MINISTÈRE DE LA TRANSITION ÉCOLOGIQUE ET SOLIDAIRE

THÉMA

Commissariat général au développement durable (CGDD)

French General Commission for Sustainable Development

Growth in wind and solar energy

What type of electricity storage?

DECEMBER 2017

Wind and solar energy are providing an increasing share of electricity production. These resources, which depend on the meteorological conditions and not on the demand, are managing the balance between supply and demand, and therefore require some attention. Over the medium term, this management process should lead to the development of storage facilities, as well as management tools making demand more flexible, as grid interactive domestic water heaters.

An initial overview of storage options is outlined here: in view of projected technical and economic developments (costs, etc.), batteries could provide a useful solution for dealing with daily fluctuations and hydropower storage (PHS) for weekly fluctuations.

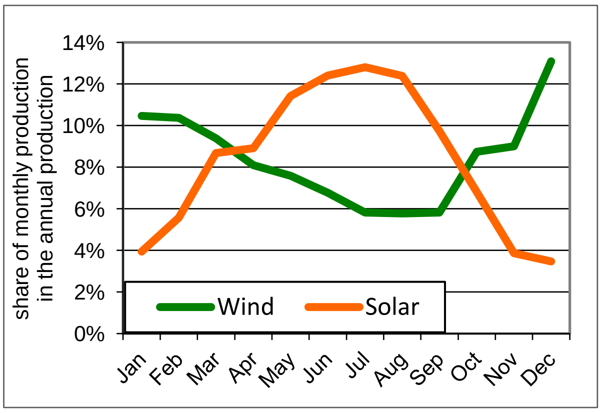
Solutions may change depending on other technical/economic conditions, which could emerge and the environmental impact of technologies.

Renewable energies been developing at a great pace since 2010 and this progress will continue under the impetus of the long-term energy French program (PPE) pursuant to the law on energy transition towards green energy: these energies will represent between 28 to 31% of electricity production by 2023. 13% is already provided by hydroelectricity, the development of which should be minimal in the future.

SEASONAL PRODUCTION

Wind energy and solar energy are intermittent and fluctuate with the meteorological conditions: in France, wind energy is at its maximum in the winter months, whereas solar energy production is at a maximum in summer *(graph 1)*. As a comparison, the profiles are similar in Greece and Germany.

Graph 1 – Monthly profiles of renewable energy production in France (average over several years)

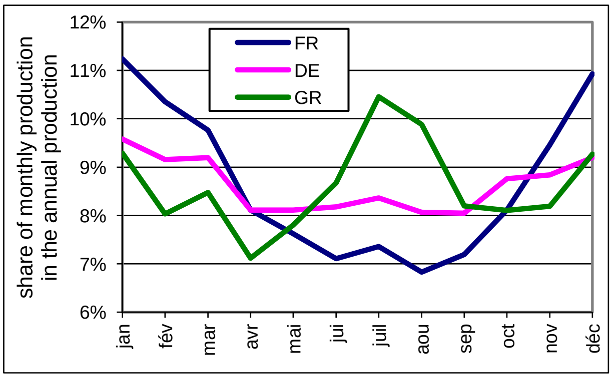


Source: data from ENTSO-E; calculations CGDD

SEASONAL DEMAND ALSO

Consumption in France peaks in winter. In Greece, it occurs in summer and Germany's profile is relatively flat *(graph 2)*.

Graph 2 – Monthly demand profiles for electricity in France, Germany and Greece



Source: data from ENTSO-E (2010-2014); calculations CGDD

BUT DIFFERENT PERIODS

The variability in wind and solar energy combines with that of demand therefore:

• For low penetrations of renewables, the demand's variability keeps a key rule

Fluctuations in the production of intermittent renewable energy combine with significant fluctuations in demand; in the end, everything seems as if renewable energies produce a base-load, i.e. continuously, and fluctuations in demand are just offset. In France, this situation persists until renewable energy production reaches 30% of consumption (including 13% hydropower).

• For larger penetrations of intermittent renewables, the variability of renewable energy production becomes a key factor

Fluctuations in demand undergo daily, weekly and seasonal cycles. Fluctuations in solar energy production are daily and those relating to wind energy are over a long period. Analysis of these fluctuations in terms of their duration and size has been carried out using a mathematical tool called the "*Fourier transform*" *(framed)*.

WHICH STORAGE?

The use of various offer/demand balance management resources reduces the impact of renewable energy fluctuations. In addition to storage itself, these resources also include managing demand (shifting consumption) and the seasonality of nuclear energy production with an active management policy of maintenance shutdowns.

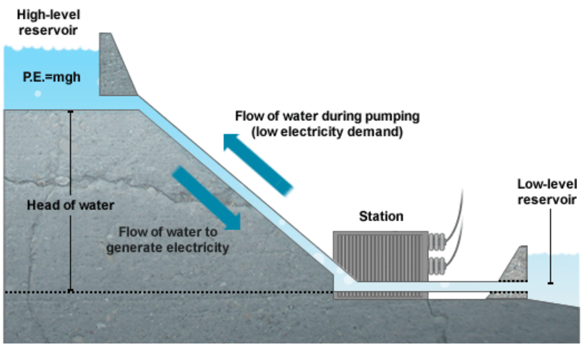
Hydropower storage is already well established

The PHS system (Pumped Hydropower Storage) is based on the following principle: during off-peak period, power is used to pump water from a low-level reservoir; during peak demand, the same water is released to produce electricity (diagram); the energy yield is 80%.

The potential of PHS varies depending on its size: when reservoirs only store water for a few hours of full power, the cycle is daily (the installed capacity in France is 2 GW); a storage capacity of a few dozen hours means a weekly cycle (2 GW installed capacity) (cf. table 2).

Cumulatively, the annual storage volume is 7TWh, i.e. approximately 1.5% of annual French consumption. The PPE is planning to "commit from now up to 2023 (…) to the development of 1 to 2 GW of PHS by 2030."

Operational diagram for a Pumped Hydropower Storage (PHS) system

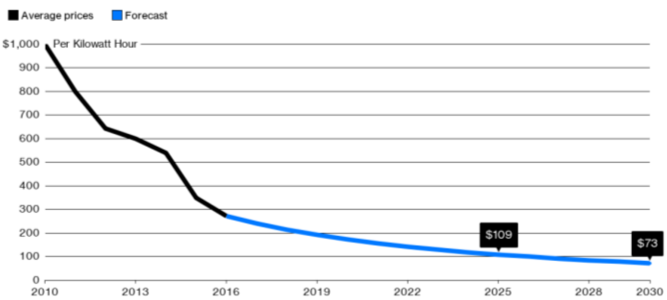


Source: http://sipsavorlodi.com

Batteries, a rapidly developing technology

The electricity storage sector has been greatly impacted by the reduction in the cost of batteries, which means, in the near future, that storage in small units for the requirements of each building over a period of several hours can be envisaged. The price of lithium batteries has reduced by a factor of two over three years; a price of €100/kWh could be reached in 2020 according to Tesla, a pioneer in electric vehicles, or 2025, according to other sources *(graph 4)*.

Graph 4 – Price of lithium batteries



Source: Bloomberg New Energy, July 2017

The service life of batteries is 2 to 5 thousand cycles. Battery-storage is well-suited for managing daily solar energy cycles The cost of storage is therefore €30 to €60/MWh, with a battery cost of 100 €/kWh and for an energy yield of approximately 80%. Beyond a storage period of 24 hours, the cost is no longer limited by the number of authorised cycles and becomes proportional to the storage period.

Power-to-gas in some situations

The power-to-gas process consists of four stages:
1 - Electrolysis of water with electricity (renewable), which produces hydrogen H_2;

2 - Reaction between this H_2 and the CO_2 to form methane CH_4;

3 - Long-term storage of this methane;

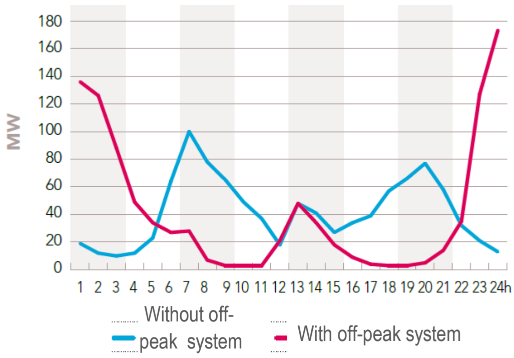
4 - Use of methane in combined gas cycles to produce electricity.

The power-to-gas process enables long-term storage (phase 3) but its energy yield is low due to losses during phases 2 and 4 of the processing. It may be used in processes that are difficult to decarbonize, in a context of inexpensive solar energy. The power-to-gas obtained in the third stage presents a better yield and provides energy in the form of methane.

Managing demand

Twelve million households have a grid interactive heaters hot water storage tank in order to benefit from advantageous pricing at off-peak hours *(graph 3);* this is a kind of a short-term storage solution.

Graph 3 - Daily electric consumption of electric hot water storage tanks depending on whether or not they are grid interactive



Source: RTE provisional forecasts 2015
Reading: A comparison of electrical consumption between households with a hot water tank running during off-peak hours (in red) with those without this scheme (in blue) shows that consumption is offset by approximately eight hours and prevents the peak hour in the evening and morning.

Other demand management systems are available, like Power-to-heat: Germany is going to use its excess wind energy to produce heat using Joule effect in urban heating networks.

COST CONVERGENCE FOR SHORT-TERM STORAGE

The costs of the various storage techniques should converge by 2025 *(table 1)*. The costs of storing domestic hot water will remain competitive, which makes this system essential given its importance in the offer/demand balance management system. For the “new PHSs” set out by the PPE’s framework, preliminary studies up to 2030 are showing a range of costs comparable to other processes.

Table 1 – Investment costs for storage systems and their total annual capacities in France

Storage system	Cost in €/MWh exc. tax	Annual volume in TWh
Grid interactive water heaters	< 24	22
Existing PHS	np	7
Batteries (up to 2030)	30 to 60	2.6 TWh*
New PHS (to 2030 - PPE)	20 to 60	2 to 4

*Hypothesis of 300,000 electric vehicle batteries used in “second life” in 2030 (24 kWh capacity, daily use).
Source: author’s calculations from RTE and PPE data

A CONTRASTING SITUATION DEPENDING ON CLIMATE SCENARIOS

Storage of electricity becomes more difficult and costly the longer it is stored. The renewables mix must be chosen in accordance with the seasonality of consumption so that it is possible to alter, over the long-term: insulation of buildings, meaning less consumption in winter and air conditioning may prevent excess production of solar energy in summer.

Secondly, the storage system must be optimized in line with the demand fluctuation period of the renewable energies concerned *(cf. table 2)*.

Table 2 - Storage resources in accordance with their characteristic periods (from Fourier transforms) and their installed capacities in France

period / storage system & installed capacity	**<25 hours**	25h<T <200h	200h<T <1 000h	1000h<T <4 000h	6 months & +
Grid Interactive Water Heaters eq.3.2GW					
Batteries					
4 small PHS: 2GW					
2 Large PHS: 2GW					
Very Large PHS: 0 GW					
Power to gas					
Summer maintenance nuclear powerplant eq.9GW					

*Reading: **Orange**: hot water storage tanks draw on average 6.4 GW during off-peak hours: they have an action equivalent to an average storage/withdrawal capacity of 6.4/2 = 3.2 GW; maintenance shutdowns in summer of nuclear power stations enables a power 18 GW greater than the summer’s power to be supplied, which is equivalent to a storage/withdrawal capacity of 18/2 = 9 GW. **Brown**: resources dedicated to storage currently operational in France. **Green,** the ones that do not exist in France: batteries, very large PHSs and power-to-gas.*

In countries where peaks in electricity consumption are linked to air conditioning in summer (like in Greece), solar energy combined with storage in batteries may be the best solution. As all of these resources are available at small power levels, a reduction in the size of networks and the development of self-consumption can be envisaged.

Countries in which peaks in consumption occur in winter, like France, will prioritize wind energy. France also experiences fluctuations occurring over periods of several weeks during which the batteries are of little use and for which storage in large hydropower reservoirs (PSP which can store two to five weeks of wind production) will remain the most suitable solution. The number of sites that can host PSPs is nevertheless limited.

Moreover, large electrical networks will also remain essential.

The data originates from:

● for mainland France, the electrical network manager, RTE, which has an open data policy, in half hourly increments: https://opendata.rte-france.com/pages/accueil/

and on domestic hot water, a profile of RTE (2015 forecast): http://www.rte_france.com/sites/default/files/bp_2015_donnees_sur_la_demande.xlsx

● for other European countries, the association ENTSO-E which provides information at hourly intervals 2015: https://transparency.entsoe.eu/

Text box- SPECTRAL ANALYSIS OF ELECTRICAL SYSTEM FLUCTUATIONS

Method

Here are the key aspects of the method used:

● demand for electricity, as well as wind and solar energy production are analyzed as hourly time series;

● the Fourier transform breaks down time series into “spectrums” i.e., the frequency fluctuations that it consists of;

● every spectrum frequency may be linked to one or more optimum storage resources. The action of the storage resources reduces the spectrum value, within the range of the frequencies concerned and within the power limit of the stored capacity;

● by applying inverse Fourier transform, we get the demand as it would be modified by the tested storage options.

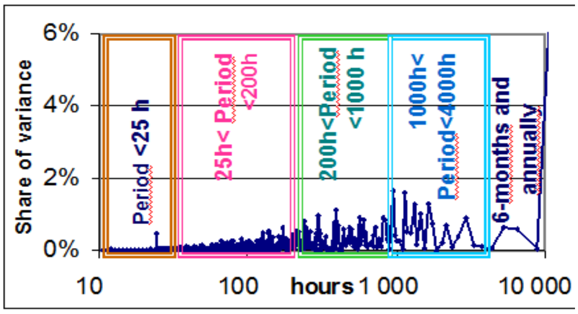
Spectral analysis shows that each storage system has a characteristic range *(table 2)*. From a spectral analysis grid interactive water heaters may be reduced to a combination of flat consumption and daily storage system.

Results of the models

Electricity consumption in France is characterized by daily fluctuations (over 24 hour and 12 hour periods), weekly fluctuations (periods of 168 hours and 84 hours) and seasonal fluctuations linked to electric heating. Fluctuations in solar energy are mainly on a daily basis.

The wind energy spectrum is very volatile and its fluctuations occur over long periods *(graph 5)*.

Graph 5 – Fluctuations in wind energy production



Source: data from RTE; analysis CGDD

The study presented is limited to systems that deal with fluctuations in demand or production of more than half an hour in the wholesale electricity market. It does not examine the developments in “system services” which enable short-term fluctuations to be managed (less than half an hour).

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Editor-in-chief: Laurence Demeulenaere
Written by: Jean-Marc Moulinier
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Commissariat général au développement durable

Service de l’économie, de l’évaluation et de l’intégration du développement durable
(Department of Economics, Evaluation and Integration of Sustainable Development)

Sous-direction de la Mobilité et de l’Aménagement (MA)
(Sub-directorate for Mobility and Development)

Tour Séquoia
92055 La Défense cedex - France

Email: ma.seei.cgdd@ecologique-solidaire.gouv.fr

www.ecologique-solidaire.gouv.fr