# A 100% RENEWABLE ELECTRICITY MIX?

## ANALYSIS AND OPTIMIZATION

## THIS WEBSITE GIVES AN OVERVIEW OF THE STUDY AND SUMMARIZES IT IN 6 MESSAGES:

1. Combination of technologies is crucial
2. An intelligent and flexible electrical system is essential
3. The electricity mix is robust to meteorological hazards
4. Network development is necessary and can pool the potential
5. The economic impact can be anticipated
6. The balance between production and demand is achieved at any time

This scientific prospective study aims to **better understand the functioning of a 100% renewable electricity system in France.** Power generation and consumption must be equalized at every moment. However, renewable energy such as photovoltaic and wind power are producing at the discretion of the weather. **Is it possible to supply the French electricity mix with 100% renewable energy?**

Analyses are based on a model used to determine the optimal renewable parks by region and to check every hour that the balance between production and demand can be achieved. The horizon of such electricity mix would probably be relatively distant (post 2050). The investment path between today and 2050 is not in the scope of the study. Several prospective scenarios have been constructed and optimized in order to scan a range of possibilities.

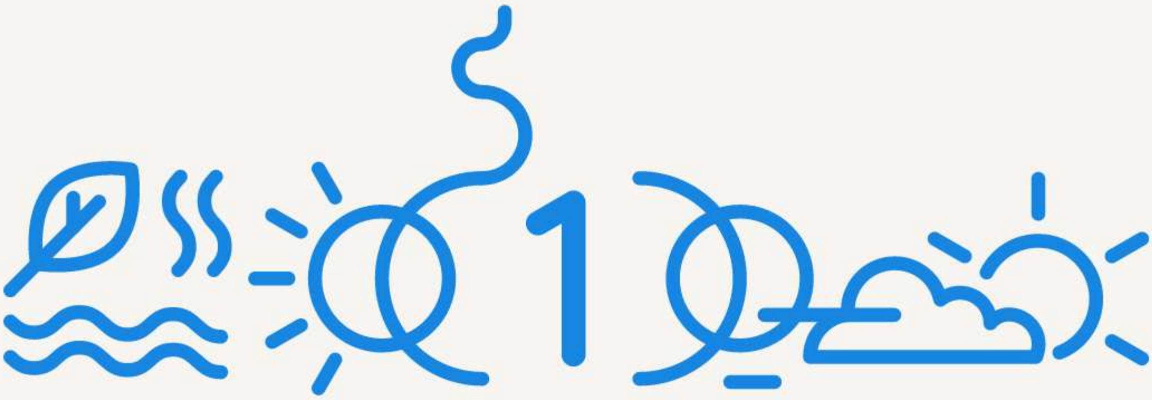
What can we learn from this study?

100% RENEWABLE ENERGY

➔ That more than one electricity mix seems technically possible to achieve 100% - 80% renewable, with production matching demand on an hourly basis.

➔ That a 100% renewable mix can be reached thanks to profound changes in the whole electric system but at a total cost probably of the same range than a 40% renewable mix.

**Demonstration.**



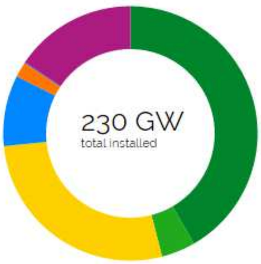
## COMBINATION OF TECHNOLOGIES IS CRUCIAL

Several renewable power mixes are possible, requesting several types of renewable energies, completing each other. The geographical distribution of the means of production is optimized: more solar in the south, where the sun is most important; more wind where the wind blows stronger. One thus takes advantage of the most interesting (and therefore economically cheaper) potential.

**53%**
**OF PRODUCED ENERGY IS MADE OF ONSHORE WIND**

Installed capacity | Produced energy

**Metropolitan France**




| | | |
|---|---|---|
| ● | 96 GW | Onshore wind |
| ● | 10 GW | Offshore wind |
| ● | 63 GW | Solar |
| ● | 21 GW | Hydraulic |
| ● | 4 GW | Biomass |
| ● | < 1 GW | Geothermal |
| ● | < 1 GW | Marine renewable energy |
| ● | 36 GW | Storage |

To determine an electric mix for 2050, it is necessary to rely on some assumptions for which there is a margin of uncertainty. Based on these forward-looking assumptions, optimization results in several different mixes. 3 scenarios are presented below in addition to the central scenario: If the cost of network development becomes binding, the electricity mix is refocusing around places of consumption.

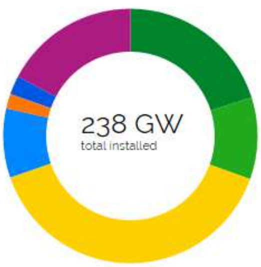
If the social acceptability of renewables is more moderate, onshore wind is less installed for the benefit of less-visible energy, such as marine energy, offshore wind and solar on the roof.

If emerging technologies (marine energy in particular) see a strong technological progress and a significant gain on their costs, they can take a substantial place in a 100% renewable electricity mix.

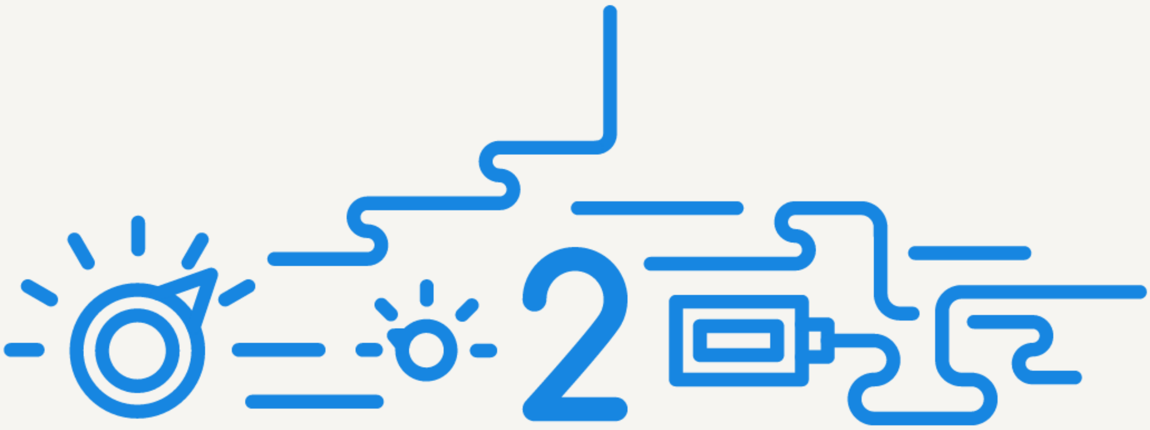
**If the cost of network development becomes binding the electricity mix is refocusing around places of consumption.**

Central scenario | High cost of network | Moderate acceptability | Emerging technologies accessible

**Metropolitan France**




| | | |
|---|---|---|
| ● | 48 GW | Onshore wind |
| ● | 25 GW | Offshore wind |
| ● | 93 GW | Solar |
| ● | 21 GW | Hydraulic |
| ● | 4 GW | Biomass |
| ● | < 1 GW | Geothermal |
| ● | 6 GW | Marine renewable energy |
| ● | 41 GW | Storage |



# AN INTELLIGENT AND FLEXIBLE ELECTRICAL SYSTEM

In the 100% renewable energy mix, as the vast majority of production is ensured by variable and not controllable means, it is necessary to introduce more intelligence to drive flexibility for different time horizons:

- Demand management provides a daily flexibility. It consists in controlling certain uses (such as hot water or electric vehicle charge) in line with the needs of the power management system.

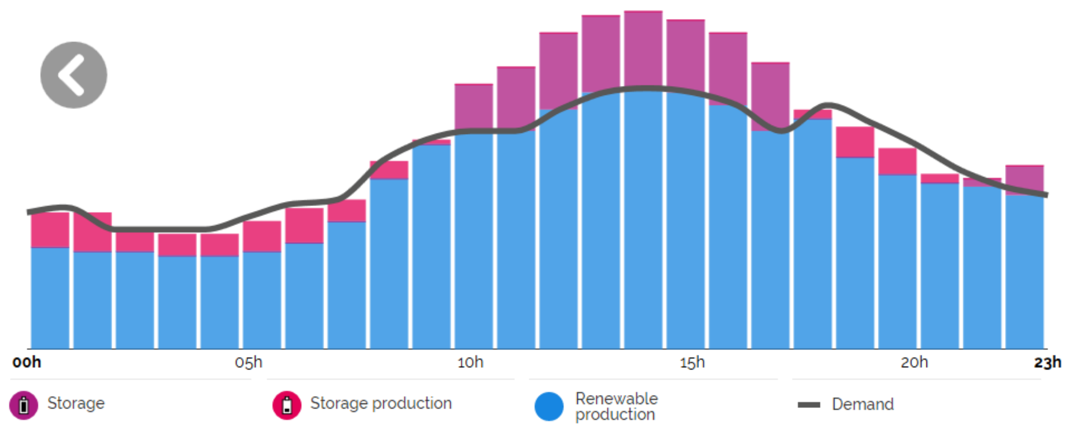
- Storage includes hydraulic means of production (energy transfer pumping station), storage batteries and compressed air (compressed air energy storage). It allows energy transfer during the day or the week.

- Power to gas to power (storage of the overproduction thanks to its gas transformation) brings flexibility over a longer time scale: overall synthesis gas is produced in the spring and summer for use in winter through combustion turbines. It enables inter-seasonal flexibility.

The animation below shows these levers in an average day in France in 2050, and also in the longer term. The demand management allows to postpone some consumption at times when production will be more responsive. Storage created by overproduction will complement the production when demand for electricity is not addressed fully by production.

## Demand management brings daily flexibility

Renewable surplus is stored on hours where production is higher than demand. Storage production happens on slots where there is a lack of production to meet demand.




This tab shows the day of June the 7th. The first view presents renewable production and demand. Demand management is adjusted to be maximal on production peaks.
By clicking on the animation again, short term storage and storage production can be viewed: one stores during the hours when production exceeds demand, and one uses storage on hours where production is not sufficient to meet demand. One thus reaches equilibrium.

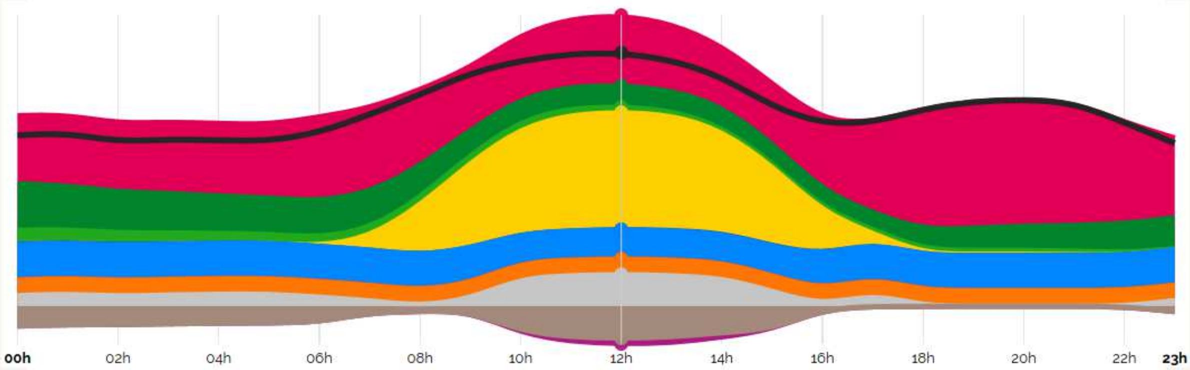
## AN ELECTRICITY MIX ROBUST TO METEOROLOGICAL HAZARDS

Mainly composed of wind and solar resources, the electricity mix has been tested on seven years of sun and wind. It allows, for example, to overcome an extreme winter (a winter power peak like 2012) or a week during which the wind drops. Four days were selected to demonstrate this robustness:

**The electricity mix was tested on seven years of temperature, sunlight and wind**

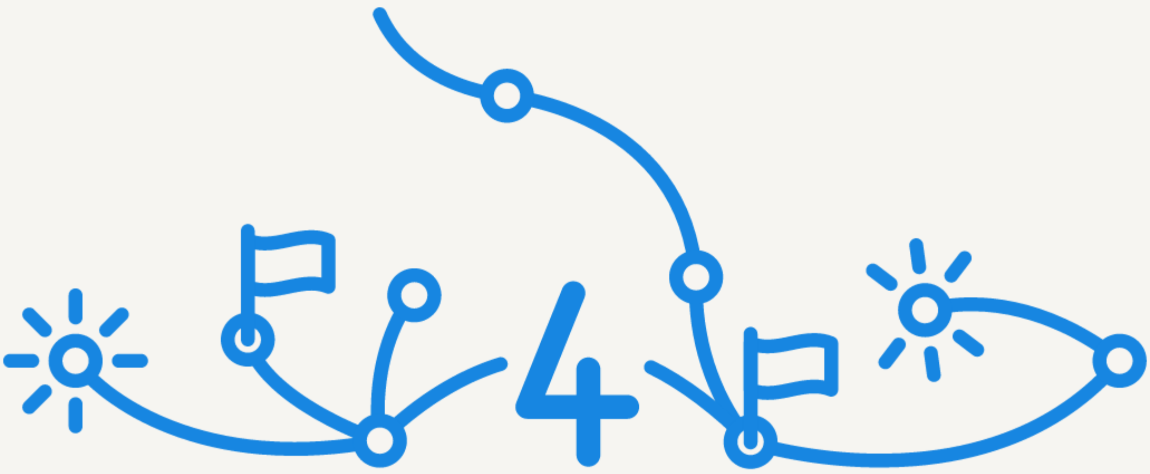
### A day without wind - Febuary the 28th

The wind blows little on that day. It is found that the (managed) demand curve is focused at noon, when solar output is important. Means of storage production are highly stressed. There is a global export balance on this day : the electrical system does not need to tap into the energy production of neighboring countries despite the wind power shortage.




Données à **12h**

| | | | | | |
|---|---|---|---|---|---|
| 1,6 GW | Stockage | 20 GW | Déstockage | 6 GW | Éolien terrestre |
| 1,5 GW | Éolien en mer | 33,2 GW | Solaire | < 1 GW | Énergies marines renouvelables |
| 8,1 GW | Hydraulique | < 1 GW | Géothermie | 4,4 GW | Biomasse |
| 9,1 GW | Import | 9,1 GW | Export | 72 GW | Demande |

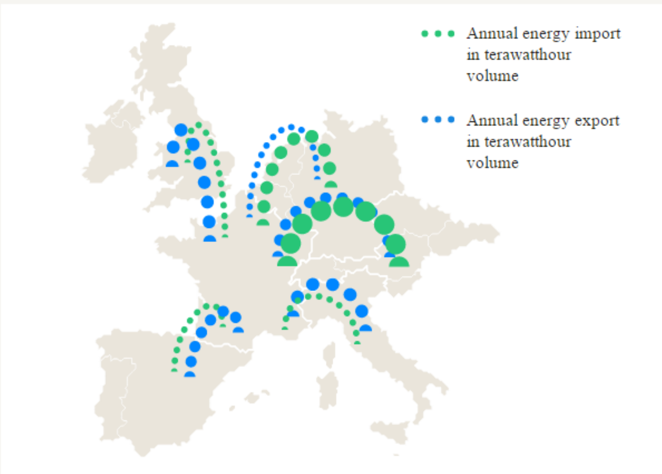



## NETWORK DEVELOPMENT IS NECESSARY AND CAN POOL THE POTENTIAL

The network acts as a potential pooling system. In a renewable mix, its importance grows: compared to today the need for inter-regional lines has increased by 36%. Although the means of production of a 100% renewable energy mix are highly decentralized, the network can deliver the electricity sometimes produced locally in excess at the discretion of the weather, to offset production shortfalls elsewhere in the territory.

The proposed model does not rely on electrical self-sufficiency of France, which is already widely interconnected with neighboring countries in 2014. The interconnections with neighboring countries are taken into account, ensuring that trade is balanced. In this model, they have an electric mix of 80% renewable. All electricity imports are counterbalanced by exports of renewable electricity produced in France.

**All electricity imports are counterbalanced by exports of renewable electricity produced in France**




| | |
|---|---|
| Central Europe → France | 17,83 TWh |
| Iberia → France | 8,41 TWh |
| Mid Europe → France | 11,95 TWh |
| South Europe → France | 7,98 TWh |
| UK & Ireland → France | 9,95 TWh |

| | |
|---|---|
| France → Central Europe | 6,39 TWh |
| France → Iberia | 15,62 TWh |
| France → Mid Europe | 4,97 TWh |
| France → South Europe | 13,43 TWh |
| France → UK & Ireland | 15,71 TWh |

## EVALUATION OF THE ECONOMIC IMPACT

The economic impact of such a scenario has an estimated extra cost of 2% compared to a scenario with 40% of electricity from renewable sources. The main parameters affecting its cost are:
- social acceptability of renewable energies,
- technological advances,
- energy demand management.

Unfavourable assumptions concerning these parameters imply from 5% to 14% of extra cost. Conversely, favourable financing conditions facilitating access to low interest rate involve a 14% cost reduction.

This cost, which takes into account total cost of electricity generation, network and storage, is broken down as follows:
- renewable means of production (65% of cost),
- network development (27% of cost),
- storage and flexibility of the demand (8% of cost).

**5%**

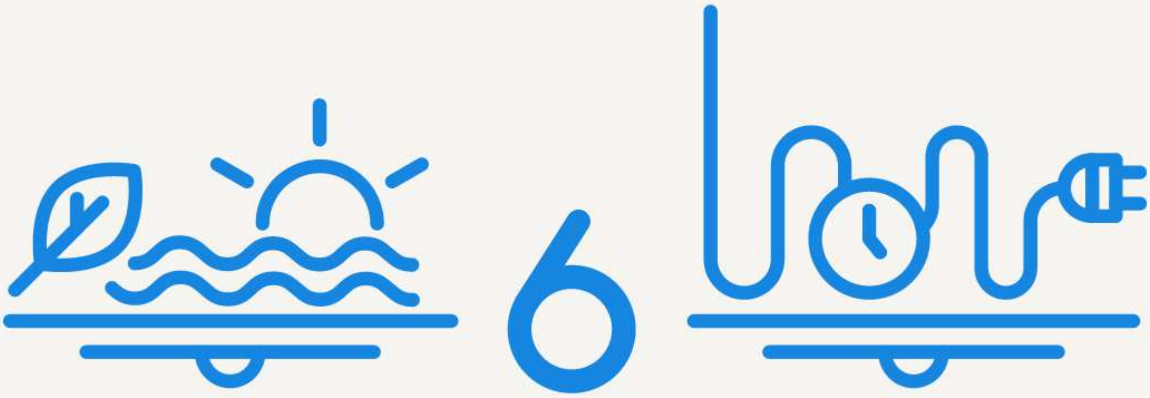
This is the extra cost compared to a case of weak demand management

**2%**

This is the extra cost compared to a scenario where renewable energy accounts for only 40% of the energy mix

**Costs breakdown**

- 65% Renewable means of production
- 27% Network cost
- 8% Demand storage and flexibility



## BALANCE OF PRODUCTION AND DEMAND IS REACHED ALL YEAR ON AN HOURLY BASIS

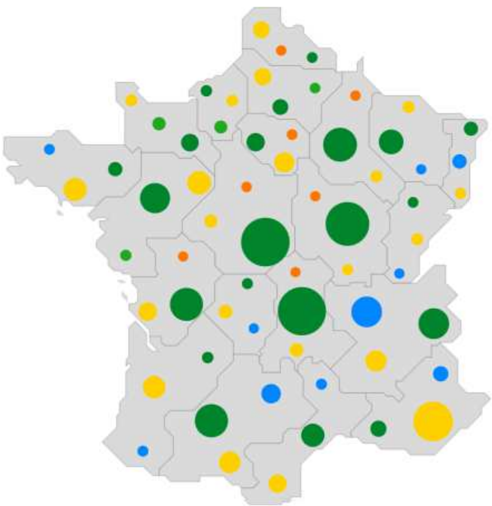
The timetable is simulated from early June to late May for technical reasons related to optimization. Indeed, this division is used to simulate a complete winter and implement a realistic and coherent water management (mainly lakes and dam).

Use the animation below to explore in more details the proposed energy mix for a particular day or during a given period using the play / pause button and by moving (drag & drop) the label indicating the day the cursor is on. The animation shows the trade flows of electricity between French regions and the allocation of energies, hour by hour.

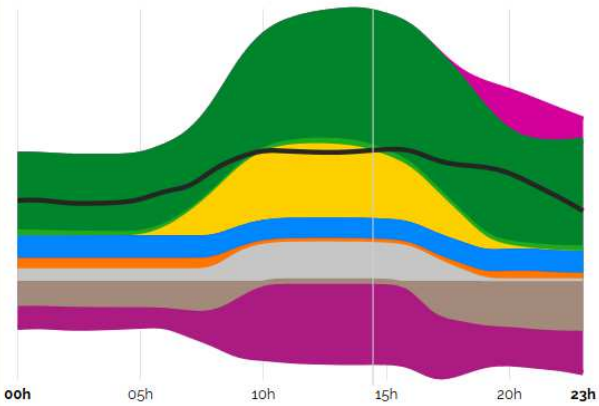
FIND THE FULL STUDY ON ADEME'S WEBSITE


Flows | **Production**

Data at **14h**



Data at **14h**




| | | | | | |
|---|---|---|---|---|---|
| ● | 35,2 GW | Storage | ● | 0 GW | Storage production |
| ● | 58,1 GW | Onshore wind | ● | 2,5 GW | Offshore wind |
| ● | 31 GW | Solar | ● | 0 GW | Marine renewable energy |
| ● | 8,9 GW | Hydraulic energy | ● | < 1 GW | Geothermal energy |
| ● | 1,4 GW | Biomass | ● | 16 GW | Import |
| ● | 0 GW | Export | ▬ | 56,3 GW | Demand |