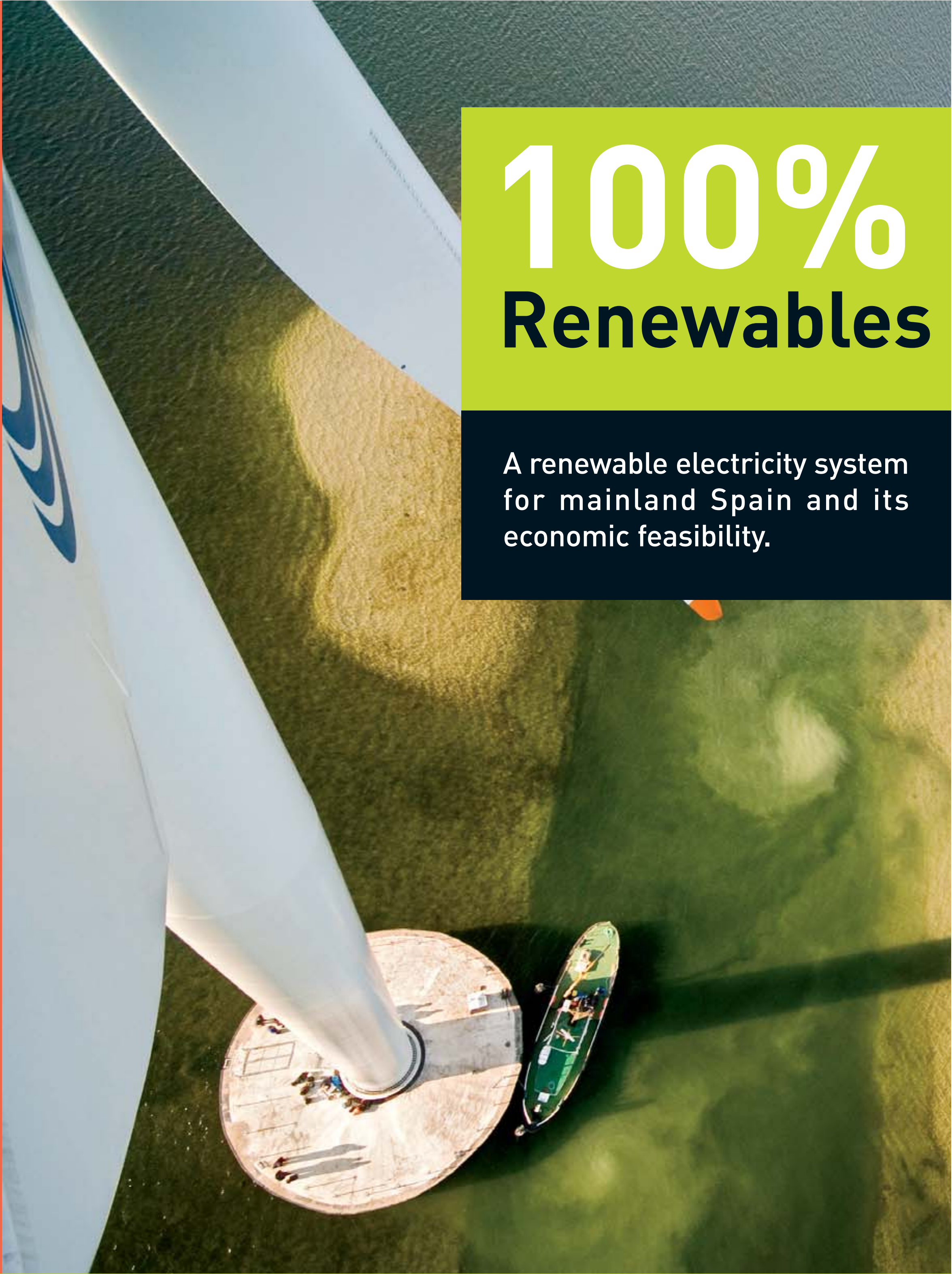
SUMMARY OF CONCLUSIONS



100% Renewables

A renewable electricity system for mainland Spain and its economic feasibility.

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1

PRESENTATION

The report of the United Nations group of experts on climate change (IPCC) confirms that human beings are causing a rapid global warming without precedent, the consequences of which may be very prejudicial to life if average temperatures reach more than 2°C above the level they stood at in the pre-industrial era. The likelihood of avoiding exceeding the two degree limit depends mainly on our slowing down and stabilising the greenhouse gas levels in the atmosphere, for which a drastic reduction in emissions is required. Given emissions are mainly due to our current energy system, based on the burning of fossil fuels, 'an energy revolution' is needed which would enable us, on the demand side, to put an end to our current squandering of energy by savings and efficiency, and on the generation side, to replace dirty energy sources by others whose use is sustainable, which are none other than the renewables.

The problem is that, those who make the key decisions, besides tackling the political and economic interests of the supporters of the 'old energy model', are faced with a fundamental doubt: they don't believe it is possible to change it. Even in Spain, which has come to the forefront as world leader in the development of the renewables such as wind power, support for these clean energy sources is constantly being questioned. This is creating growing tension as the penetration of the renewables in the electricity system ceases to be merely token, and even more so according to some, such as in the case of wind power, when they reach what some consider to be their 'technical limit '. Having reached this point, two very different conceptions of the role that the renewables may and ought to play meet head-on: a complementary role as yet another element in the system, or a leading role capable of displacing conventional forms of generation. The model and the degree of support for one or other energy source will depend in the long run on what the horizon is which is being sought.

The **aim** of the survey "100% renewables" is to quantify and technically evaluate the **feasibility of a scenario based on renewable energy sources for the electricity generating system in mainland Spain.**

In this document we present a summary of the main conclusions of the report relating to the temporal analysis and the grid, which together with the conclusions of the cost analysis (see document 100% RENEWABLES: COST COMPARISONS) show that **there are many possible configurations, with different combinations of electricity generating systems based on renewable sources, to satisfy the predicted demand in 2050.** We also show in this document examples of combinations of renewable technologies ('generation mix') depending on the different requirements, which enable us to understand the main technical, economic and geographical features of these mixes.

The greatest contribution of this survey resides in setting out, for the first time, the technical and economic feasibility of the 100% renewable generation systems and to have opened up the way to finding some answers. Although there are many analyses to be developed before these systems can be introduced, we have progressed enough to be able to see clearly that renewable energy is viable, and now it is the job of other organisations and entities to take it up and make it a reality. After this study there are no longer any excuses for not carrying on urgently with the progress made in this direction.

2

METHODOLOGY

Once capacity, generation and cost ceilings have been analysed, the rest of the survey has adopted the methodology described below.

Temporal analysis

The most important analysis is that of renewable generation capacity and its temporal link to demand, that is, it is not enough to know how much can be produced, but how to deliver it to consumers, when and where required. Bearing in mind costs and production and demand time variation, it is a case of determining what combinations of renewable generation technologies may be employed to satisfy demand completely. Given that many options arise, it must be determined which of them will be the best, both in terms of installed capacity and ways of utilising it (dispatch). In the case of 100% renewable systems, this analysis cannot be undertaken separately.

- In order to do so, first of all and by way of comparison, the scenario of a stand-alone system to cover the electricity needs of a single family household **has been analyzed.** This is fairly easily done nowadays, despite which it is even technically easier and economically less expensive to meet the electricity demands with renewable technologies for the whole of mainland Spain than for a single family household. The comparison with the household scenario shows that putting forward the 100% renewable option is not as 'unattainable' as is often thought, and that we already have cases (standalone systems) which no one doubts are possible and which are actually much more complex.
- Subsequently **an analysis of temporal generation capacity** has been carried out on each of the technologies, studying how generation varies for each technology over the year and the effect of installing different renewable energies (spatial spread and technological diversity) in different geographical areas.
- Outlined below is a **detailed temporal analysis of the matching of generation capacity to electricity demand.**

Starting from the current situation, hydroelectric power and onshore wind power dominate the renewables. Renewable technologies have been introduced by order of merit in their performance in the 2050 cost structure, irrespective of storage capacity and without requiring them to adapt their output to demand (merely dissipating excess energy and only using biomass stations for operations at point of consumption). In this way different mixes with **different levels of meeting demand are analysed.**

Then we have looked at how **the models presented are affected on introducing energy storage capacity.** In order to do this it has been assumed that the electricity system operates with no other regulation than the dissipation of excess energy and not using biomass when there is surplus generation from other energy sources. It has also been assumed that the storage system has a cost of 10 €/kWh (in 2050) and an overall charge-discharge output of 70%.

3

Analysis of the electricity generating system

Finally, an analysis of 100% renewable generating systems has been tackled using the normal tools for 'conventional' analysis of the grid.

- The first of these analyses has been carried out using "generation expansion models", in order to determine an **optimal combination** for technologies to be installed.

- Once a generation mix is available, the next step in conventional grid analysis comprises determining **which technologies of those installed is most suitable for use at a given time to satisfy demand.** To this end a "grid generation operation" has been employed. The effects of economic investment have been incorporated into it in order to determine which stations to install (generation expansion) and which to use (optimal dispatch); two problems which, for generation systems based on renewables, must be solved simultaneously.

- The final step taken has involved **optimising economically** the mixes obtained, first by incorporating the thermosolar hybridization effect, that is, using thermoelectric stations which can operate even when there is no solar radiation, using biomass as fuel, and then considering cost values for energy which has not been supplied, between 2 and 10,000 c€/kWh_e.

BASIC CONCEPTS

In the first place it is advisable to introduce some key concepts for this analysis:

- **Solar multiple (SM):** ratio between nominal installed capacity and maximum demand capacity. That is, how much power or capacity a system has installed in relation to the maximum electricity demand, that is, how many stations have to be "spare" in order to resort to them when others are not available. For example, a mix with SM = 2 will have as many stations installed in order to have capacity equivalent to double the maximum capacity which could be required at any moment.

- **Capacity factor (CF):** ratio between useful energy generated and the maximum that could be generated operating at normal power for a whole year. That is, it gives us an idea of the extent to which we use installed capacity in a power station or in our whole system, in other words, how much of the installed capacity is being utilized. For example, a power station with CF = 60% means that this power station has produced 60% of the maximum energy which would be generated if the power station could be kept in operation at nominal capacity for the whole period under consideration.

- **Solar fraction (SF):** fraction of the demand met by the renewable generation system. That is, how much energy renewables generate compared to overall demand. For example, SF = 100% mean that the whole demand is covered by renewable energies.

4

CAN A SYSTEM BASED SOLELY ON RENEWABLES MEET ALL OUR ELECTRICITY NEEDS?

This is, without a doubt, the main issue when analysing the technical feasibility of a system based 100% on renewable energy, to check if it is possible to generate all the electricity required at all times. The study analyses in the first place the **temporal generation capacity for each technology,** and then it carries out a detailed analysis of **how** the generation capacity of a system based on renewables **matches** electricity demands throughout the year.

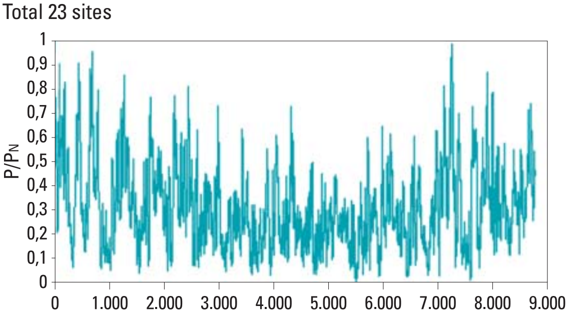
The object of this analysis is to be able to evaluate how much energy can be used from what it is possible to generate with installed capacity (regulation performance), and to check how it depends on the spread of the technologies which are installed (mix) and the means of operating them (dispatch).

4.1. Generation by technologies

The analysis of how generation for each technology varies over the year, includes the effect of spatial spread, that is the effect of adding up generation of one single technology spread across all the provinces. The result is conservative, given that having considered each province represented by a single temporal series, we are not taking into account the effect of geographical spread within each province. Even so, spatial spread gives rise to much a more even generation, since at each site generation is available at different times. It is the same effect that occurs when electricity demand, which on the mainland scale, is fairly even, with an annual minimal demand which is 42.96% of the maximum. The results for each technology are given below:

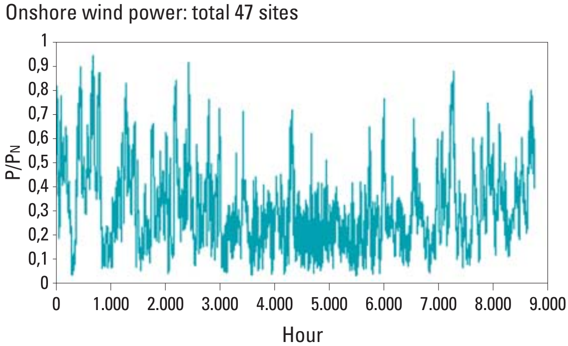
Offshore wind power is the dominant resource in winter-autumn, with reduced generation capacity in the middle months of the year:

Electricity capacity generated over the year for the temporal series obtained by averaging all the offshore mainland sites, as a relative value to the nominal installed capacity.



Onshore wind power follows a similar pattern to offshore wind power:

Electricity capacity generated over the year for the temporal series obtained by averaging all Onshore wind power, as a relative value to the nominal installed capacity.

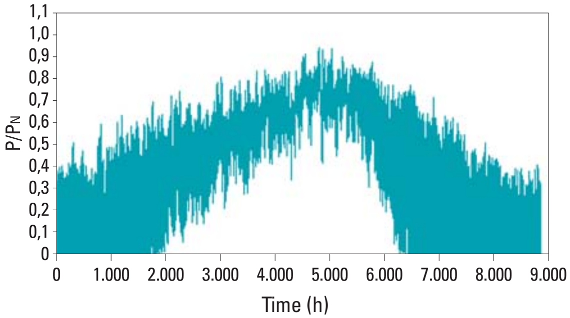


4.1

Thermosolar power is the dominant resource in spring-summer:

Electricity capacity generated over the year for the temporal series obtained by averaging all thermosolar, as a relative value to the nominal installed capacity.

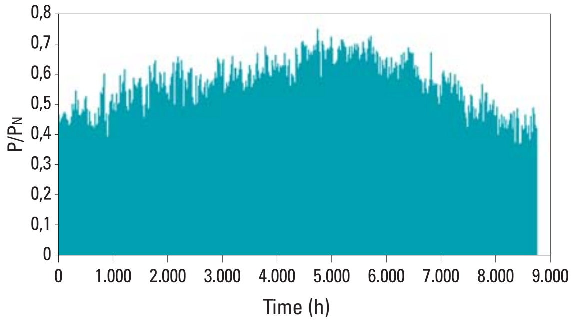
Thermosolar: total 47 sites



Photovoltaic power with azimuthal monitoring is also dominant in spring-summer, but with greater seasonal regularity than thermosolar power:

Electricity capacity generated over the year for the temporal series obtained by averaging all azimuthal PV, as a relative value to the nominal installed capacity.

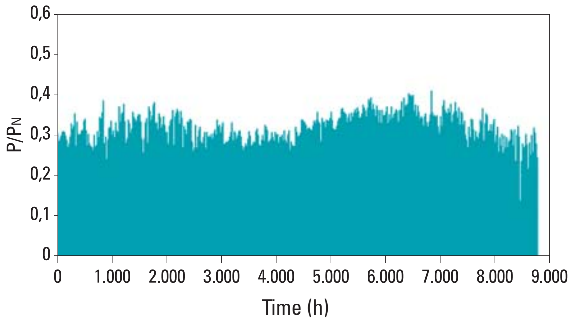
FV azimuthal PV: total 47 sites



Photovoltaic power installed on buildings is dominant in autumn-spring (the following combination of orientations for the installation of photovoltaic modules has been taken: for every four modules on roofs, 2 southward, 2 south-eastward, 2 south-westward, 1 eastward and 1 westward):

Mainland series for integrated photovoltaic energy obtained on grouping all the provincial photovoltaic series as a result of averaging the different orientations with the list shown (4 roof + 2S + 2SE + 2SW + 1E + 1W).

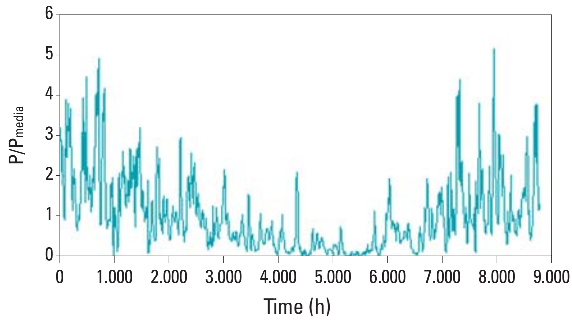
47 mainland sites. Total capacity PV on buildings



Wave technology provides the following profile:

Hourly capacity series dimensioned with the average annual capacity of the mainland series resulting from averaging the 22 provincial sites.

Days: 22 sites



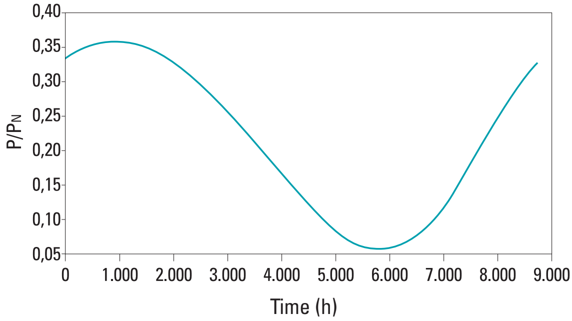
4.1

4.2

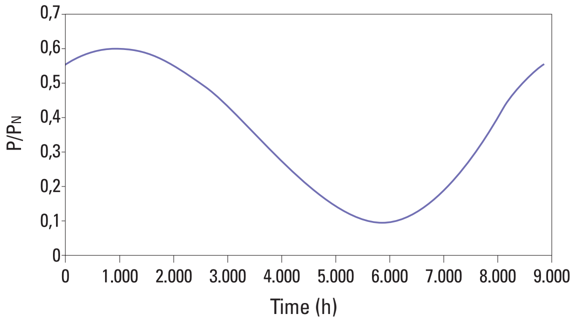
Hydroelectric power shows considerably less variability compared to the rest, because of the storage and concentration effect of hydrological basins and reservoirs. In a renewable system, because of their storage capacity, operation of hydroelectric stations would be different from current practice.

Hourly series for hydroelectric capacity under an ordinary and special regime for the mainland obtained by modulating potential generation assumed for the year 2050 (IIT, 2005) with the average historic producible in the year 2003. These hydroelectric capacity series do not assume any regulation of the electricity system with technology.

RO hydroelectric with historic producible modulation



RE hydroelectric with historic producible modulation



As far as biomass and geothermal stations are concerned, they are capable of operating at constant output throughout the whole year, besides providing the possibility of adjusting their outputs to regulate the system, depending on production from variable generation stations, such that if operated properly they can provide regulation capacity and guarantee output.

4.2. Examples of generation mix

In order to analyse generation-demand temporal matching we have developed the least favourable technical scenario in order to demonstrate that even in this case it is possible to meet the energy demand. That is, different combinations of renewable technologies or technological mixes have been sought which respond to the needs of an energy demand which, as currently occurs, does not incorporate demand management[1].

Generally speaking, any renewable mix is characterized by spatial spread and technological diversity. Furthermore, it must be borne in mind that the majority of these renewable technologies have great regulatory capacity, that is, they can adjust their ouput to demand at any time, and do so more quickly than conventional technologies, when it comes to reducing delivered power below power availability (which depend on the sun, the wind, etc.) at any moment in time.

[1] *Demand management is the term for the series of measures whose aim is to modify the way in which energy is consumed, whether by saving a particular amount of energy or displacing its consumption to a different time. It includes regulation measures, incentives, consumer information, price tags, etc.*

4.2

However, many of the renewable technologies are unable to regulate power above available output at any given moment in time, that is, if at a particular moment the wind in an wind turbine allows 500 kW to be delivered, the machine cannot provide any more.

This situation, in a generation system in which extensive use is not made of demand management, obliges us to have available a 'standby capacity' (stations which are not generating or which are on standby to generate at any time when a power shortfall occurs) greater than that of conventional generation systems, whose function is to maintain electricity generation even when the available resource decreases.

There are several means of achieving this standby capacity in 100% renewable mixes: increasing installed capacity, using storage capacity and regulation from technologies such as reservoir hydroelectricity (including pumping), biomass, geothermal and thermosolar, or better still hybridization using biomass (gassified) from thermosolar stations, that is, stations which can use either solar energy or biomass as a fuel source[2].

Of the countless combinations of renewable technologies to meet electricity demand which can be put together, here we are going to show some illustrative examples seeking different objectives: technological diversity, the lower generation costs, combination with demand management. We also demonstrate another mix which, besides meeting overall electricity demand, achieves coverage of all energy demand.

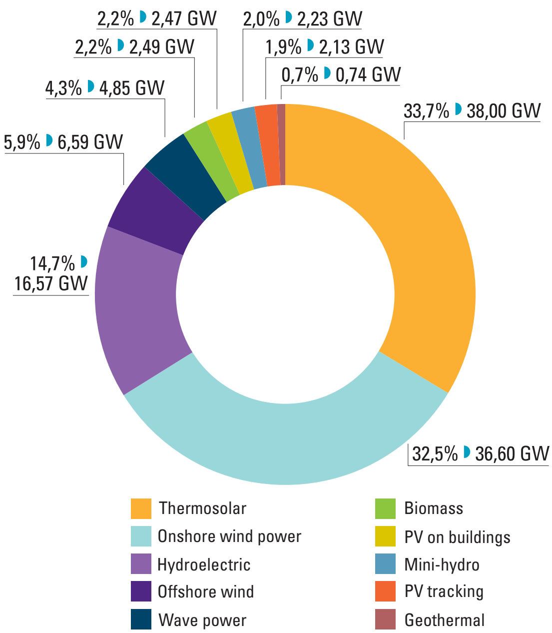
[2] *We have adopted a sizing criteria for renewable mixes consisting of the requirement that they have a standby capacity of at least 15% above maximum deficit output, and with energy available having a regulation capacity of at least 25% above annual energy deficit.*

100% renewable mix.
Aim: technological diversity

In the first place we give an example of a mix capable of completely satisfying electricity demand in 2050 using renewable energies (SF = 100 %), whose main feature is technological diversity, that is, it makes use of a wide range of technologies based on renewable sources, and manages to completely meet demand thanks to a small storage capacity.

The mix in this example would have an installed capacity of 112,680 MW, with the following technology spread:

Installed capacity by technology.



4.2

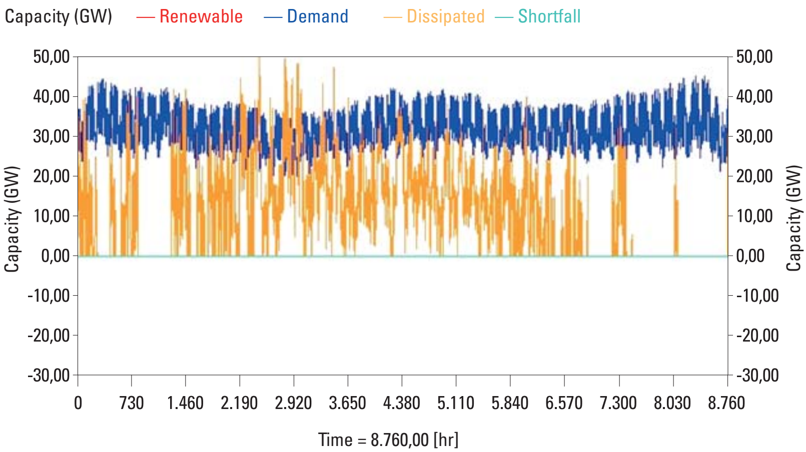
The following table summarizes the main features of this mix.

Main characteristics of the mix.

Installed capacity	112,68	GWp
Available energy	396,48	TWh/a
Solar Multiple (SM)	2,5	
Accumulation capacity	1,5	TWh
Meeting demand (SF)	100	%
Energy shortfall in relation to annual demand	0	%
Energy to be dissipated in relation to annual demand	34,4	%
Available generation in relation to annual demand	141,6	%
Energy contributed by biomass	3,9	TWh/a
Maximum deficit capacity	0	GW
Maximum dissipated capacity	60,9	GW
Annual electricity cost (LEC) with no hydro investment	4,51	c€/kWh
Solar-biomass hybridization	No	
Mini-hydro operation	Base	
Fraction used of the onshore wind power capacity ceiling	4	%
Fraction used of the thermosolar capacity ceiling	1,387	%
Land occupation	2,47	%

In the following graph we can see how over the year available output is generated to meet demand at all times, as well as those times when surplus capacity would be dissipated.

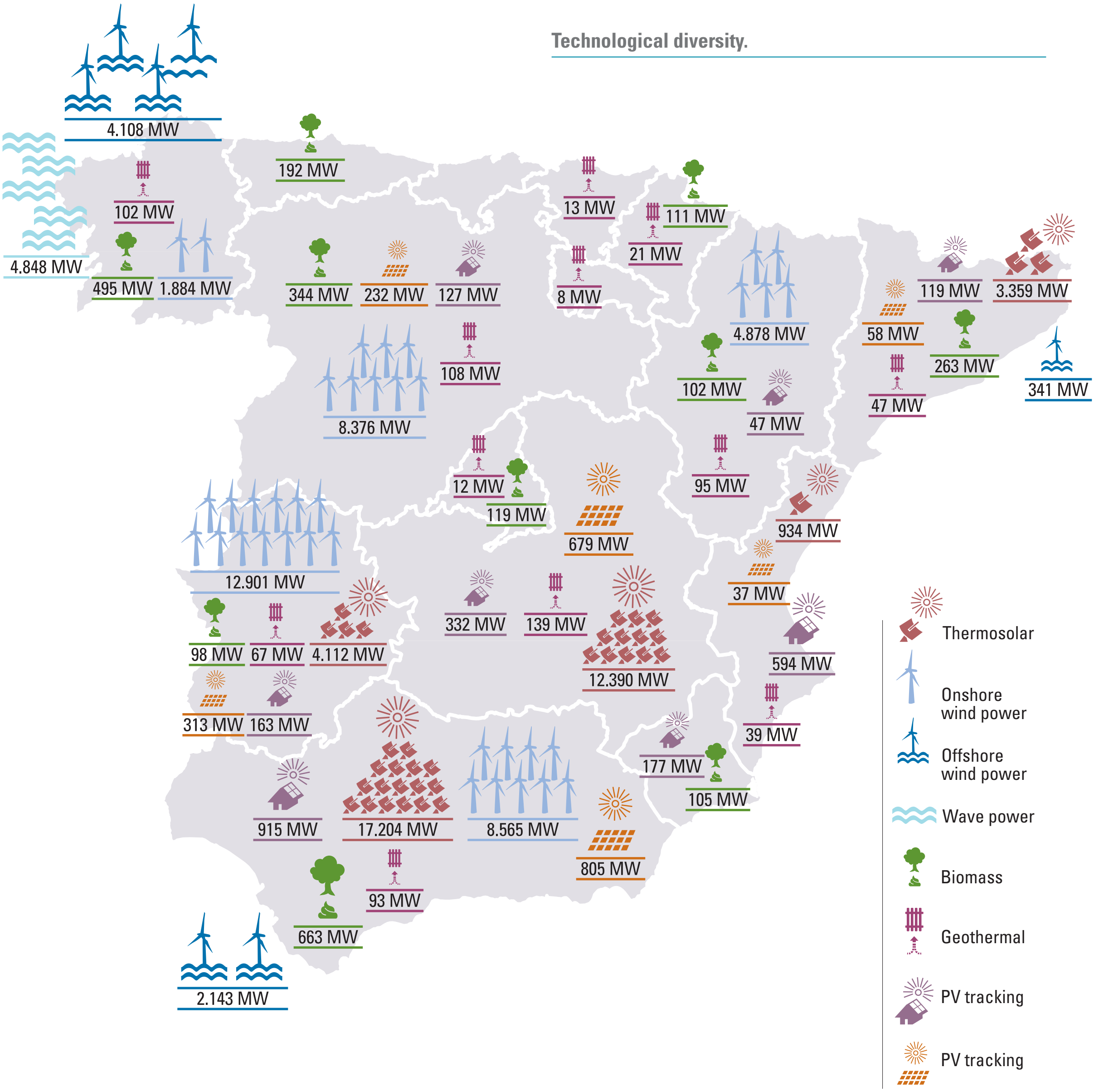
Annual hourly development of available capacity, demand, dissipation and shortfall for a mix with SM = 2,5 with a storage capacity of 1.5 TWh. SF = 100%.



4.2

The map shows us the geographical spread by autonomous communities for installed capacity. The provinces with lowest generation costs have been chosen for the respective technologies. Water technologies are not shown because they use already existing sites.

Technological diversity.



4.2

100% renewable mix.
Aim: economic optimization

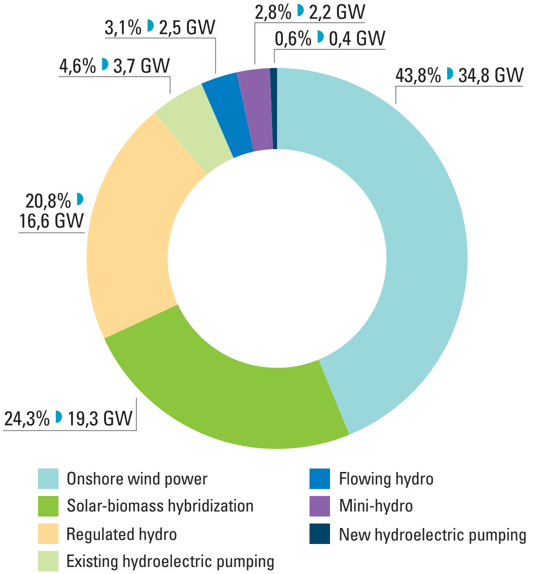
In this scenario we show a mix in which the economic optimum is sought, that is the minimum cost for the electricity generated, maintaining the condition of completely meeting electricity demand in 2050 with renewable energies (SF = 100 %), not taking into consideration any kind of demand management.

To determine optimum dispatch, that is, how generation is spread over the various stations installed in order to minimize running costs, aspects have been introduce such as taking into consideration the storage capacity of hydroelectric reservoirs and optimization of their management, including thermosolar hybridization and the optimization of its management, including hydroelectric pumping (with its storage and power regulation capacity) and optimizing operation of each technology throughout the year according to its variable costs and availability.

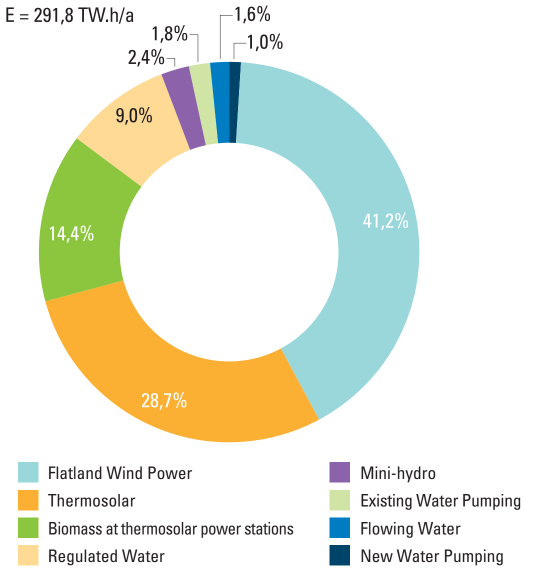
For minimum cost analysis, investment and life cycle costs have been optimized, using a special model which, by calculating some 500,000 equations, simultaneously resolves the problem of which power stations to build and which to operate at any moment in time throughout the year.

The mix in this example would have an installed capacity of 79,600 MW, with the following technology spread:

Installed capacity by technology.



Electricity configuration and generation of a mix, optimized in a life cycle incorporating thermosolar hybridization to totally meet demand (SF = 100%). SM = 2.20; LEC = 2.47 c€/kWhe.



4.2

Electricity generation at thermosolar power stations, all of them hybrid with biomass, is broken down between that which would be achieved using solar energy and that which, at the same stations, would be achieved with biomass.

The following table summarizes the main features of this mix.

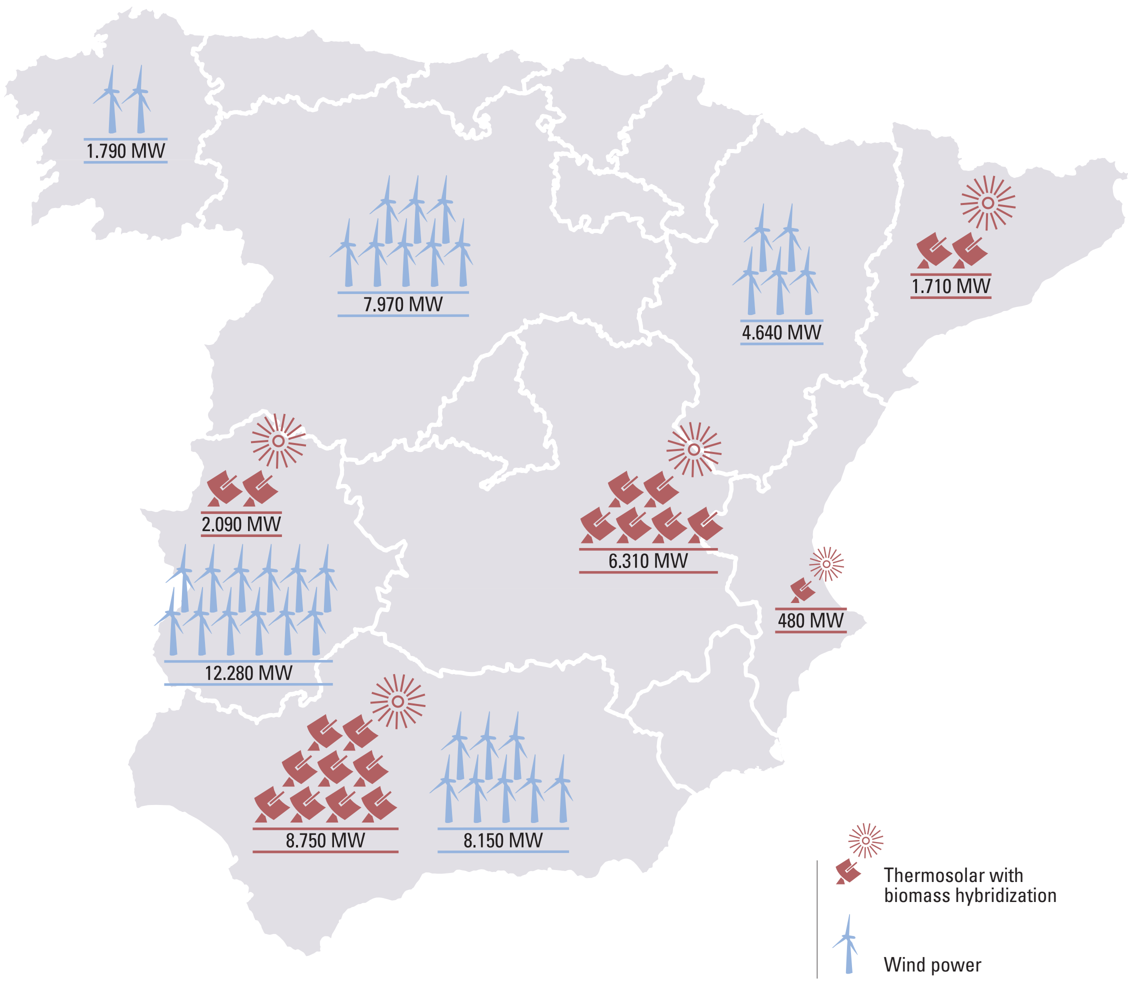
Main characteristics of the mix.

Installed capacity	79,6	GWp
Available energy	291,8	TWh/a
Solar Multiple (SM)	2,2	
Meeting demand (SF)	100	%
Annual electricity cost (LEC) with no hydro investment	2,47	c€/kWh
Maximum electricity cost	9.883	c€/kWh
Duration of maximum electricity cost	1	Hour
Solar-biomass hybridization	Yes	
Mini-hydro operation	Base	
Fraction used of the onshore wind power capacity ceiling	3,8	%
Fraction used of the thermosolar capacity ceiling	0,7	%
Fraction used of the thermosolar-biomass hybridization capacity ceiling	39,2	%
Land occupation	2,4	%

4.2

The map shows us the geographical spread by autonomous communities of installed capacity. The provinces with lowest generation costs have been chosen for the respective technologies. Water technologies are not shown because they use already existing sites.

Economic optimization.



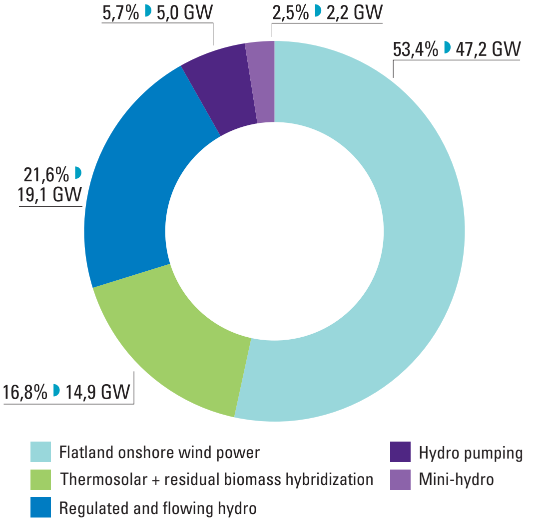
4.2

100% renewable mix.
Aim: to make the most of demand management

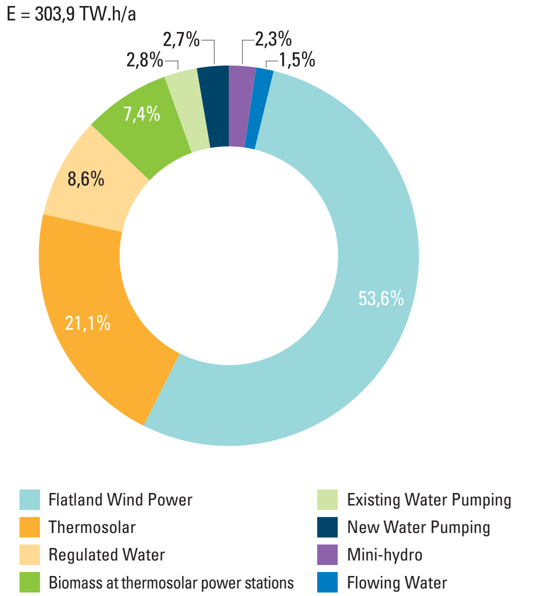
In this scenario we seek to reduce even further the cost of electricity, in order to achieve the minimum possible cost, studying the effect of managing peaks by means of demand management without relinquishing the use of renewable energy sources only. To do se we have assumed a non-supplied energy cost (NSEC) of 500 c€/kWhe, such that at those times when the of electricity generation exceeds this value (owing to the additional investment required), recourse is had to demand management to avoid this consumption occurring at that time (displacing it to times with surplus generation capacity).

In the following graphs we see the main characteristics of this mix, the spread by technologies of installed capacity (88,400 MW) and of energy generated, the spread throughout the year of non supplied capacity (substituted by demand management) and the cost of electricity throughout the year.

Installed capacity by technology.



Electricity configuration and generation of a mix optimized for NSEC = 500 c€/kWhe. SM = 2.29; SF = 99.993%; LEC = 2.42 c€/kWhe.

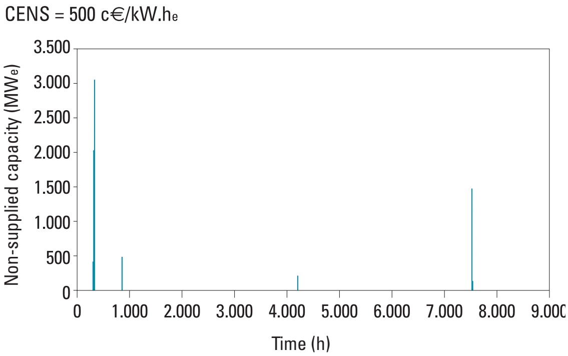


4.2

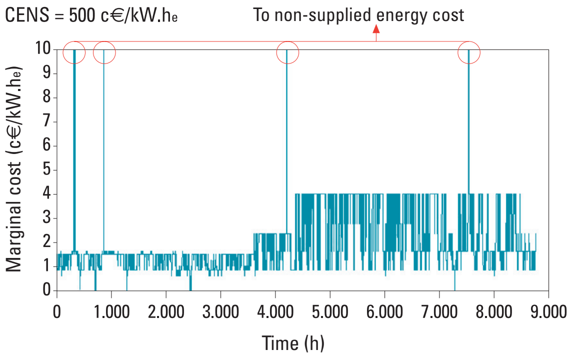
Main characteristics of the mix.

Installed capacity	88,4	GWp
Available energy	303,9	TWh/a
Solar Multiple (SM)	2,29	
Meeting demand (SF)	99,993	%
Annual electricity cost (LEC) with no hydro investment	2,42	c€/kWh
Maximum electricity cost (CENS)	500	c€/kWh
Hours in the year in which the production of electricity is less than demand	7	
Solar-biomass hybridization	Yes	
Mini-hydro operation	According to costs	
Fraction used of total mainland onshore wind power capacity ceiling	5,2	%
Fraction used of total mainland thermosolar capacity ceiling	0,5	%
Type of biomass used	Residual	
Fraction used of mainland residual biomass generation ceiling	44	%
Fraction used of total mainland biomass generation ceiling	21,1	%
Land occupation	3	%

Annual hourly development of non-supplied capacity for a mix optimized for CENS = 500 c€/kWhe. SM = 2,29; SF = 99,993%; LEC = 2,42 c€/kWhe.



Annual hourly development of the marginal electricity cost for a mix optimized for CENS = 500 c€/kWhe. SM = 2,29; SF = 99,993%; LEC = 2,42 c€/kWhe.



4.2

This example is very conservative, and only leaves 0.007% of the total energy requirement ungenerated at the time required (consumption displacement), but in fact it would be economically more favourable to act on demand instead of generating electricity in all those cases in which, being technically possible, it is cheaper to manage demand for electricity (saving it or displacing it to other times when there is a surplus of generation capacity) than to generate it. These would be the scenarios in which the cost of kWh managed would be less than that of kWh generated (in other words, for much lower NSEC values).

In this scenario, using NSEC = 500, a particular scenario is shown, but now from NSEC = 8 c€/kWh_e practically 100 % SF is achieved, that is, the generation system continues to cope with the vast majority of demand even enabling demand management measures to come into play from low cost levels.

100% renewable mix.
Aim: to meet all energy demand
(not just electricity)

Finally, we are going to show an example of how it would be possible using renewables to meet not just all the electricity demand, but also all energy demands for mainland Spain in 2050.

Let us remember that for the whole study we assume a total final energy demand in 2050 of 1,525 TWh/year, of which 280 TWh/year would be electricity demand. Therefore, if besides the electricity demand we were to meet, using electricity, the rest of the energy demands, additional electricity demand would be 1,525 - 280 = 1,245 TWh/year. To assess the amount of electricity that would have to be generated to meet all these final demands, we assume that 60% of these other demands would be spread over the demand for heat/cold in buildings, industrial and other sectors and 40% in the transport sector (this, in turn, spread 75% over vehicles using electricity and 25% using hydrogen), and we assume the following performances: 90% for electricity conversion into useful heat, 70% vehicles using electricity and 25% for vehicles using hydrogen. Therefore, to meet a final energy demand of 1,245 TWh/year, it would be necessary to supply 1,862 TWh/year. This involves an additional electricity demand of 1,862 TWh/year by 2050, to be added to the 280 TWh/year original electricity demand, resulting in a total electricity demand of 2,142 TWh/year.

We shall see next, in the case of this example, how the 851 GW of installed capacity would be spread by technology , the 2,390 GWh of electricity which would be generated (to meet the 2,142 TWh of demand), the potential development in relation to the total available and the 14.9% of the country that would be occupied.

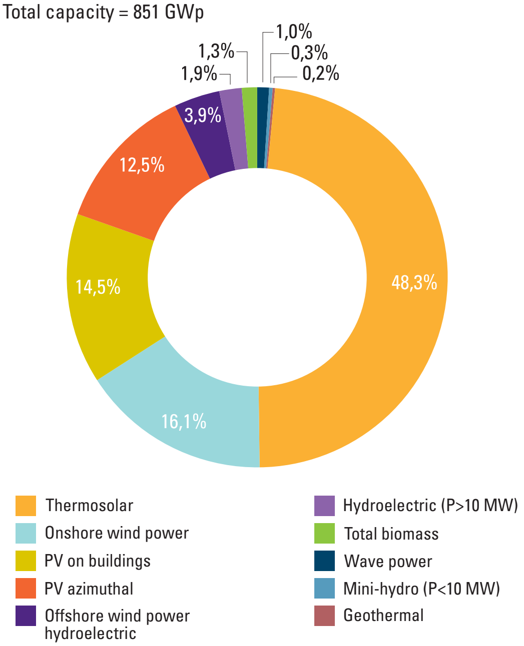
4.2

Composition, generation capacity and land occupation of a mix with 851 GWp nominal installed capacity.

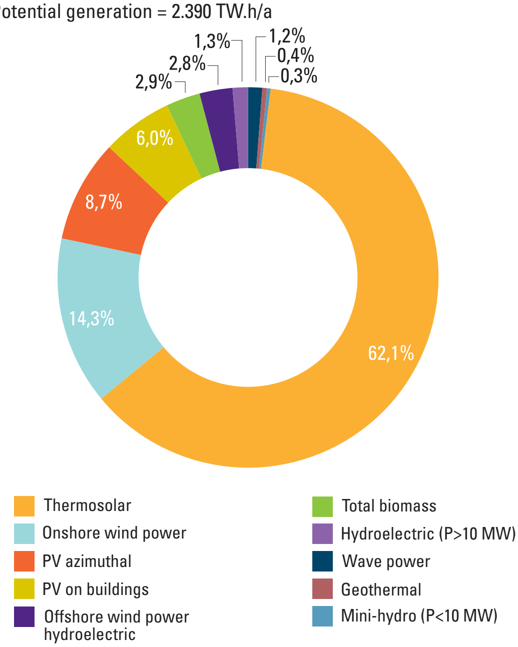
	Capacity (GW_p)	Generation (TW.h/year)	Capacity development (%)	Land occupation (%)
Hydroelectric (P >10 MW)	16,6	30,7	100	-
Mini-hydro (P < 10 MW)	2,2	6,9	100	-
Onshore wind power	137,3	342,8	15	8,50
Offshore wind power	33,0	66,8	20	-
PV on buildings	123,6	142,3	25	-
PV azimuthal	106,3	207,3	15	1,32
Total biomass	11,0	69,1	-	3,05
Residual biomass and biogas	8,25	50,9	100	-
Energy crops	1,61	10,6	30	1,90
Short rotation forestry crops	1,16	7,6	20	1,15
Scrubland	0,0	0,0	0	0,00
Thermosolar	410,8	1.484,6	15	1,99
Wave power	8,4	29,6	10	-
Geothermal	1,49	9,8	50	0,00
Total renewables	**850,7**	**2.389,7**	-	**14,9**

Percentage output and generation capacity distribution of the different technologies considered in mix with 851 GWp nominal installed capacity.

Total capacity = 851 GWp



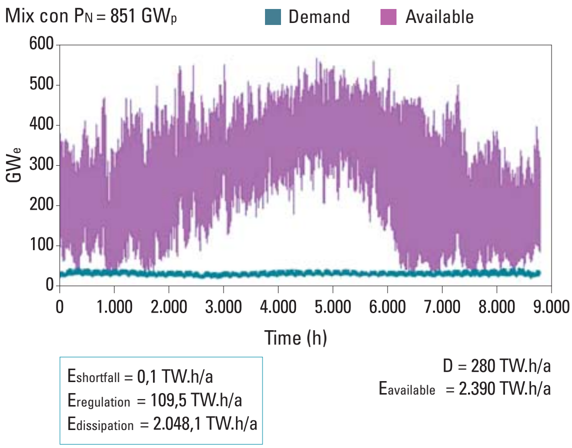
Potential generation = 2.390 TW.h/a



4.2

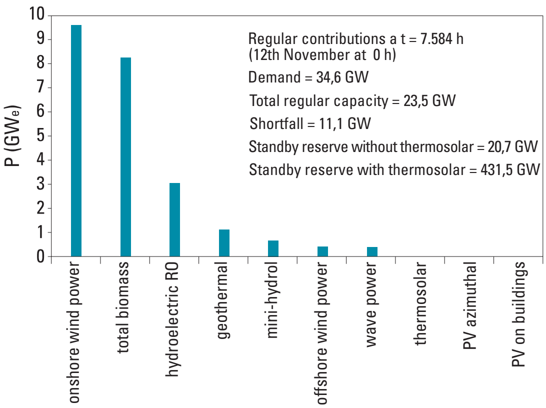
We shall also see how electricity generation would vary in comparison to original electricity demand.

Annual hourly generation capacity development together with that of mainland demand, for a mix with 851 GWp nominal installed capacity.



We see that, compared with an original annual electricity demand of 280 TWh, a total of 2,390 TWh would be available. The small capacity deficit throughout the year amounts to 0.1 TWh, which could be entirely met by demand management, or by energy storage systems or by the 110 TWh available at power stations which could regulate its generation. Once all the original electricity demand is met, 2,048 TWh is surplus enabling this mix to meet effortlessly the 1,862 TWh additional electricity demand. Even at the most critical moment in the year there would be sufficient reserves to meet the demand, as we can see from the graph:

Contribution of the different technologies of a mix with 851 GWp meeting demand at t = 7.584 h (12th November at 0 hrs), the maximum capacity shortfall.



However, this example has not been optimized as the previous ones that we have seen, but this does not mean that all this renewable capacity is required to meet overall demand, but that it shows one of the possible ways of doing it. Neither does it mean that the best way of meeting total demand is by generating electricity in every case, but that 100% renewable electricity generation can be achieved.

4.3. Meeting demand: conclusions

As we have seen, multiple combinations of renewable generation system can be implemented to completely meet electricity demand throughout the year, and even total energy demand, taking into account that:

- An important feature of the renewable generation mix is technological diversity, thanks to which available energy resources become very regular over time. Albeit there exists sufficient renewable potential to easily bring together a mix which meets demand, even at those critical moments (heating peaks), by employing a few technologies, **by providing greater technological diversity to the generation mix enables us to reduce the total capacity to be installed and increase supply security.** These aims are also achievable by using the regulation capability of technologies such as hydroelectricity, biomass and geothermal.

- Besides, everything possible would have to be done to **boost the takeoff of thermosolar technology, because of its unique advantages:** high potential, capacity availability for demand peaks (in hybridization with biomass), daily energy storage capacity, the generation of economic activity in Spain, Spanish industrial leadership, use in key regions of the world and the contribution to sustainable development.

- Due to the fact that a mix which meets 100% of electricity demand and guarantees security of supply using renewable energies involves the need to dissipate a large amount of energy, it would be **advisable to integrate the total energy system to meet all or part of the rest of energy demands, via the surplus electricity from the renewable electricity system.**

5

PARADIGM CHANGES NEEDED FOR IMPLEMENTING FOR A RENEWABLE SYSTEM

The report put forward different "paradigm changes" needed to break some barriers currently preventing us even from contemplating a completely renewable system:

- **Renewable technologies as the main element of the electricity system**

  · For renewable technologies to go from being peripheral to the electricity system to being considered as the main elements, they will have to go from being operated "in maximum capacity mode" (provided the power station is available, it has to pump the electricity it generates into the grid) to doing so in "regulatory mode" (the power stations must operate as electricity demand requires it).

- **The role to be played by electricity and demand management**

  · To avoid dissipating a large amount of renewable generation capacity, this energy could be used for other energy demands, such as low temperature heat demands or for vehicles. This would provide a huge "distributed storage capacity" (stored heat in buildings, hot water tanks and heating, vehicle batteries...), very useful for demand management. In this way the conversion to sustainability in the building and transport sectors could be accelerated, together with the use of other renewable non-electric options.

  · Demand management should seek to displace consumption to central times in the day (the opposite to the current situation), which is when there is most generation in solar power stations.

  · An integrated renewable system would enable us, by using renewables, to meet, in addition to electricity demand, a large part (even 100%) of the energy demand of the building and transport sectors, more economically than by dealing with the two things separately (by utilizing some renewable technologies solely for electricity generation and other renewable technologies soley for non-electricity demands). This could lead the way to achieving the channelling of these other sectors towards sustainability in the short time available, albeit this would not be the only way of doing it and, of course, during the transitional stage other non-electrical renewable options would have to be relied upon to meet the demand of these sectors.

6

HOW MANY RENEWABLE STATIONS WOULD BE NEEDED AND HOW SHOULD THEY BE USED, AT MINIMUM COST?

Having seen that it is possible to completely meet demand by means of renewable energies, and that there are multiple combinations to achieve it, we present below the main results and conclusions for each of the stages of the study aimed at responding to the issues of how much renewable capacity would be required and what would be the operating mode of generators, in order to meet demand with renewables at minimum cost. Firstly, we present the conclusions relating to capacity needed to be installed: analysis of the solar multiple and an analysis of the storage capacity. Finally, we present conclusions relating, in addition to a combination of technologies to be installed, to the way of operating the generator park to obtain minimum cost: grid analysis and non-supplied energy cost analysis.

Need for installed capacity (analysis of a solar multiple)

We can adjust the capacity needed to be installed to completely meet demand with renewables, bearing in mind that:

- Geographical spread and technological diversity in the mainland system allows greater coverage to be achieved with renewables (SF) and a lower costs (LEC[3]) for each level of installed capacity (SM) in relation to what is achieved in a single family stand-alone system, such that what in the mainland system is achieved with a generator park of SM = 2, requires a stand-alone system to employ SM > 30.
- As installed renewable capacity increases, that part of demand not covered by renewables becomes more critical in terms of capacity than of energy, that is, the problem is not in having sufficient energy but rather being able to supply it at the very moment when demand is high. The most suitable solution would be to cover these deficits with good demand management, or in its absence to use power stations which can regulate their generation, such as thermosolar installations with biomass or hydroelectric and geothermal power stations, or with small storage capacity.
- In a system with a high percentage of renewables, **the most suitable use of biomass would be in the hybridization of thermosolar power stations.**
- From SM = 2,5 capacity which will not be used throughout the year is of the order of required electricity capacity, which would force a huge quantity of energy not to be used. This assumes that, at these SM values, the cost of electricity supplied is greater than what it would be if, using the same generation mix, the surplus electricity were used, and this difference grows as the SM increases. Therefore, **mixes with an SM above 2.5 would be more suitable within a framework of integrated energy systems, in which the huge surplus generation capacity in relation to electricity demand can be set aside to meet other energy demands.**

[3] *LEC: Levelized cost of electricity (see document entitled 100% RENEWABLES: COST COMPARISON)*

- We can see **the cost of regulating by using a specific generator park to meet demand** as the difference between the electricity cost in that mix and the minimum that would obtain if all the electricity generated were used. For example, the cost difference is just 0,53 c€/kWh in a SM = 2 mix , but it rises to 29.13 c€/kWh in a SM = 15 mix.

Analysis of storage capacity

Very little energy storage capacity is required, or even none at all, for managing the system properly, bearing in mind that:

- For storage capacity to be able to meet the entire demand, the total generation system performance must allow there to be more surplus energy available (dissipation) than what is required (deficit) in total over the year. **The greater the balance throughout the year between dissipation and deficit, the less storage will be needed.**

- **From SM = 2,5, it is less cost effective to meet demand using storage capacity than continuing to increase installed capacity.** But it will be even cheaper to use the available capacity at the thermosolar plants in hybridization with biomass, and cheaper still to manage the few deficit peaks using demand management.

- To meet 100% of demand with an SM mix above 2.5 **the low storage capacities required are available with proper management of hydroelectric resources and existing pumping.**

- **The optimum economic value of storage capacity (0.15 TWh) corresponds to a 4 hour range** compared to average electricity demand.

Analysis of the electricity generating system

Analysis of the optimum combination of generation technologies to be installed and which of them is advisable to use at any particular time to meet demand, allows electricity generation cost to be optimized in a completely renewable system , taking into account that:

- The mixes obtained **by including life cycle cost** (as a result of optimizing the of the problem of matching which power stations to install and which to operate) have **considerable technological diversity, not being dominated by any single technology.**

- **Hydroelectric pumping** is used with much greater capacity factors to those currently employed, albeit it does not require huge installed capacity.

- Proper development planning of the renewable generation mix can point in quite a different direction to the one the current market situation would take us in. Lack of this planning would lead us to making far from optimum investments, and consequently higher life cycle electricity costs, this being conditioned by the investments made. Therefore, **to achieve an economically optimum 100% renewable mix, proper planning is required,** otherwise the most economical renewables at the time will be fully developed and dirty energy will not be completely displaced.

- Optimized mixes make extensive use of **hybridization with biomass at thermosolar power stations,** which then have continuously available generation, playing the same role that conventional thermoelectric stations do.

- The **marginal electricity cost,** for optimized mixes using solar-biomass hybridization, is kept pegged for practically the whole year **below 2.4 c€/kWh$_e$.** There is only around one hour per year in which the marginal cost shoots up to much higher values.

- When dealing with a generation mix employing a major contribution from renewable technologies, the existing limitations of conventional tools for grid analysis have been shown. **Major technical and scientific development is required to adapt the analytical tools to the new situation,** which should be tackled as a matter of highest priority.

- **The ability to manage a 100% renewable generation mix properly, even using the current transmission grid, does not seem to represent a significant technological barrier.** Qualitatively, the results obtained in relation to generation capacity management, available potential and its homogeneous spread across the peninsula, lead us to believe that a 100% renewable system could be operated, although it would probably require major adjustments both to the grid and to the current operating scheme. The electricity transmission grid is a means not an end, and it should be adapted to the requirements of a renewable generation system.

Analysis of cost of non supplied energy (CNSE)

We can further improve electricity generation costs in a renewable system thanks to demand management, taking into account that:

- From the economic standpoint, **the most appropriate solution would be the combination of a renewable mix optimized for a reasonable amount of the cost of non-supplied electricity (NSEC), plus suitable demand management[4].**

- So as not to oversize a technology irreversibly, it must be taken into account that **the structure of the optimum generation mix varies significantly according to the NSEC.**

- **By increasing the value of the NSEC does not have to increase the installed capacity and land occupation,** since for mixes with high solar fraction values, thermosolar technology substitutes wind power, reducing the need for installed capacity.

- **A huge hydroelectric pumping capacity is not required to meet the decouplings between generation capacity and demand** (a maximum of 2.69 GW pumping, with NSEC = 8 c€/kWh$_e$, would suffice, compared to 15 GW which could be installed with existing reservoir capacity).

[4] *For example, an optimized mix for NSEC = 5 c€/kWh$_e$ has a LEC = 2,24 c€/kWh$_e$ (and in the absence of demand management would provide SF = 92%), while the optimized mix to meet demand completely (SF = 100 %) has a LEC = 2,48 c /kWh$_e$ (although there is one hour per year in which it would reach a marginal maximum cost of 9,.883 c€/kWh$_e$).*

7

- The optimization resulting from the calculations undertaken is relative, since it is based on technological and cost projections, and over such a long term period reality could be very different. Besides, the specific results in respect of determining "optimum" mixes would be different depending on the degree of utilization of demand management. What is important is that it has been shown that **tools can be developed for analyzing and optimizing mainland electricity generation mixes based on renewables and on very favourable associated cost** (below 2.5 c€/kWh_e).

- **Hybridization with biomass of thermosolar power stations provides appreciable supply security and reduces the generation system cost.** However, given the relative scarcity of biomass in our country, we must be careful not to use it more intensively than is advisable.

- Although the 'optimum' mixes do not require more than a few technologies, **it is advisable to employ greater technological diversity, even though this involves greater costs,** to achieve better spatial spread of generation capacity and to obtain an improvement on hypothetical transmission congestion. For example, it would be desirable to have sufficient capacity close to the areas of greatest demand.

- **Demand management would be the most economical and suitable way of meeting the rare peaks in capacity arising throughout the year.** However, what matters is the relationship between demand and generation capacity at any given time, demand management schemes could be very different to those employed currently, since in a renewable mix it could be more appropriate to displace demand to central hours of the day, despte this being when the absolute demand peak occurs, given that solar generation capacity could make these times into "valleys" in relative terms.

FINAL CONCLUSION

After the detailed analysis of mainland electricity generation systems based on renewables, from the point of view of temporal generation-demand coupling, costs and investment and use optimization, it is concluded that:

- **Consideration of a generation system based 100% on renewable energies is feasible,** both for meeting electricity demand and for total energy demand.

- **The total costs of the electricity generated are perfectly adoptable and very favourable** in relation to a tendentious scenario.

- **There are sufficient tools to guarantee demand is met** over the complete useful life of the generation system.

8

GREENPEACE PROPOSALS

To prevent dangerous climate change an energy revolution is required to change the way in which we generate and use energy. This report shows that Spain can reach a 100% renewable horizon for her electricity generation, and it is even possible to consider such an ambitious target for meeting all her energy needs. "100% Renewables" is economically and technically feasible, and provides the only serious option for changing the energy model with one which enables humanity to survive climate change without causing or aggravating other serious environmental and social problems. Spain can and must assume leadership of this energy revolution. What is needed is the political will to do it. The least we can demand of a responsible State is that it analyses seriously and in detail the 100% renewable option and includes it in its energy planning targets. For this reason, Greenpeace asks the Spanish Government:

- To set mid and long term **binding energy planning targets**, specifically the following ones:
  - Energy efficiency: a 20% reduction in primary energy demand on current levels by 2020.
  - A 30% contribution of renewables to primary energy by 2020, rising to 80% by 2050.
  - **A 50% contribution of renewables to electricity generation** by 2020 **rising to 100%** by 2050.
  - An 80% contribution of renewables to building conditioning by 2050.
- Adopt **CO_2 emission reduction targets** to contribute to a 30% emission reduction in the EU on 1990 levels by 2020 and 80% by 2050.
- To strengthen the premium system, by a **Renewable Energies Law,** to ensure compliance with targets and definite and stable returns on investment, which must be more attractive than investment in dirty energy.
- **Bring to an end market distortions** which harm renewable energies. Put an end to all the subsidies, direct and indirect on fossil fuels and nuclear energy, to internalize all external social and environmental costs, ensuring that final energy prices reflect all costs according to the source of energy used. To contaminate must be made costly.
- **To reform the electricity market,** removing barriers to renewables by:
  - Administrative processes and simplified, coordinated and standard authorizations for the whole country for renewable projects.
  - Priority access to the grid guaranteeing renewable generators, removing any access tariff discrimination.
  - Grid modification and extension costs spread across all consumers.
  - Complete separation of activities between generation and distribution companies, not permitting them to belong to a single company group.

· The right of all consumers to choose the energy source they use, establishing an official electricity labelling system and a guarantee of origin for all electricity, which ensures that all electricity marketing companies are required to state on their bills, in a standard format, the energy source employed and the environmental impact.

- To adapt electricity and gas pipeline **grid design,** as well as the tools and regulations for their management, to facilitate the implementation of a 100% renewable system.

- To use **demand management** to achieve a 100% renewable system at the lowest possible cost.

- To put a stop to squandering energy, imposing **compulsory efficiency levels** for energy consumption on all electrical household appliances, buildings and vehicles.

- **To continue research** initiated by Greenpeace to analyze the technical feasibility of a 100% renewable electricity system, providing the economy resource needed to develop tools to enable the analysis to be undertaken.

ENERGY REVOLUTION PROJECT

Greenpeace commissioned a team from the Technology Research Institute of the Pontifical University of Comillas, headed by Dr. Xavier García Casals, to conduct a technical study whose aim 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 make good 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 were submitted entitled **"Renewables 2050. A report on the potential of renewable energies in mainland Spain"** 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.

In 2007 the report **"100% RENEWABLES. A renewable electricity system for mainland Spain and its economic feasibility"** offers the results of the second stage of the study, in which the feasibility of a scenario based on renewable energies for electricity generation on the mainland are quantified and assessed from a technical standpoint. **The analyses show technical and economic feasibility of a system based 100 % on renewables.**

GREENPEACE