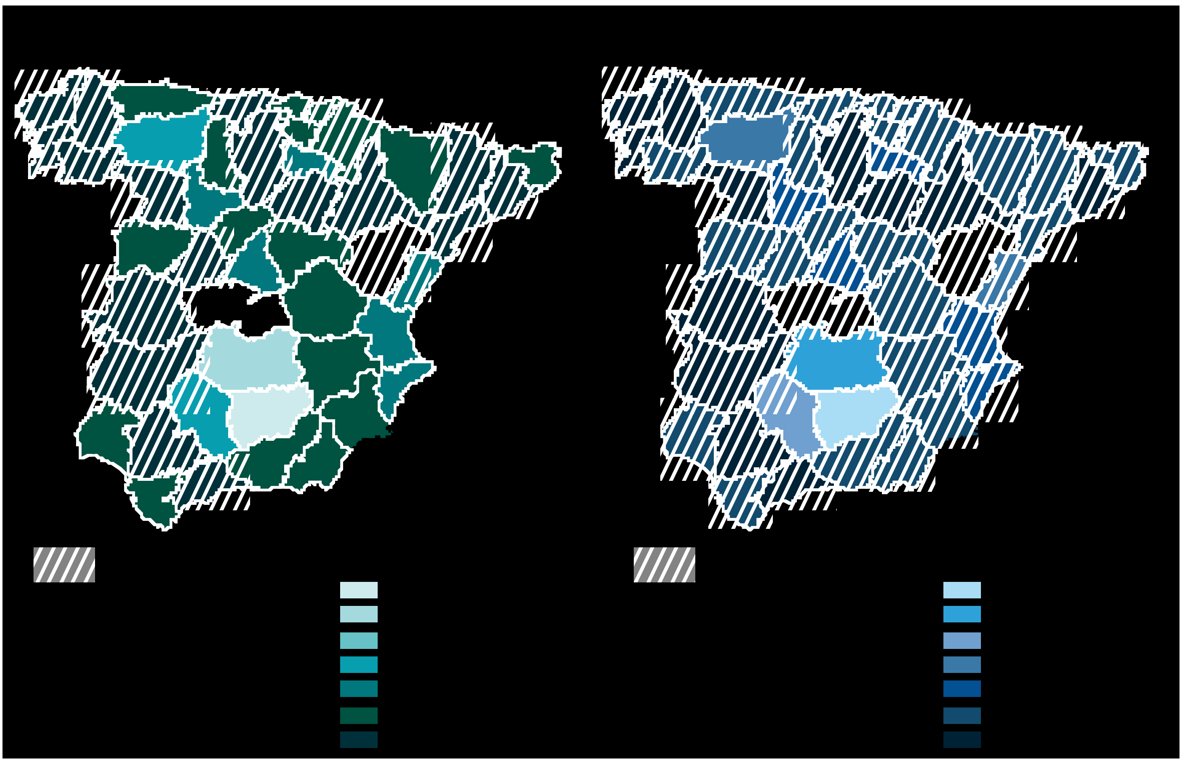
The lowest cost fuel is waste, whilst the use of scrubland and short rotation forestry crops (dry zone) are the highest cost ones. Costs for the year 2050, are considerably lower than those of a thermal or nuclear scenario by the year 2050.

[5] *It is assumed that gas from the gas generators used will be generated separately for each biomass source, additionally a nil effective net rate of inflation acting on biofuels is contemplated.*

ONSHORE WIND POWER

The distance between machines and the wind potential of a site, exert an important effect on the cost of electricity generated using this technology. In the cost analysis a difference has been made between flatland and rough terrain wind power, given the greater installation difficulty which rough terrain presents and the employment of smaller-sized machines. In both cases and due to the maturity of this technology at present, costs may evolve putting them in the period of industrial maturity in the year 2025. Data for flatland sites is shown below.

Onshore Wind Power. Provincial distribution of the cost of electricity (LEC) and CO_2 disposal. *(i = 8%, f = 2.6% and N = 20 years)*



As we can appreciate from these figures, already currently, but not especially by the year 2050, we find many sites with wind power electricity costs significantly lower than those projected for thermal and nuclear ones in 2050. On flat land, wind power electricity costs fluctuate, applying the current cost structure, between minimum values of 2.82 c€/kWh$_e$ and maximum one of 12.92 c€/kWh$_e$, even reaching in some cases negative CO_2 disposal costs, that is, less than current costs for a combined cycle power station. By the year 2050, all mainland flatland sites will give costs with values between 1.51 c€/kWh$_e$ and 6.90 c€/kWh$_e$. The best correspond to Zamora, Zaragoza, Málaga and Pontevedra. There are many areas with negative CO_2 disposal cost values. On rough terrain, wind power electricity costs fluctuate between 2.99 c€/kWh$_e$ and 13.67 c€/kWh$_e$. By the year 2050, all mainland rough terrain sites will give costs between 1.77 c€/kWh$_e$ and 8.09 c€/kWh$_e$.

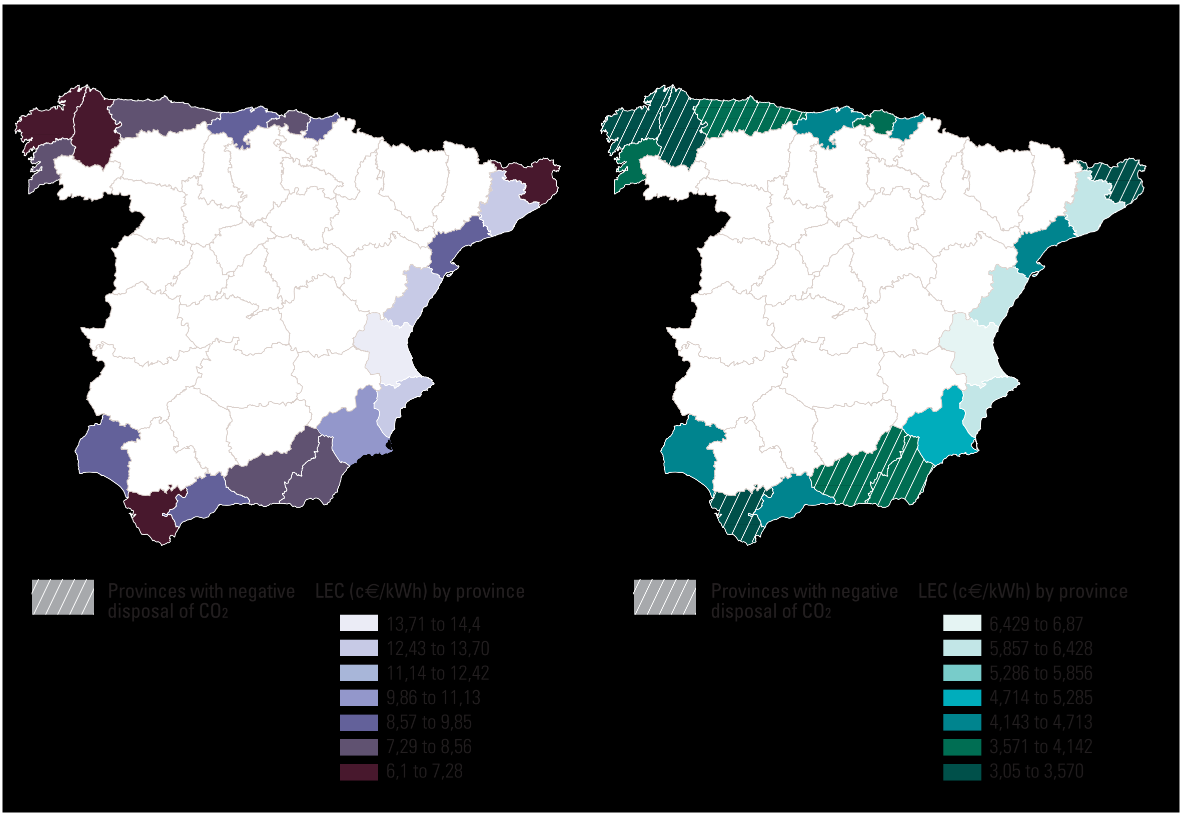
These results are a direct reflection of the current positive situation of wind power technology, having covered a considerable part of their learning curve.

OFFSHORE WIND POWER

Like onshore wind power, the distance between machines and the wind potential of a site, exert an important effect on the cost of electricity generated using this technology.

For cost development the growth rates of global installed capacity and of progress rates are assumed.

Offshore Wind Power. Provincial distribution of the cost of electricity (LEC) and CO_2 disposal. *(i = 8%, f = 2.6% and N = 20 years)*



Current costs of generated electricity using offshore wind power fluctuate between a minimum value of 6.14 c€/kWh$_e$ and a maximum one of 14.39 c€/kWh$_e$. These costs exceed those of a combined cycle power station in 2003, so all the cost values for CO_2 disposal are positive.

By the year 2050, all mainland sites will give costs between an average minimum value of 3.05 c€/kWh$_e$ and a maximum one of 6.86 c€/kWh$_e$. These costs are significantly lower than those projected for thermal and nuclear ones in 2050. CO_2 disposal costs in 2050 reach negative values in provinces with the best resources6 such as Corunna, Girona, Cádiz or Almería.

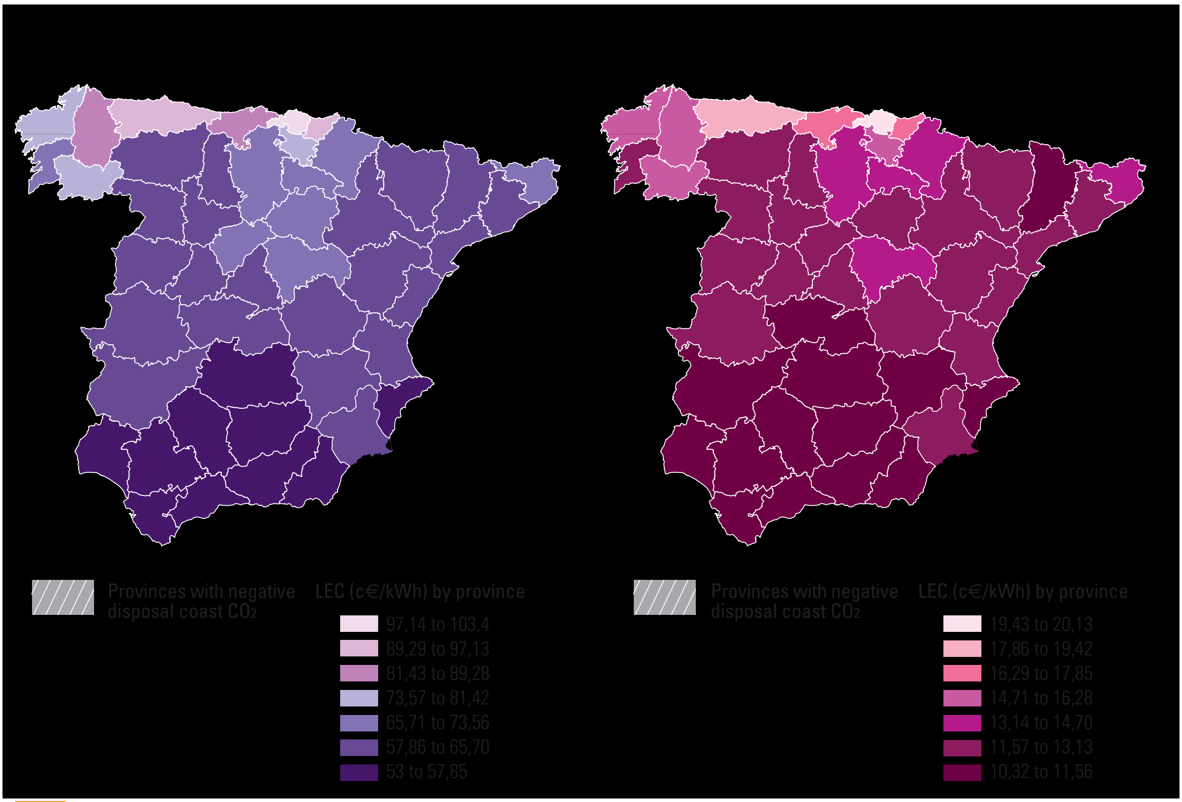
[6] *In this second stage of the study, having data on the temporal series of offshore wind power resource, geographical distribution of offshore wind power is modified in respect of the data presented in Renewables 2050, although overall potential is kept.*

PHOTOVOLTAIC INSTALLED ON BUILDINGS

For photovoltaic technology economic performance is determined by the availability of solar resources, orientation and investment costs of the equipment.

The study considers installations placed on roofs and facades with different orientations (S,E,W, SE, SW) so for a single site there is a very large variation in capacity factors. We show on the map the costs of photovoltaic power installed on roofs.

Installed Photovoltaic. Provincial distribution of the cost of electricity (LEC) and CO_2 disposal. *(i = 8%, f = 2.6% and N = 40 years)*



In the case of photovoltaic panels installed on roofs, electricity costs fluctuate, using the current cost structure, between minimum values of 53 c€/kWh$_e$ and maximum ones of 103.4 c€/kWh$_e$. In 2050 the costs would be between a minimum value of 10.33 c€/kWh$_e$ and a maximum one of 20.12 c€/kWh$_e$, so quite a few mainland sites would have costs lower than thermal and nuclear ones for the year 2050. Cádiz, Seville, Almería and Granada are the most favourable provinces. As we can see, photovoltaic electricity costs can be expected to experience a greater reduction by the year 2050, although they will continue to be relatively higher compared to other technological options on many mainland sites, especially in the case of more unfavourable orientations.

If we consider all possible orientations for photovoltaic installed on buildings, current costs according to orientation and province fluctuate between 53 and 245.8 c€/kWh$_e$, falling by the year 2050 to situate themselves between 10,3 and 47.9 c€/kWh$_e$.

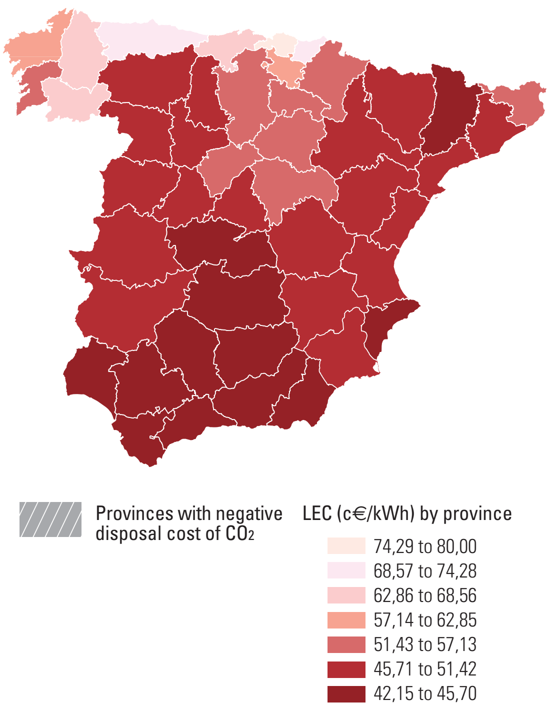
TRACKING PHOTOVOLTAIC

Like installed photovoltaic technology, for tracking photovoltaic panels, economic performance is determined by the availability of solar resources, orientation of the solar field and investment costs of the equipment.

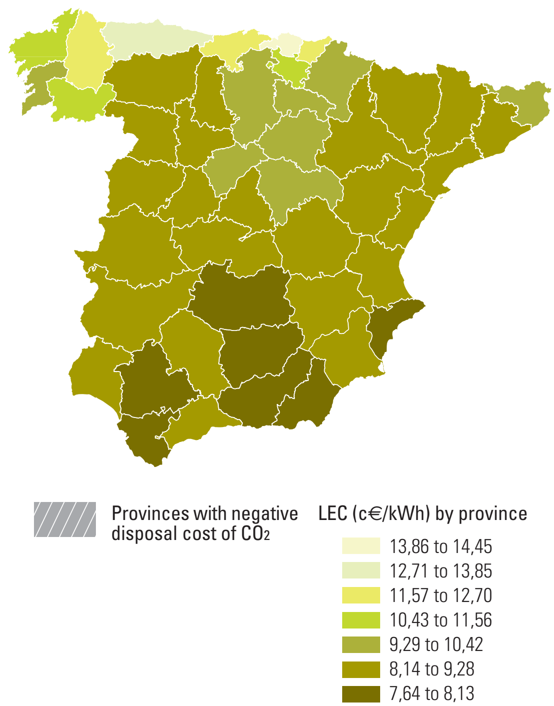
In this case an increase of 25% in the investment cost compared to installed photovoltaic panels has been considered.

Tracking photovoltaic. Provincial distribution of electricity (LEC) and CO_2 disposal costs *(i = 8%, f = 2.6% y N = 40 years)*

Current costs



Costs in 2050



The most favourable case for solar photovoltaic power is that offered by tracking photovoltaic panels. As we can see from the maps the current cost of electricity comprises values between 42.2 and 79.6 c€/kWh$_e$ depending on the province chosen. In 2050 it will comprise between 7.6 and 14.4 c€/kWh$_e$, lower than the projected cost for nuclear and thermal in many mainland sites. The most favourable provinces are Cádiz, Seville, Ciudad Real and Granada.

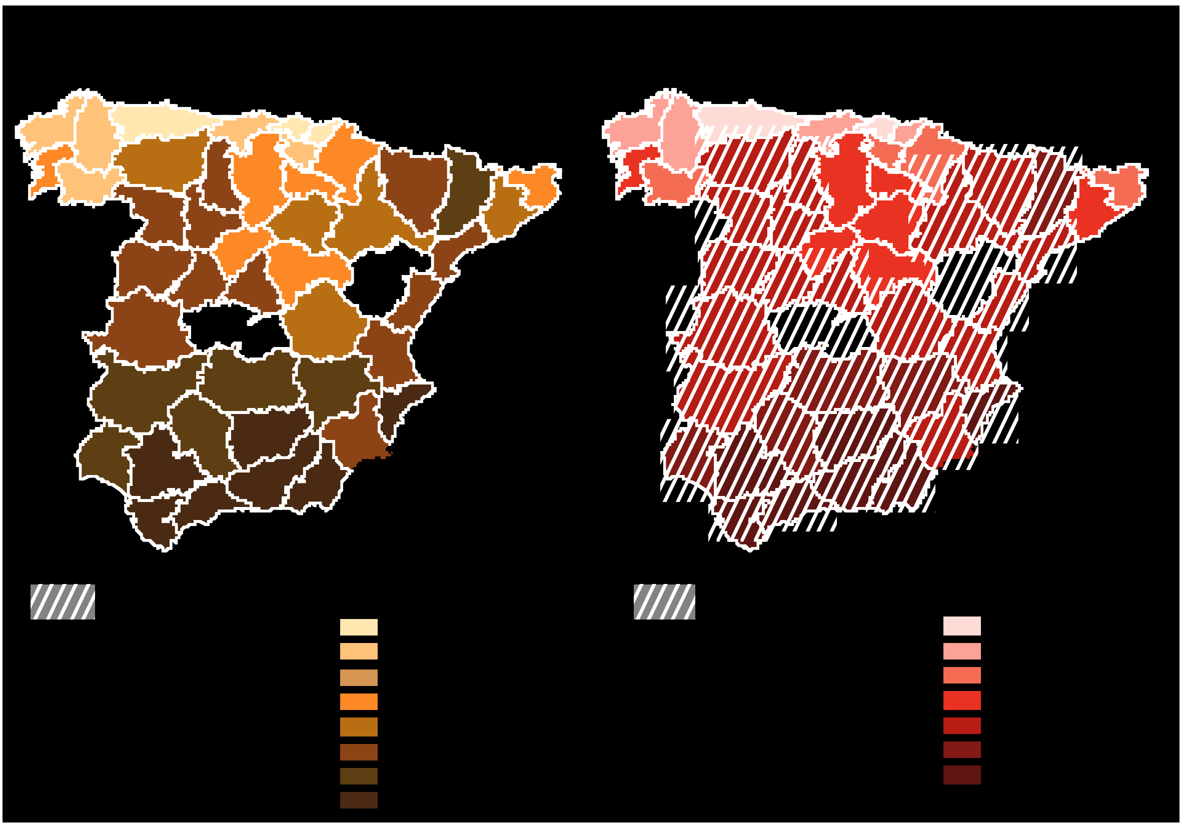
As we can see, costs of electricity generated using this technology will experience a considerable reduction by the year 2050, although they will continue to be relatively higher compared to other technologies on many mainland sites.

THERMOSOLAR

In the case of thermosolar electricity, the development of costs is associated with output volume, in addition to other factors such as: size, sizing criteria, storage capacity and technological development, enabling us to have access to power cycles with better performance.

In the case of this study, the factors employed are those outlined in "Renewables 2050" using North-South facing cylindrical parabolic collectors.

Thermosolar. Provincial distribution of the cost of electricity (LEC) and CO_2 disposal. *(i = 8%, f = 2.6% and N = 30 years)*



As we can see, under the current cost structure, the cost of electricity fluctuates, in the different provinces, between 11.03 c€/kWh$_e$ and 27.96 c€/kWh$_e$. The CO_2 disposal cost has positive values in all provinces.

Under the projected costs for the year 2050, the cost of electricity is significantly reduced situating itself in values between 3.07 and 8.13 c€/kWh$_e$. These costs are significantly lower than those projected for thermal and nuclear ones in 2050.

The negative value of the CO_2 disposal cost in some provinces reflects the fact that the cost of thermosolar electricity reaches lower values to those of the benchmark (value of a combined cycle power station in 2003).

The best sites correspond to the autonomous communities of Andalusia and Castilla-La Mancha.

3.3

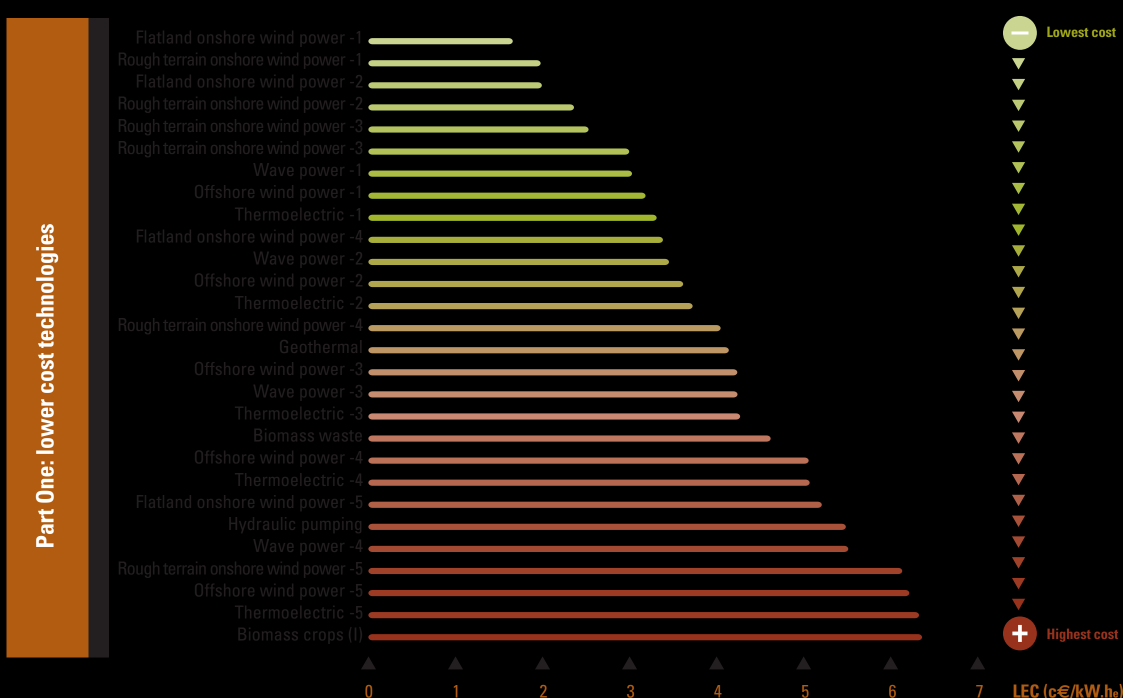
3.3. Comparison of technologies. Synthesis of results

In this section we are going to present jointly the main findings of the costs projected for 2050 of the different technologies considered in the study.

Each of the technologies has been grouped into a maximum of 5 categories, which are obtained by standardizing into equal intervals electricity costs for the provinces. The total potential of the technology, on a mainland basis, is divided into 5 categories, 1 being those which perform the best and 5 the worst. Each of the categories within a technology may be considered as a different technology from the point of view of the optimum generation or dispatch expansion models.

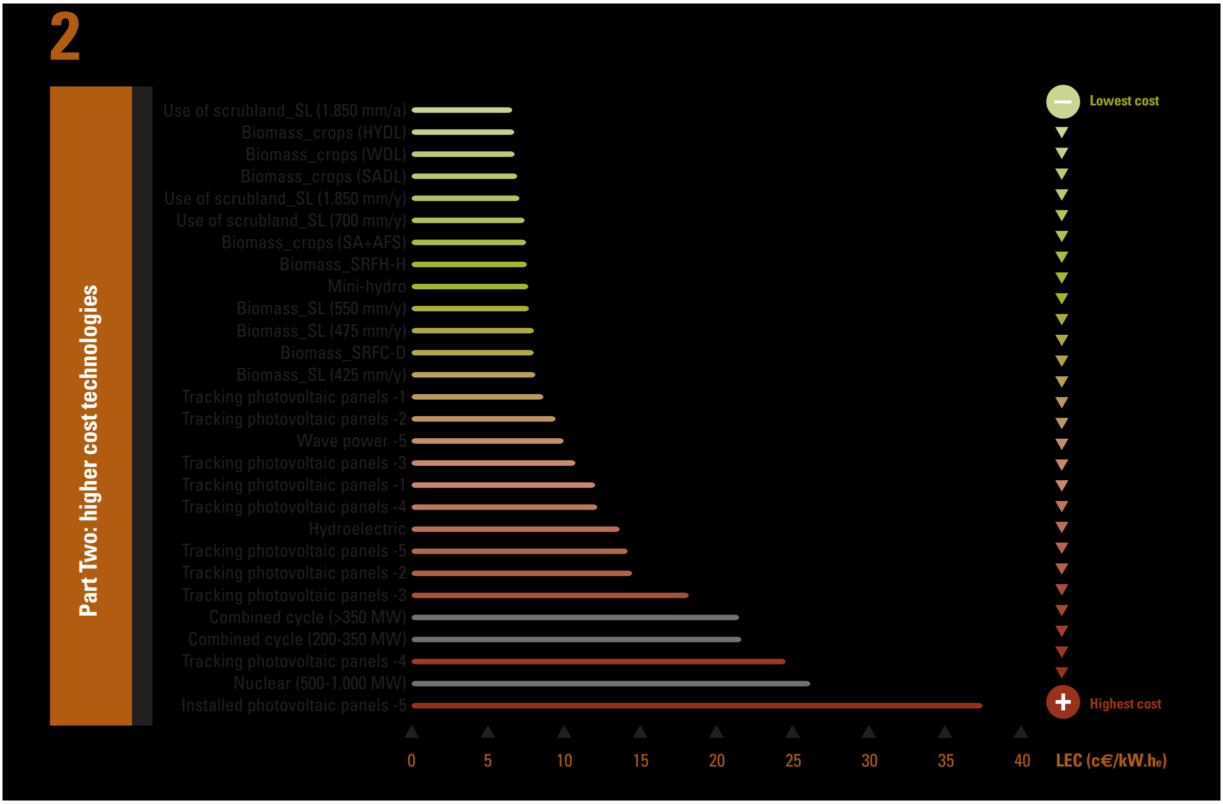
In the following figures we show graphically, in ascending order, the cost of electricity for the year 2050, of each of the categories.

1



I- Irrigated. **SL-** Use of scrubland. **HYDL'5f-** High yield dry land. **WDL -** Wet dry land. **SADL-** Semi-arid dry land.
SA+AFS- Arid dry land and agroforestry system. **SRFC-H-** Short rotation forestry (humid zone). **SRFC-D-** Short rotation forestry (dry zone)

3.3



As we can see from the figures, within the lowest cost categories that in 2050, both for flatland and rough terrain wind power, not only the categories on the best sites (which correspond to 1), but also 2, 3 and 4 would have a lower electricity cost or equal to the benchmark value at 4c€/kWhe; that is, than that of a thermal power station applying the 2003 cost structure. Categories 1 and 2 corresponding to thermosolar power would also enter into this bracket, the same as offshore wind power and wave power technology, in the event that this technology were to be considered to have reached its industrial maturity by 2050.

Geothermal is grouped in a single category, with an electricity cost of 4.12 c€/kWhe, since it is assumed that by 2050 new techniques will have been developed which standardize its cost. Similar costs are also to be found for category 3 offshore wind power, wave power and thermoelectric power (4.20; 4.23; 425 c€/kWhe respectively).

Within biomass technology, which uses waste as its fuel, it is the one which has the lowest electricity cost: 4,60 c€/kWhe. The cost of electricity with other fuels (energy crop, forestry crop and scrubland) would range between 6.35 c€/kWhe and 8.06 c€/kWhe.

The cost of electricity from categories 4 of offshore wind power, thermoelectric and wave power would be between 5 and 6 c€/kWhe.

3.3

In this same bracket flatland wind power and hydraulic pumping would also come into category 5. Mini-hydro would have an electricity cost of 7.52 c€/kWh$_e$.

Electricity costs for categories 5 offshore wind power and thermoelectric would have placed between 6 and 7 c€/kWh$_e$. In this same bracket would also be found category 5 rough terrain wind power.

Within the higher cost renewable technologies we find biomass, mini-hydro, hydroelectric and photovoltaic.

As can be appreciated, the combined cycle and nuclear technologies appear last –more than 21c€/kWh$_e$[6] for combined cycle and almost 26 c€/kWh$_e$[7] for nuclear– with higher costs than all the categories of all the renewable technologies, with the exception of the last categories of photovoltaic installed on buildings – which correspond to the worst orientations of the worst mainland sites.

In the following table investment and maintenance costs are provided, current ones and those in 2050, for all the technologies analysed.

	Average investment cost (current) €/kW$_e$	Operating and maintenance cost (current) c€/kWh$_e$	Average investment cost (2050) €/kW$_e$	Operating and maintenance cost (2050) c€/kWh$_e$
Geothermal	between 7.774 and 3.888 depending on category	4	1.729	1,50
Wave power	3.600	betwen 24,14 and 4,68 depending on category	825	betwen 2,64 y 0,82 depending on category
Biomass	6.223	0,80	2.503	0,42
Onshore wind power (flatland)	880	betwen 1,32 y 0,43 depending on category	481	betwen 0,88 y 0,28 depending on category
Onshore wind power (rough terrain)	950	betwen 1,77 y 0,57 depending on category	520	betwen 1,32 y 0,43 depending on category
Offshore wind power	1.600	betwen 3,23 y 1,66 depending on category	864	betwen 1,35 y 0,69 depending on category
Installed Photovoltaic	8.114	betwen 14,20 y 4,53 depending on category	962	betwen 11,84 y 3,78 depending on category
Photovoltaic with Monitoring	10.123	betwen 4,74 y 2,87 depending on category	1.200	betwen 3,95 y 2,39 depending on category
Thermosolar	4.439	2,80	1.373	0,40
Mini-hydro	2.500	2,42	1.800	1,74
Nuclear (500 – 1.000 MW)	2.200	0,94	3.200	8,94
Combined cycle (200 – 350 MW)	520	0,35	520	3,35
Combined cycle (> 350 MW)	422	0,29	422	3,29

[7] *In this case in particular a current fuel cost of 2.3 c€/kWh$_{PCI}$ is considered, inflated with an average 2.5 % above general inflation until 2050, which leads to a fuel cost in 2050 of 6.82 c€/kWh$_{PCI}$, and with an increase of O&M costs due to environmental reasons of 3 c€/kWh$_e$. The cost of electricity generated using a combined cycle which appear in the conclusions (15c€/kWh$_e$) correspond to the average forecasts that have been made.*

[8] *In this case a current fuel cost of 0.55 c€/kWh$_{PCI}$ is considered, inflated with an average 3% above general inflation until 2050, which leads to a fuel cost in 2050 of 2.02 c€/kWh$_{PCI}$, and with an increase of O&M costs due to environmental and safety reasons of 8 c€/kWh$_e$). The cost of electricity generated by nuclear power which appears in the rest of the document (20 c€/kWh$_e$) correspond to the average forecasts which have been made.*

3.4

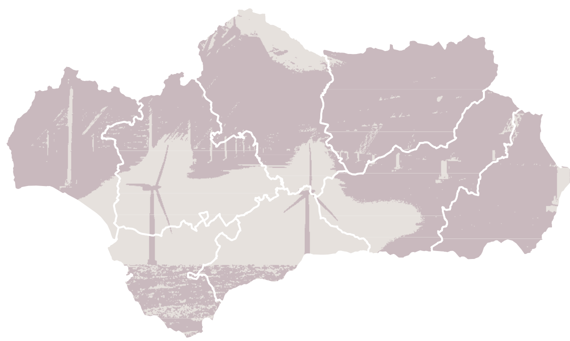
ANDALUSIA

The best technical categories for Andalusia would correspond to the solar technologies, where all the provinces have the best category (category 1) in thermosolar and photovoltaic.

3.4. Results by Autonomous Community

Below we show for each autonomous community, on a province by province basis, the best technical categories for the technologies whose costs depend on the site[9], as well as on the electricity cost projected for each of them to 2050.

These results are interesting for appreciating the spatial distribution of the renewable energy resources, as well as acting as a guide to the development of the promotion and support of the different renewable technologies on a province by province basis.



The electricity costs projected for 2050 are around 3.29 c€/kWh$_e$ for thermosolar, 8.45 c€/kWh$_e$ for tracking photovoltaic and 11.86 c€/kWh$_e$ for photovoltaic installed on the roofs of buildings.

The lowest electricity costs are associated with onshore wind power, and some provinces such as Málaga and Seville have the best technical category for this technology, with a projected electricity cost for 2050 of 1.67 c€/kWh$_e$ for wind power on flatland and 1.97 c€/kWh$_e$ on rough terrain. For offshore wind power in Cádiz the best technical category has a projected electricity cost for 2050 of 3.18 c€/kWh$_e$.

[9] *Biomass is not shown, since the cost variation depends on the type of fuel. Geothermal is not shown either, since by around 2050 its technical development will permit a homogeneous provincial distribution of electricity costs. In relation to mini-hydro in the project a large increase to current capacity has not been considered, in any event a provincial cost cannot be attributed to it since it depends on the specific sites.*

ARAGON

The best technical for Aragón correspond to wind power

In Teruel and Zaragoza the best technical category is onshore wind power (category 1), with an electricity cost projected for 2050 of 1.67 c€/kWh_e for flatland wind power and 1,97 c€/kWh_e on rough terrain.

In relation to solar technologies, all the provinces of Aragón are to be found in the second technical category for solar thermoelectricity and tracking photovoltaic, with a projected electricity cost for 2050 of 3.70 c€/kWh_e for thermosolar and 9.38 c€/kWh_e for tracking photovoltaic. Huesca and Teruel have the best technical category in photovoltaic installed on roofs with a projected electricity cost for 2050 of 11.86 c€/kWh_e.

ASTURIAS

The lowest cost technology corresponds to onshore wind power.

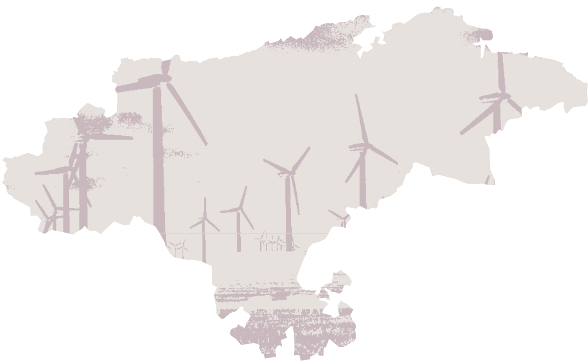
In Asturias the lowest cost technology is onshore wind power (category 2), with an electricity cost projected for 2050 of 2.01 c€/kWh_e for flatland wind power and 2.37 c€/kWh_e on rough terrain.

For offshore wind power the cost of electricity projected for 2050 is at 4.20 c€/kWh_e corresponding to the third category for this technology.

Wave power technology would have an electricity cost projected for 2050 of 3.45c€/kWh_e corresponding to the second category for this technology.

CANTABRIA

The lowest cost technology corresponds to onshore wind power.



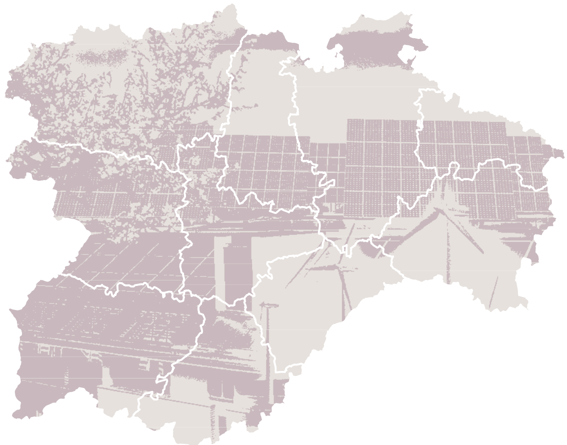
In Cantabria the lowest cost technology is onshore wind power (category 2), with an electricity cost projected for 2050 of 2.01 c€/kWh$_e$ for flatland wind power and 2.37 c€/kWh$_e$ on rough terrain.

Wave power technology would have an electricity cost projected for 2050 of 3.45c€/kWh$_e$ corresponding to the third category for this technology.

In this community for offshore wind power the cost of electricity projected for 2050 would stand at 4.20 c€/kWh$_e$ corresponding to the third category for this technology.

CASTILLA Y LEÓN

The best technical category for this community is wind power.



In Soria and Zamora the best technical category is onshore wind power (category 1), with an electricity cost projected for 2050 of 1.67 c€/kWh$_e$ for flatland wind power and 1,97 c€/kWh$_e$ on rough terrain. In Ávila, Burgos and Salamanca the cost of wind power (category 2) in 2050 would be 2.01 c€/kWh$_e$ for flatland wind power and 2.37 c€/kWh$_e$ on rough terrain.

In relation to the solar technologies, in Ávila, León, Palencia, Salamanca, Valladolid and Zamora solar thermoelectric is the second technical category with a projected electricity cost for 2050 of 3.70 c€/kWh$_e$. The best technical category for tracking photovoltaic is to be found in Salamanca with a projected electricity cost for 2050 of 8.45 c€/kWh$_e$. Ávila, Palencia, Salamanca and Zamora have the best technical category in photovoltaic installed on roofs with a projected electricity cost for 2050 of 11.86 c€/kWh$_e$.

CASTILLA-LA MANCHA

The best technical catgories for Castilla-La Mancha correspond to solar power.

In Albacete, Ciudad Real and Toledo the best technical category (category 1) is solar thermoelectricity with a projected electricity cost for 2050 of 3.29 c€/kWh$_e$. In these same provinces the best category is tracking photovoltaic with an electricity cost in 2050 of 8.45 c€/kWh$_e$.

Albacete, Ciudad Real, Cuenca y Toledo are in the first category of photovoltaic installed on the roofs of buildings, with an electricity cost in 2050 of 11.86 c€/kWh$_e$.

The lowest cost technologies are onshore wind power: in Albacete the best is to be found with an electricity cost projected for 2050 of 2.01 c€/kWh$_e$ for flatland wind power and 2.37 c€/kWh$_e$ on rough terrain.

CATALONIA

The best technical category for Castilla-La Mancha corresponds to solar power.

In Lleida the best technical category (category 1) is solar thermoelectricity with a projected electricity cost for 2050 of 3.29 c€/kWh$_e$. In this same province the best category is tracking photovoltaic with an electricity cost in 2050 of 8.45 c€/kWh$_e$. Lleida and Tarragona have the best technical category in photovoltaic installed on roofs with a projected electricity cost for 2050 of 11.86 c€/kWh$_e$.

The best technologies correspond to onshore wind power. The best categories for the community are to be found in Barcelona, Lleida and Tarragona (category 2) with an electricity cost projected for 2050 of 2.01 c€/kWh$_e$ for flatland wind power and 2.37 c€/kWh$_e$ on rough terrain. For offshore wind power the best technical category is to be found in Girona which has a projected electricity cost for 2050 of 3.18 c€/kWh$_e$.

COMUNIDAD VALENCIANA

The best technical category for this community corresponds to solar power.

In Alicante the best technical category (category 1) is solar thermoelectricity with a projected electricity cost for 2050 of 3.29 c€/kWh$_e$. In Castellón and Valencia (category 2) the projected electricity cost for this technology would be 3.70 c€/kWh$_e$.

In Alicante the best technical category (category 1) is tracking photovoltaic with a projected electricity cost by 2050 of 8.45 c€/kWh$_e$. And in all the provinces of the Community of Valencia the best category of photovoltaic is installed on the roofs of buildings, with an electricity cost in 2050 of 11.86 c€/kWh$_e$.

EXTREMADURA

Extremadura has the best technical categories both in wind power and solar power.

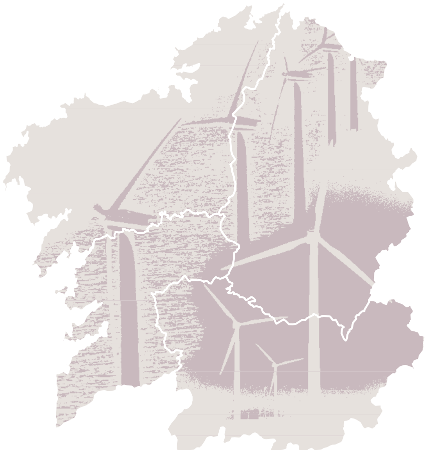
The lowest are wind power where both Badajoz and Cáceres have the best category of onshore wind power (category 1) with an electricity cost projected for 2050 of 1.67 c€/kWh$_e$ for flatland wind power and 1.97 c€/kWh$_e$ on rough terrain.

In relation to solar, in Badajoz the best technical category (category 1) is solar thermoelectricity with a projected electricity cost for 2050 of 3.29 c€/kWh$_e$. In Cáceres (category 2) the projected electricity cost for this technology would be 3.70 c€/kWh$_e$.

In both provinces the best category is photovoltaic installed on buildings with an electricity cost in 2050 of 11.86 c€/kWh$_e$. And in Badajoz the best technical category (category 1) is tracking photovoltaic with a projected electricity cost for 2050 of 8.45 c€/kWh$_e$.

GALICIA

Galicia has the best technical categories of wind power (offshore and onshore) and wave power.



The lowest technologies correspond to onshore wind power. In Corunna, Lugo and Pontevedra the best technical category is onshore wind power (category 1), with an electricity cost projected for 2050 of 1.67 c€/kWh$_e$ for flatland wind power and 1,97 c€/kWh$_e$ on rough terrain. In Ourense the cost of wind power (category 2) in 2050 would be 2.01 c€/kWh$_e$ for flatland wind power and 2.37 c€/kWhe on rough terrain. In Corunna and Lugo the best technical category (category 1) is wave power with a projected electricity cost by 2050 of 3.03 c€/kWh$_e$. For offshore in Corunna and Lugo wind power is the best technical category (category 1) with a projected electricity cost for 2050 of 3.18 c€/kWh$_e$.

Regarding solar energy in Pontevedra the best categories in the community, with an electricity cost for thermoelectricity (category 2) projected for 2050 is 3.70 c€/kWh$_e$, for photovoltaic installed on roofs (category 2) is 14.29 c€/kWh$_e$ and for tracking photovoltaic (category 2) with an electricity cost projected for 2050 of 9.38 c€/kWh$_e$.

MADRID

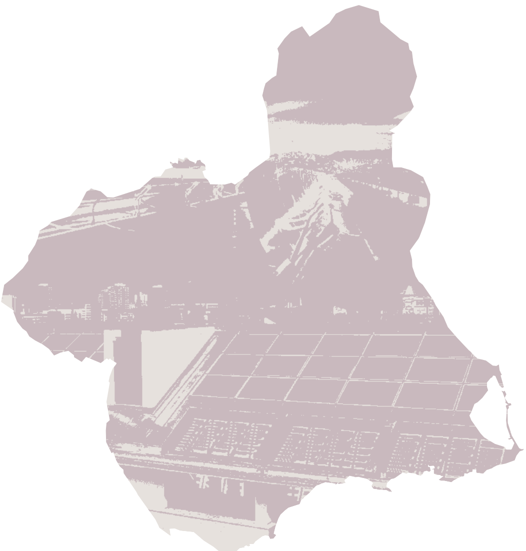
The best technical categories of the Community of Madrid are represented by solar power.

The cost of electricity projected for 2050 for solar thermoelectricity (category 2) would be 3.70 c€/kWh$_e$, for photovoltaic on the roofs of buildings (category 2) would be 14.29 c€/kWh$_e$, and for tracking photovoltaic (category 2) the cost of electricity projected for 2050 would be 9.38 c€/kWh$_e$.

One of the lowest cost technologies would correspond to onshore wind power, although the technical characterization would be low (category 4). The cost of electricity projected for 2050 would be 3.40 c€/kWh$_e$ for flatland wind power and 4.00 c€/kWh$_e$ for rough terrain.

MURCIA

The best technical categories for the Region of Murcia are represented by solar power.



The cost of electricity projected for 2050 for solar thermoelectricity (category 2) would be 3.70 c€/kWh$_e$, for photovoltaic on the roofs of buildings (category 2) would be 14.29 c€/kWh$_e$, and for tracking photovoltaic (category 2) the cost of electricity projected for 2050 would be 9.38 c€/kWh$_e$.

The lowest cost technology would correspond to onshore wind power, in category 3 of the technical characterization. The cost of electricity projected for 2050 from flatland wind power would be 3.40 c€/kWh$_e$ and 4.00 c€/kWh$_e$ for rough terrain. For offshore wind power (category 4) the projected electricity cost for 2050 would be 5.01 c€/kWh$_e$.

NAVARRE

The lowest cost technology in the Autonomous Community of Navarre would correspond to onshore wind power.

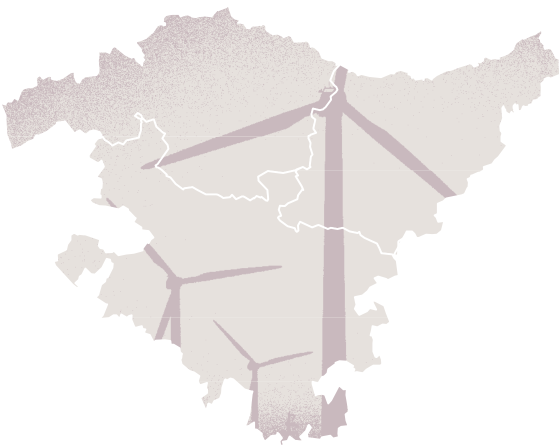
The lowest cost technology in the Autonomous Community of Navarre would correspond to onshore wind power.

The lowest cost technology in the Autonomous Community of Navarre is onshore wind power (category 2), with an electricity cost projected for 2050 of 2.01 c€/kWh$_e$ for flatland wind power and 2.37 c€/kWh$_e$ on rough terrain.

In relation to solar technologies, the best technology is photovoltaic installed on the roofs of buildings (category 2) whose projected electricity cost for 2050 would be 14.29 c€/kWh$_e$.

BASQUE_COUNTRY

The lowest cost technology in the Autonomous Basque Community would correspond to onshore wind power.

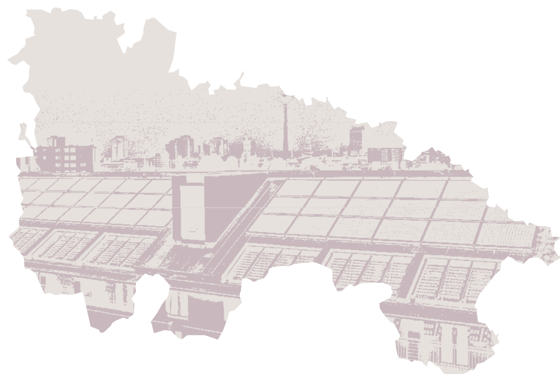


In Guipúzcoa the cost of electricity projected for 2050 would be 2.01 c€/kWh$_e$ for flatland wind power and 2.37 c€/kWh$_e$ for rough terrain. In Guipúzcoa the cost of electricity projected to 2050 would be 2.53 c€/kWh$_e$ for flatland wind power and 2.98 c€/kWhe for rough terrain.

In Guipúzcoa and Vizcaya for offshore wind power (category 3) the projected electricity cost for 2050 would be 4.20 c€/kWh$_e$. In Vizcaya for wave power technology (category 3) the cost of electricity projected for 2050 would be 4.23 c€/kWh$_e$.

LA RIOJA

The lowest cost technology in Rioja would correspond to onshore wind power (category 4).



In this community the cost of electricity projected for 2050 would be 3.40 c€/kWh$_e$ for flatland wind power and 4 c€/kWh$_e$ for rough terrain.

In relation to solar, the best technical category is solar photovoltaic installed on roofs (category 2) with a projected electricity cost in 2050 of 14.29 c€/kWh$_e$. In the other solar technologies the cost of electricity projected for 2050 for solar thermoelectricity (category 3) would be 4.25 c€/kWh$_e$, and for tracking photovoltaic (category 3) the projected cost of electricity would be 10.53 c€/kWh$_e$.

3.5

3.5. 3. Conclusions

- **The lowest cost technologies around 2050 will be the renewable ones.** Practically all of them, on reaching their period of industrial maturity, will be able to provide electricity at a lower cost, and in many cases much lower, to that projected for nuclear and combined cycle thermal.

- Onshore wind power is among the lowest cost technologies, for all mainland sites the cost of generated electricity in 2050 would be between a minimum of 1.51 c€/kWh$_e$ and a maximum of 8.09 c€/kWh$_e$.

- Within the solar technologies, the most competitive technology would be solar thermoelectricity, whose projected electricity costs for 2050 would be between a minimum of 3.07 c€/kWh$_e$ and a maximum cost of 8.13 c€/kWh$_e$ at the worst sites.

- Projected electricity costs for combined cycle power stations fired by natural gas, would be above 15 c€/kWh$_e$. Only the worst sites for solar photovoltaic on buildings would be above these costs.

- For nuclear energy, and despite the great uncertainty surrounding the associated costs, we could expect that it would lead to a nuclear electricity cost by 2050 in the order of 20 c€/kWh$_e$, considerably higher than electricity costs using many renewable technologies in 2050.

- The current energy system, is unsustainable and does not internalize all its costs. Their progressive internalization would lead us to a notable increase in the cost of electricity generated by dirty technologies. To rationalize the energy system to make it sustainable will require an economic effort, especially in the development process of the renewable technologies towards industrial maturity. This economic effort is an investment which would lead us to a sustainable system, with much lower electricity costs even than the current ones.

ENERGY REVOLUTION PROJECT

Greenpeace commissioned a team from the Institute of Technological Research of the Pontificial University of Comillas, led by Dr. Xavier García Casals, to undertake a technical study whose objective was to determine whether renewables are sufficient to meet society's energy demand. This is a key issue for knowing whether we need to develop other energy sources to cover the putative limitations of renewables, or on the contrary to verify that it is possible to avoid dangerous climate change by a complete substitution of fossil fuels by renewable energies.

In November 2005, the findings of the first part of the project entitled "Renewables 2050. A report on the potential of renewable energies in mainland Spain" were submitted in which it was concluded that electricity generation capacity from renewable sources was equivalent to more than 56 times the electricity demand of mainland Spain projected for 2050, and more than 10 times total final energy demand. It was thus demonstrated that by using renewables it is possible to have energy in more than sufficient quantities, but it failed to show whether it would be economically and technically feasible to operate the electricity system solely from renewables to satisfy projected demand.

The report "100%.Renewables. A renewable electricity system for mainland Spain and its economic feasibility" offers the findings of the second stage of the study in which the feasibility of a scenario based on renewable energies for the electricity generation system for the mainland are quantified and evaluated. **The analyses show the technical and economic feasibility of a system based 100% on renewables.**