Data on photovoltaic and wind production relevant for scenarios of the French electric systems

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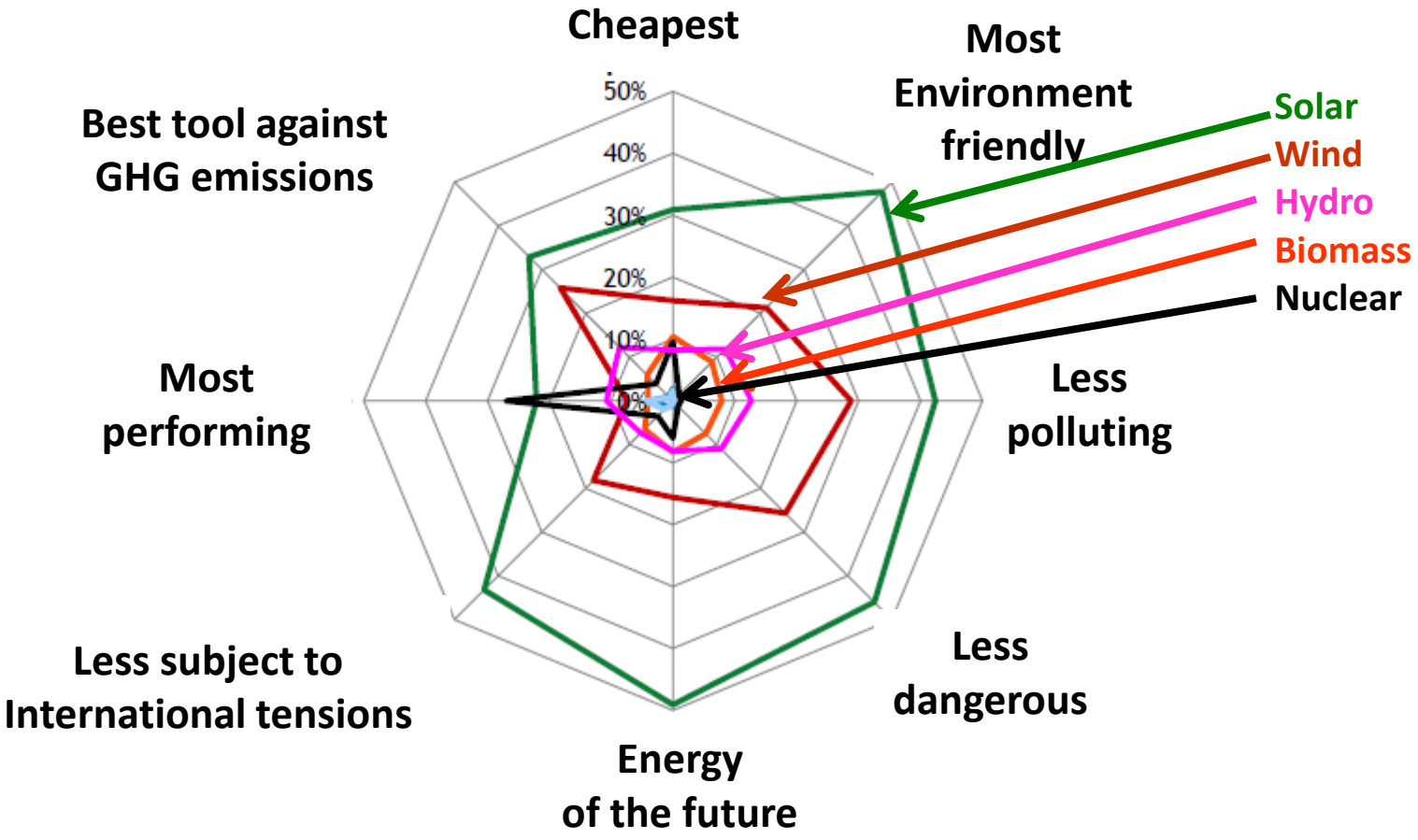
"The wind flapp'd loose, the wind was still,
Shaken out dead from tree and hill:
I had walk'd on at the wind's will,
I sat now, for the wind was still."

Dante Gabriel Rossetti
(the woodspurge)

A foundation pillar
of any energy scenario for a democracy :
what people think.

What do French people think of various means of electric production ?

Source : poll BVA 2011



Solar : the ideal energy ; Wind is second best. Intermittent renewable electricity is better considered than that which is not : Hydro et Biomass. Nuclear is bad in every respect.

Do you think that, within 10 years (by 2021) it will be possible to produce almost all the electricity that France needs solely by means of renewables ?

By Sex	Certainly Yes	Probably Yes	Total Yes	Probably No	Certainly No	No Opinion
Male	9 %	19 %	**28 %**	32 %	39 %	2 %
Female	9 %	28 %	**37 %**	38 %	20 %	5 %
Average	9 %	24 %	**33 %**	35 %	29 %	4 %

By Age	Certainly Yes	Probably Yes	Total Yes	Probably No	Certainly No	No Opinion
18 to 24	9 %	36 %	**45 %**	33 %	19 %	4 %
25 to 34	13 %	34 %	**47 %**	35 %	16 %	2 %
35 to 49	12 %	21 %	**34 %**	37 %	28 %	2 %
53 to 64	6 %	20 %	**26 %**	36 %	35 %	6 %
> 65	6 %	18 %	**23 %**	32 %	37%	7 %

According to the complete analysis which includes also "by political inclinations",
The most fervent supporter of electric renewables is a "young woman voting left"
The less opposed-to-nuclear-energy citizen is an "old man voting right ".

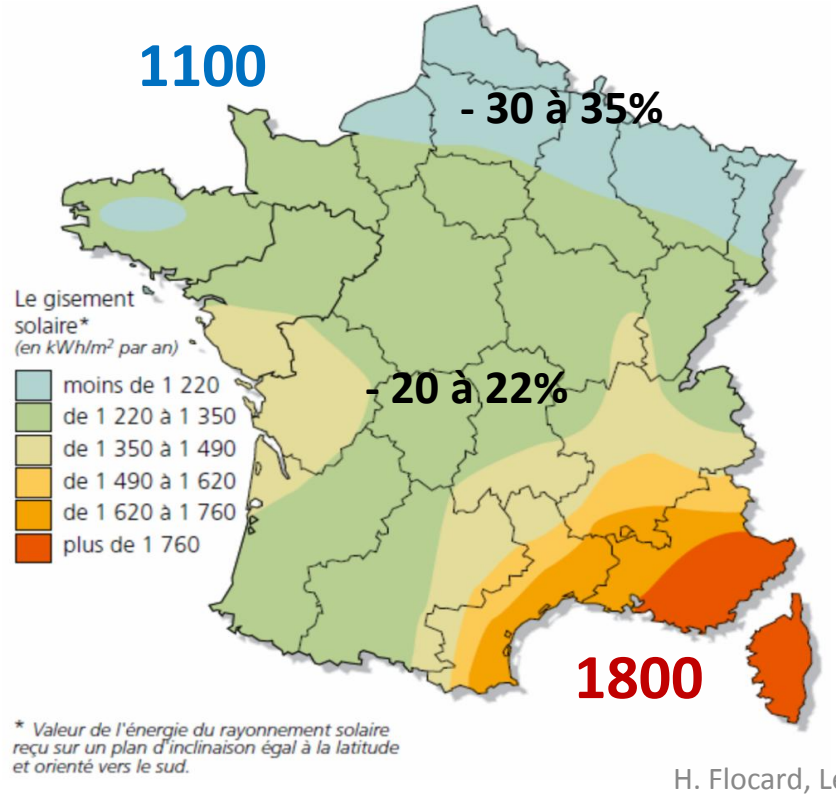
Source analysis 2011 by Daniel Boy sociologist Cevipof Sciences-Po

Continental France
Solar & Wind
Production & Implantation

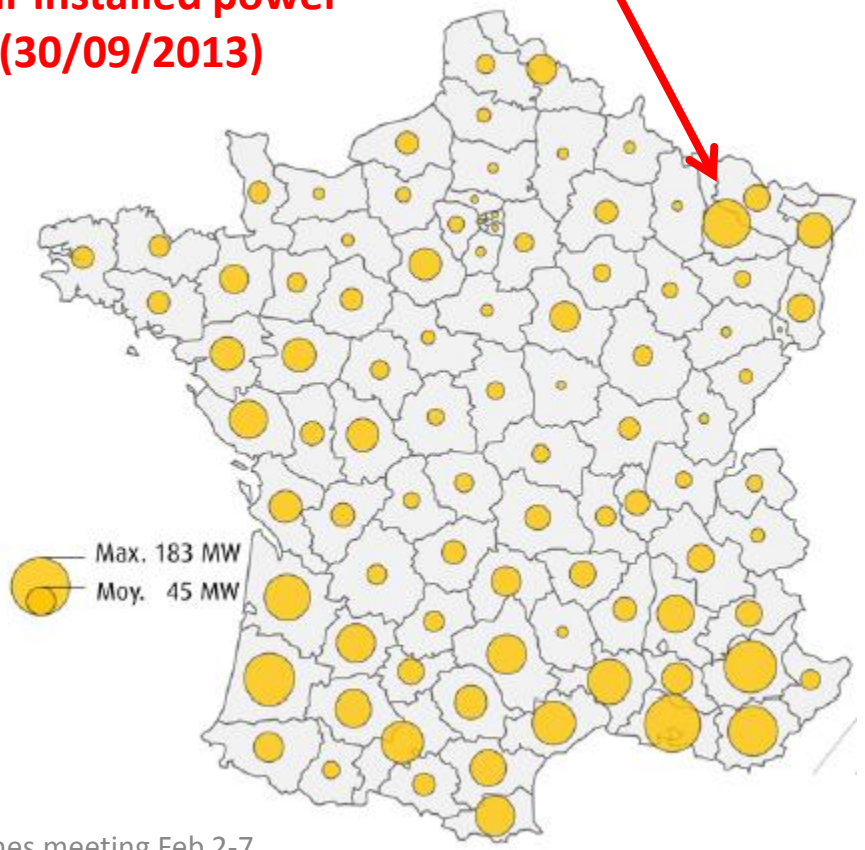
Continental France , Global solar data

- The installed power amounts to 4,3 GW (total France ~4,8 GW)
- Growth is strong but slowing down (2013 , 740 MW; 2012 990 MW; 2011 1690 MW)
- The present planned government goal for 2020 (5,4 GW) will certainly be reached.
- The volume regional implantation is coherent with the solar potential
- No visible NIMBY effect yet. Opportunity effects are observable (Lorraine, Landes)

Solar Potential
(unit kWh/m2/y)**



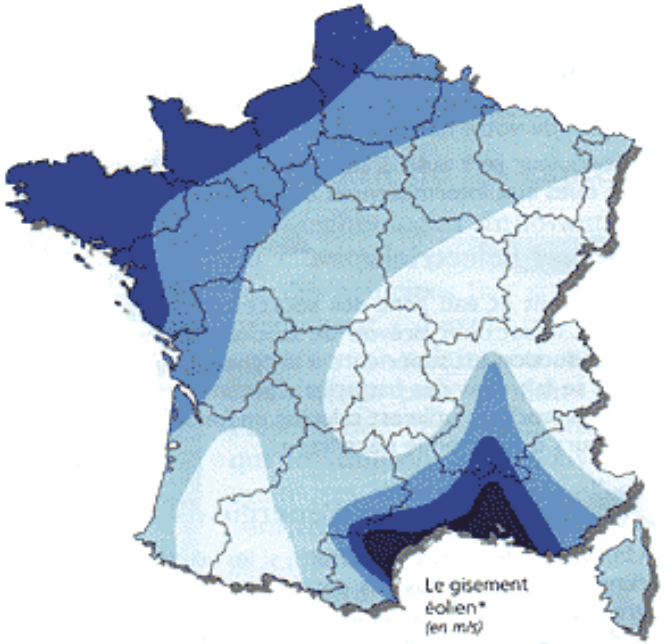
Solar installed power
(30/09/2013)



Continental France , Global wind data

- The installed power amounts to 8,1 GW (total France ~8,2 GW). Only onshore till 2017-18
- Growth is slowing down (2013 , 630 MW; 2012 821 MW; 2011 928 MW; 2010, 1200 MW)
- The present planned government goal for 2020 (19 +6 GW) will probably not be reached.
- The volume regional implantation is not coherent with the wind potential
- Very strong NIMBY effect . Opportunity effects dominate implantation.

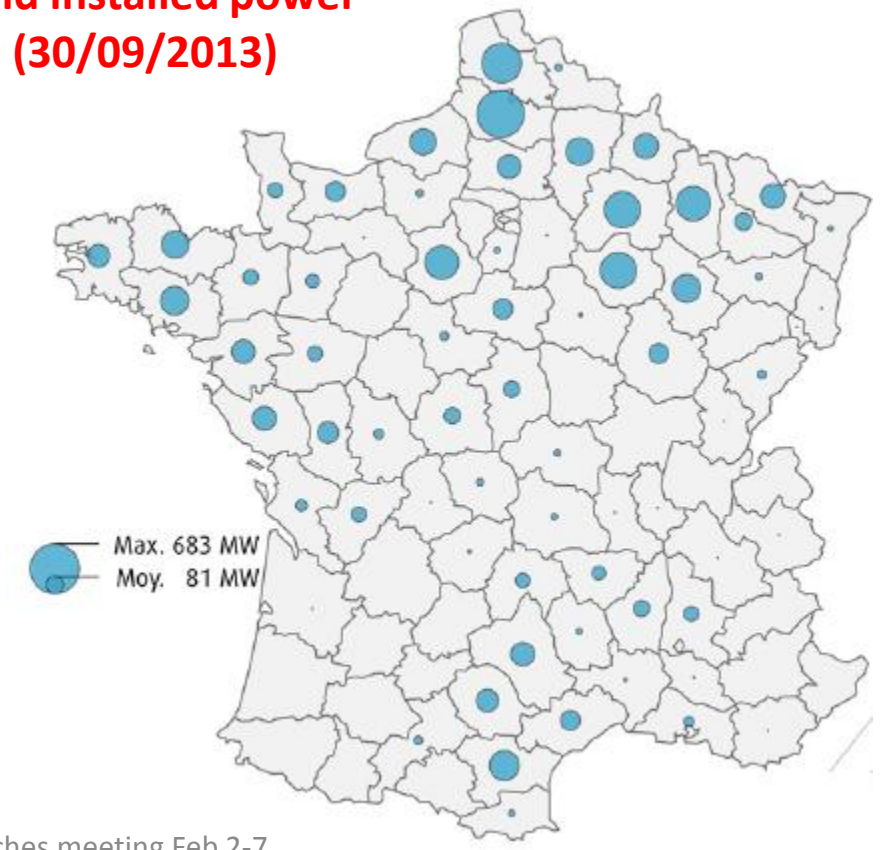
Wind potential (speed m/s)



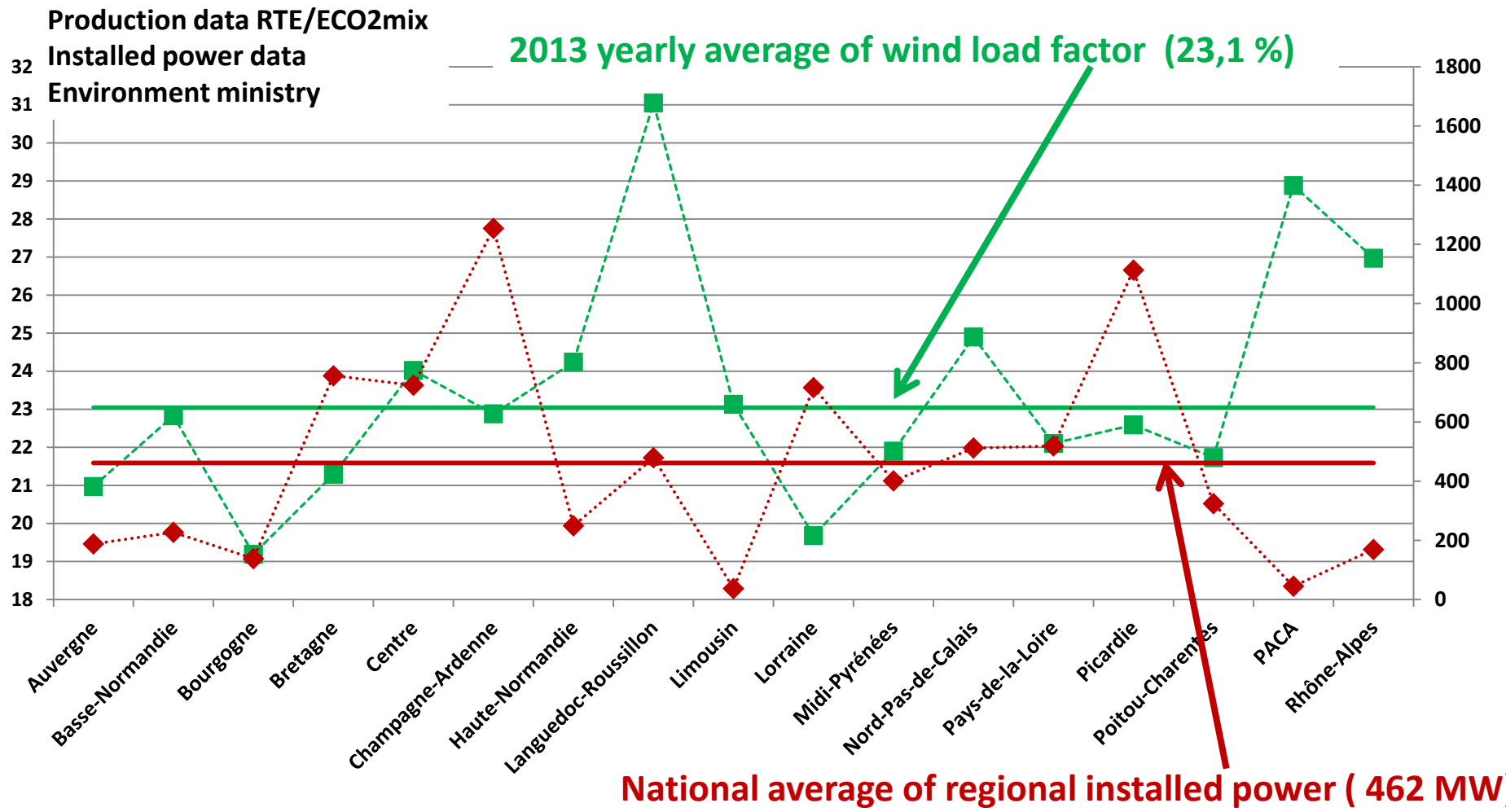
Bocage dense, bois, banlieue	Rase campagne, obstacles épars	Prairies plates, quelques buissons	Lacs, mer	Crêtes**, collines	
<3,5	<4,5	<5,0	<5,5	<7,0	Zone 1
3,5 - 4,5	4,5 - 5,5	5,0 - 6,0	5,5 - 7,0	7,0 - 8,5	Zone 2
4,5 - 5,0	5,5 - 6,5	6,0 - 7,0	7,0 - 8,0	8,5 - 10,0	Zone 3
5,0 - 6,0	6,5 - 7,5	7,0 - 8,5	8,0 - 9,0	10,0 - 11,5	Zone 4
>6,0	>7,5	>8,5	>9,0	>11,5	Zone 5

* Vitesse du vent à 50 mètres au-dessus du sol en fonction de la topographie
** Les zones montagneuses nécessitent une étude de gisement spécifique

Wind installed power (30/09/2013)



What determines French wind policy ?



From the 6 most-equipped-with-wind-turbines regions, only one (region Centre) displays a wind load factor above the national average (17 regions with wind power).

In France, wind is not always the motivation for setting up a wind turbine

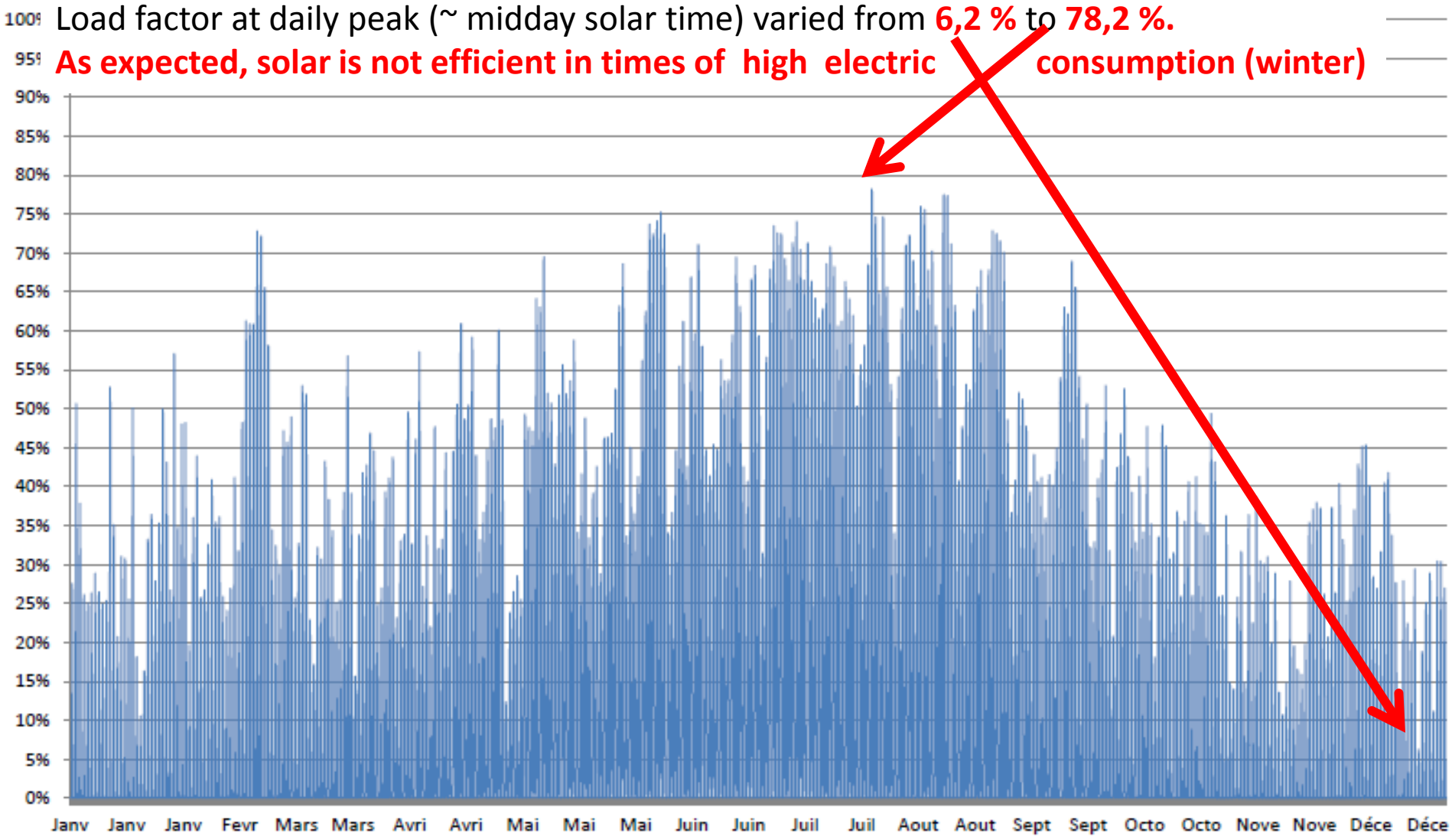
Solar, Continental France – the year 2013

Yearly average load factor **13,2 %.**

Daily average load factor varied from 1,4 % to 27,4 %.

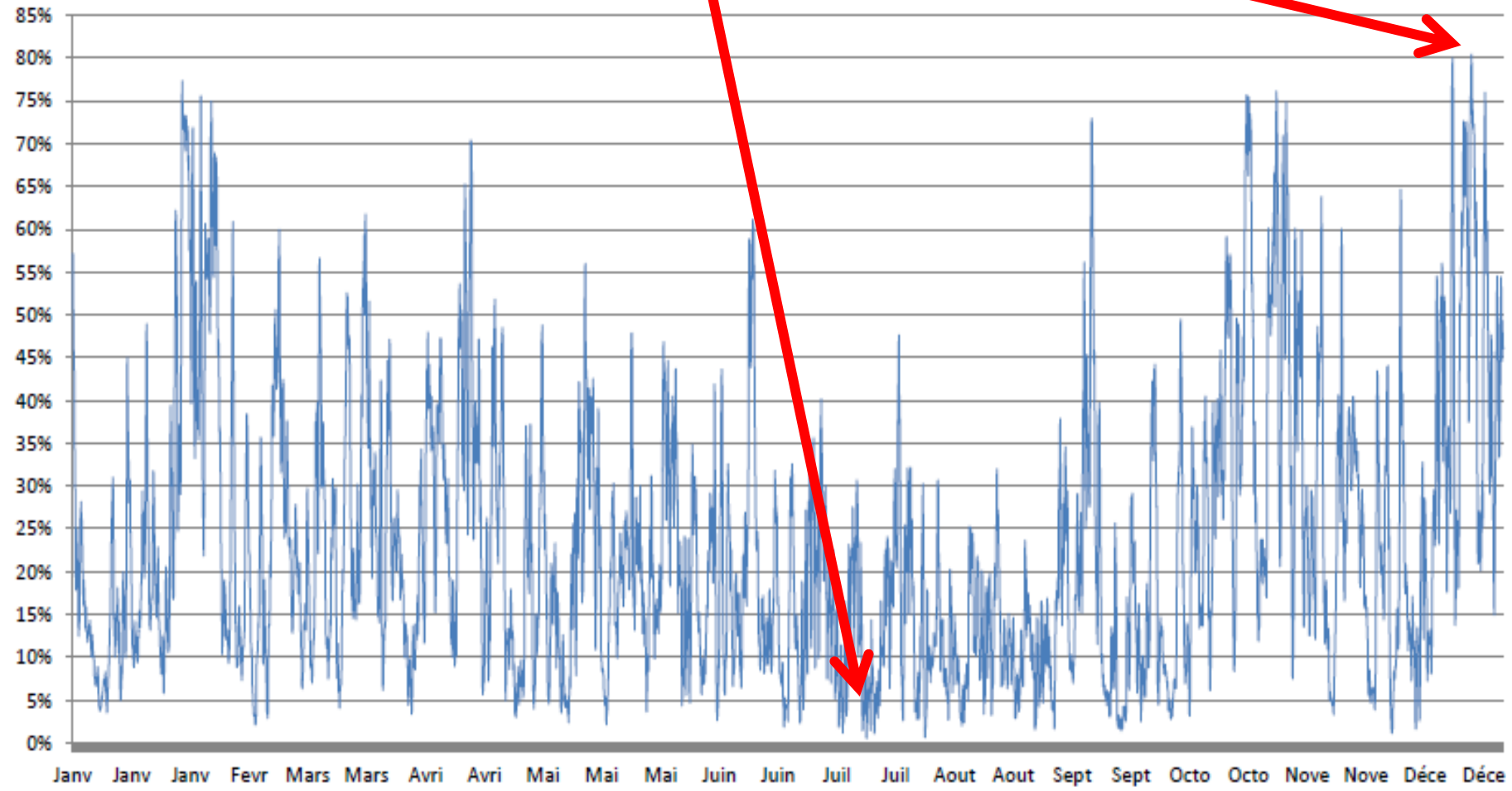
Load factor at daily peak (~ midday solar time) varied from **6,2 %** to **78,2 %.**

As expected, solar is not efficient in times of high electric consumption (winter)



Wind Continental France – the year 2013

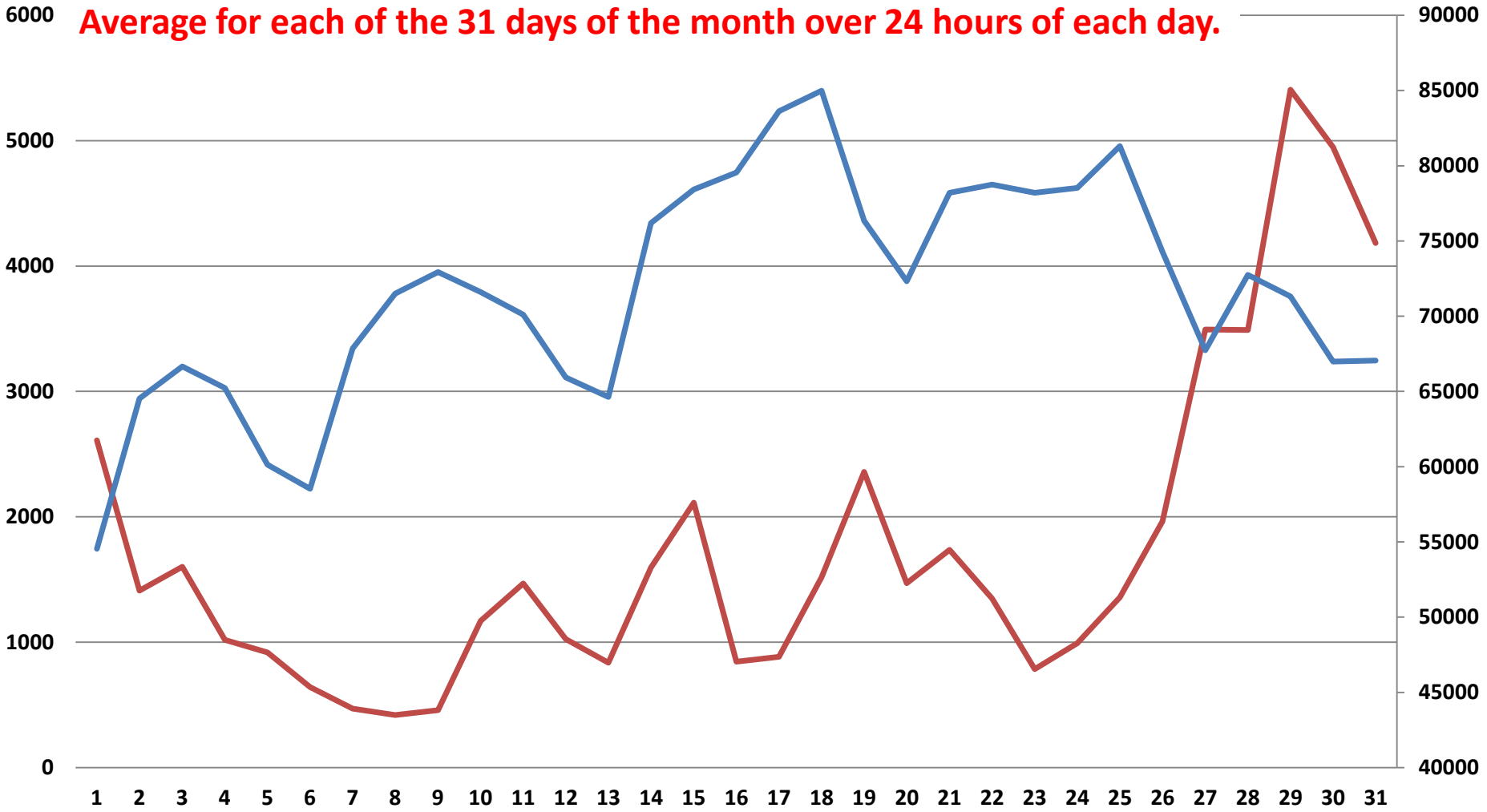
Yearly average load factor **23,1 %** (2012, 24 %; 2011, 22 %).
Daily average load factor varied from 2,2 % to 72,1 %.
Daily maximum load factor varied from 3,5 % to **80,4 %.**
Daily minimum load factor varied from **0,5 %** à 69,1 %.



Wind & Solar
Consumption vs production coherence

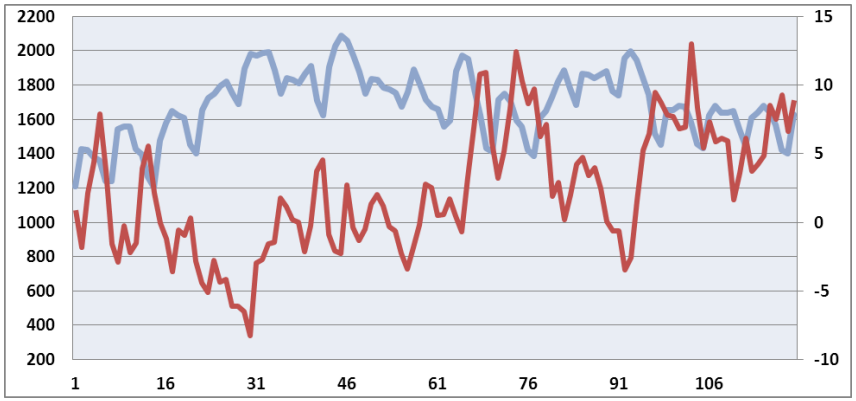
Continental France wind production
In periods of strong consumption (January 2013)

Daily averaged wind power (MW); left scale red curve.
Daily averaged power consumption (MW); right scale blue curve.

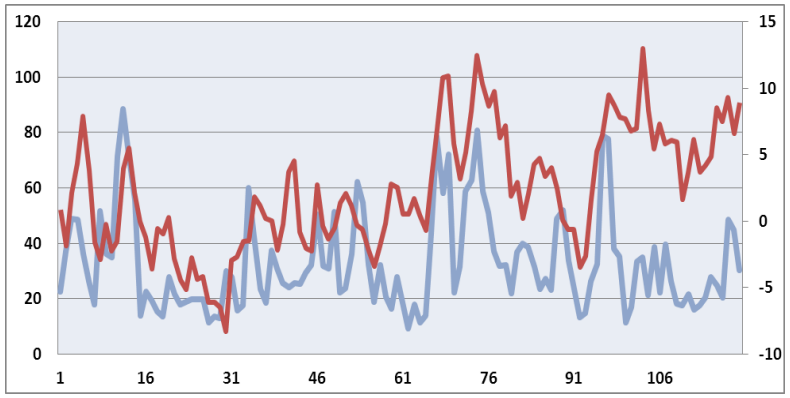


Wind power vs electric consumption
Continental France 01/11/2010 to 28/02/2011

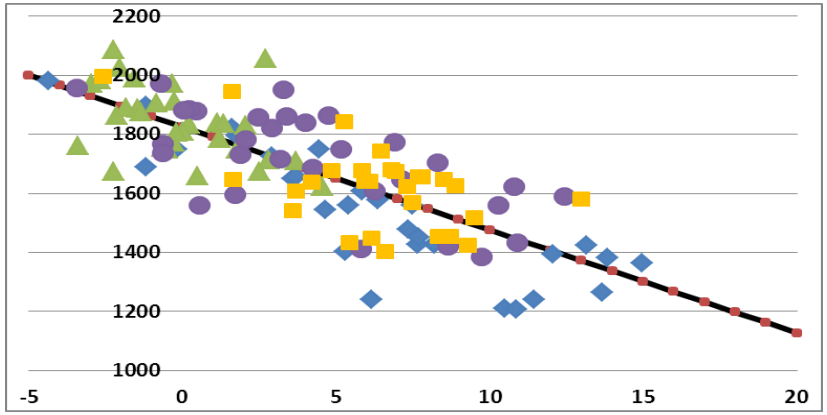
Temperature : brown curve right scale °C.



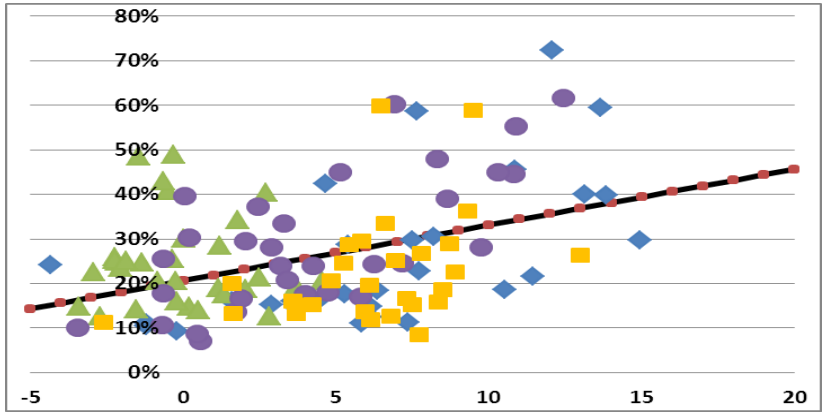
Daily electric energy consumption : Blue curve left scale GWh.



Daily wind energy production: Blue curve, left scale GWh.



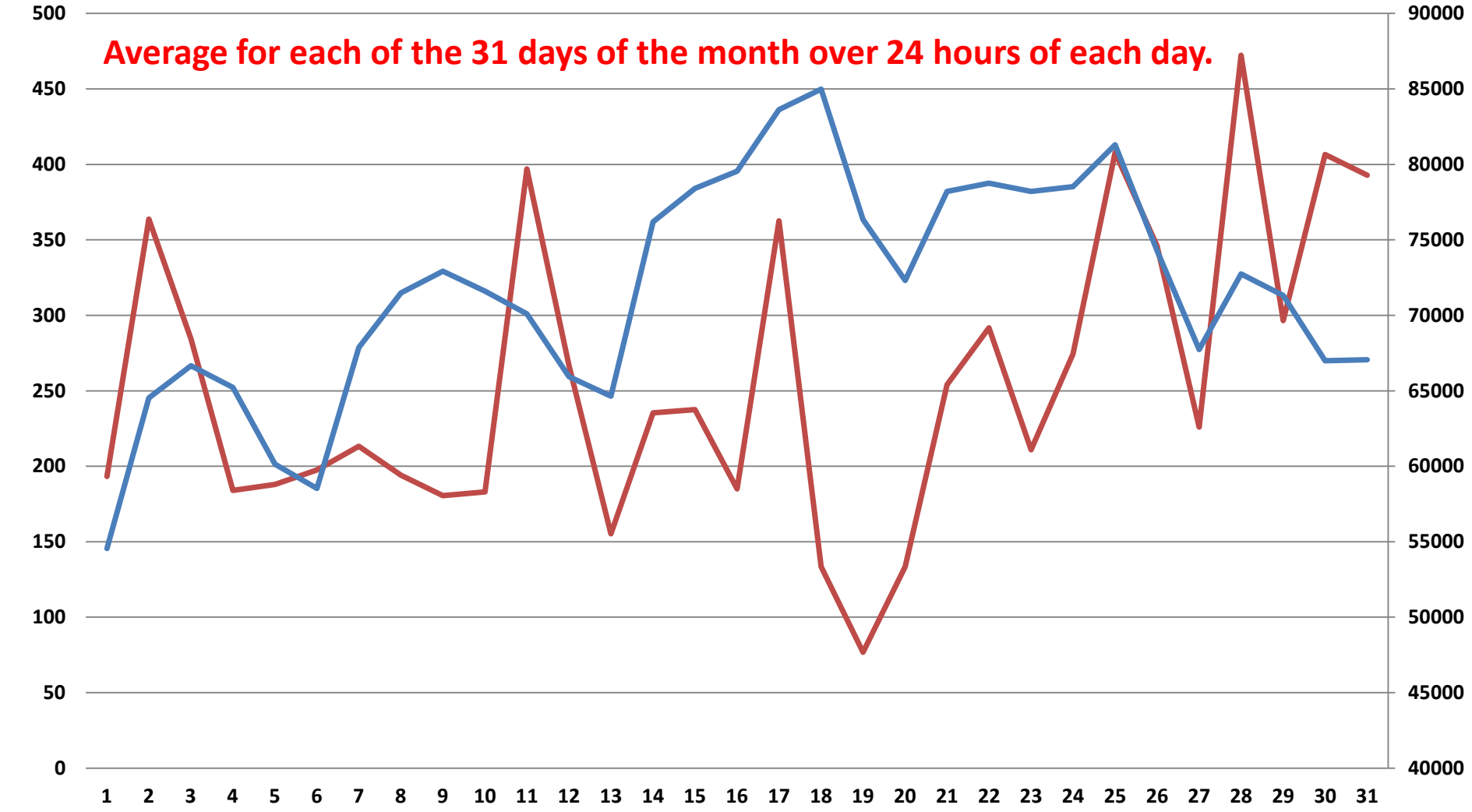
Correlation consumption (ordinate GWh) temperature (abscissa °C).



Correlation wind production (ordinate GWh) temperature (abscissa °C).

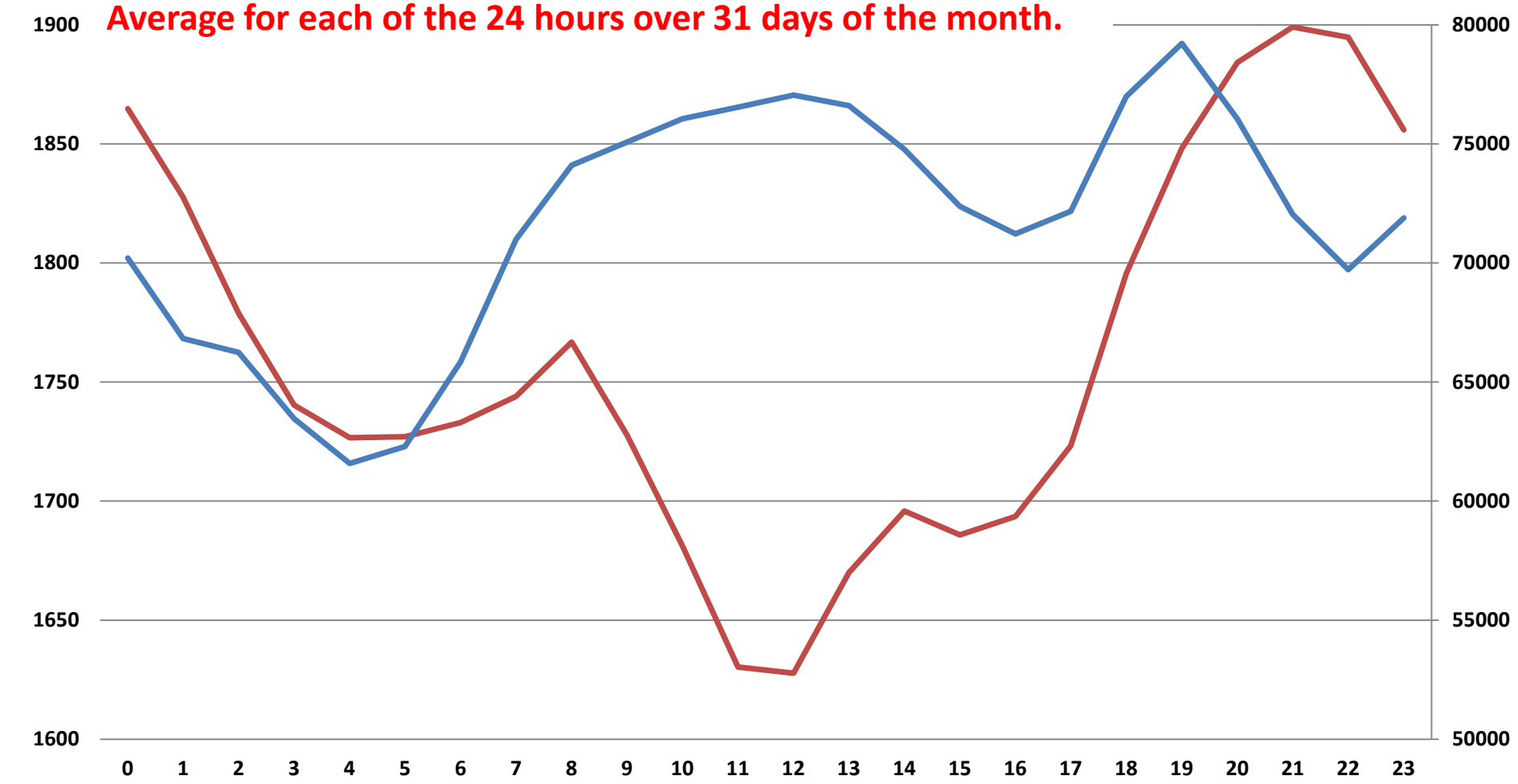
Continental France solar production
In periods of strong consumption (January 2013)

Daily averaged solar power (MW); left scale red curve.
Daily averaged power consumption (MW); right scale blue curve.



Continental France wind production
In periods of strong consumption (January 2013)

Delivered wind power per hour (MW); left scale red curve.
Power consumption per hour (MW); right scale blue curve.



Continental France solar production
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Delivered solar power per hour (MW); left scale red curve.
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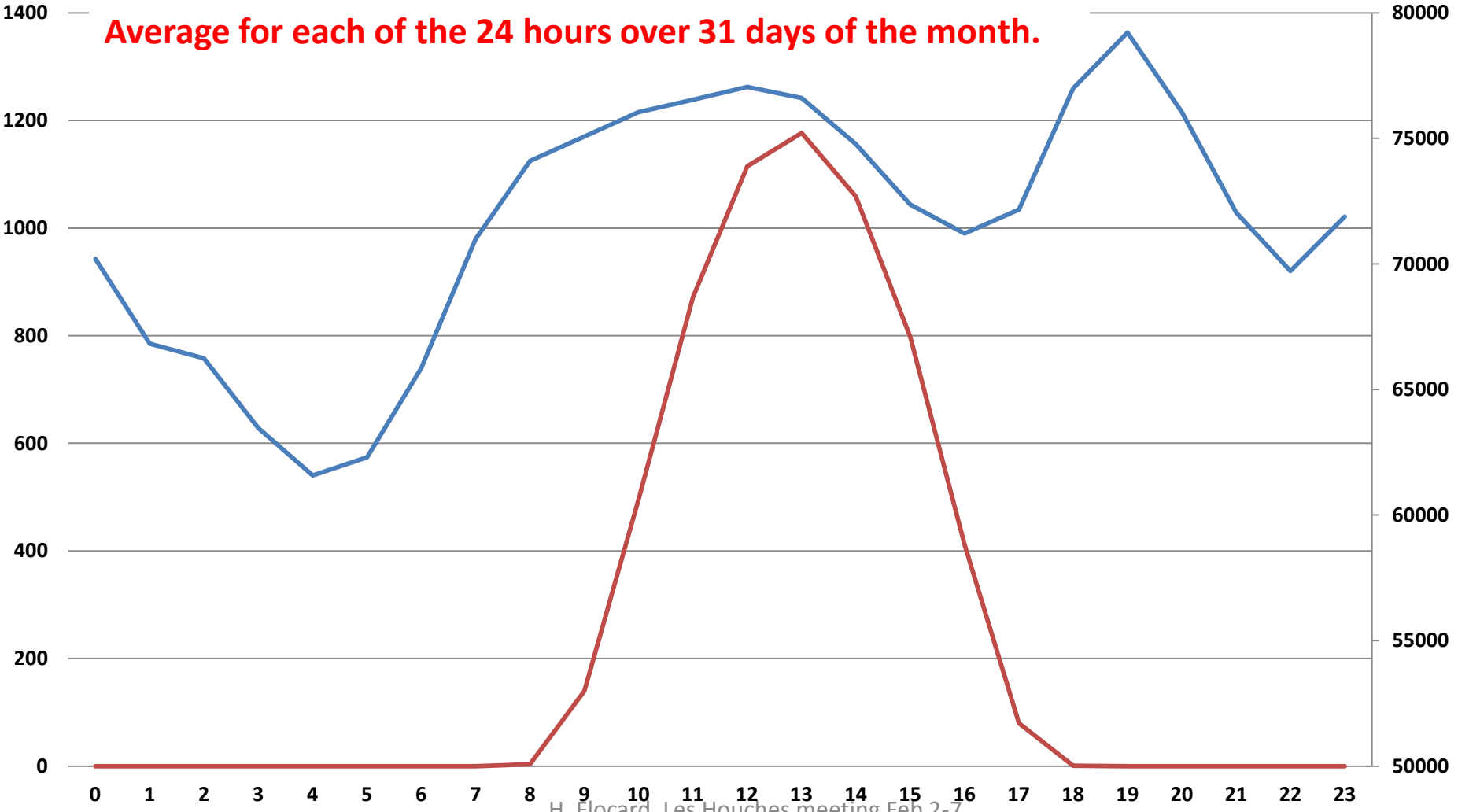


How much CO_2 emission reduction can be expected from the realization of the wind deployment French plan (Grenelle de l'environnement) 25 GW (19+6) by 2020

In all French official documents related to energy, important CO_2 emission reductions is put forward as the main goal to be attained generally followed by

- **energy independence,**
- **lowest possible energy cost for the consumer**
- **green job creation and**
- **increased proportion of renewables in the final energy mix (23 %)**

in various orders.

French CO_2 emissions

French CO_2 emissions are indeed important 350 Mt in 2011
The electricity production sector accounts only for ~8 % (27 Mt)

If the CO_2 emission problem is an important one, it is not clear why as stated by the National French Accounting Court (Cour des Comptes) most public spending should be devoted to electric renewable rather than thermal renewable

It is doubtful that electric renewables will do much on the following three subjects (independence, job creation, low cost of energy)

As a matter of fact even on the question of electric renewables the French situation turns out not so bad

Year 2013	Hydro (TWh)	Wind (TWh)	Solar (TWh)	Total (TWh)	Consumption* (TWh)	%
France	75,7	15,9	4,6	96,2	476	20,2
Germany	15,4	47,2	29,7	92,3	560	16,4

Testing the ecological potential of the wind "Grenelle" plan

Calculation based on data acquired in 2010-2011

Continental France installed wind power then : 5 GW

1) Twenty "France countries"

- living under the same climate (T and wind) and with same electric consumption
- with a wind fleet with 1, 2, 3 up to 20 more GW of wind power

2) Hypotheses

- Wind production grows at any time in proportion of installed power
- The present priority of injection of wind power into the grid is kept
- The priority is given to using additional production for CO_2 emission reduction
- Among other renewable energies only hydro can be used for balancing
- The import-export trade dominated by export can't participate to adjustment

3) First consequences

- Only dispatchable productions contribute to balancing the equation

  Consumption (t)= Production (t)

- Since CO_2 emission reduction is a priority, wind energy production is used to stop first "Coal', then "Gas" then "Oil" fired power plants

Testing the ecological potential of the wind "Grenelle" plan

Additional hypotheses systematically favorable to CO_2 emission reduction by wind

1) The grid accepts instantaneously all requested electricity transfers
2) The two grid managers involved (RTE and ErDF) coordinate instantaneously their actions
3) There is no energy losses associated to transport
4) Thermal plants ("fossil fuel" and nuclear) adjust instantaneously their productions to what is required by wind production
5) All hydro corresponds to reservoir dams and can keep in storage whichever amount of energy one wants to save
6) When "hydro" is used also to ensure balancing and replacing fossil fuel plant productions, necessary turbine power is always available
7) Pumping stations are put to the exclusive service of helping wind production in its task of CO_2 emission reduction

Testing the ecological potential of the wind "Grenelle" plan

A calculation performed in three steps

Step 1 "Instantaneous" replacement of fossil fuel production by wind production

Any available new wind power at time t is used to stop whatever "coal" then "oil" produced electricity produced at the same time

Step 2 "hydraulic"

When after step 1, there still remains some "unused "wind power

1) One stops immediately any flow of water from the reservoirs
2) This "saved-through wind" water , is used later to stop any "coal" , "gas" and 'oil" power which is not saved at step 1

Step 3 "pumping stations"

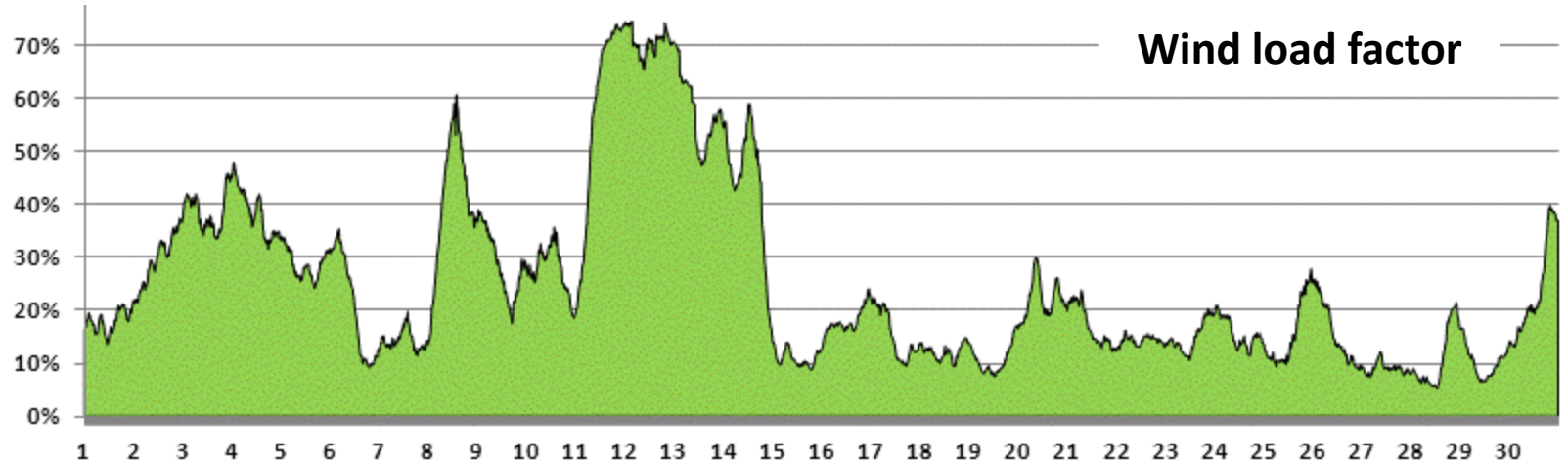
When after step 2, there still remains some "unused" wind power

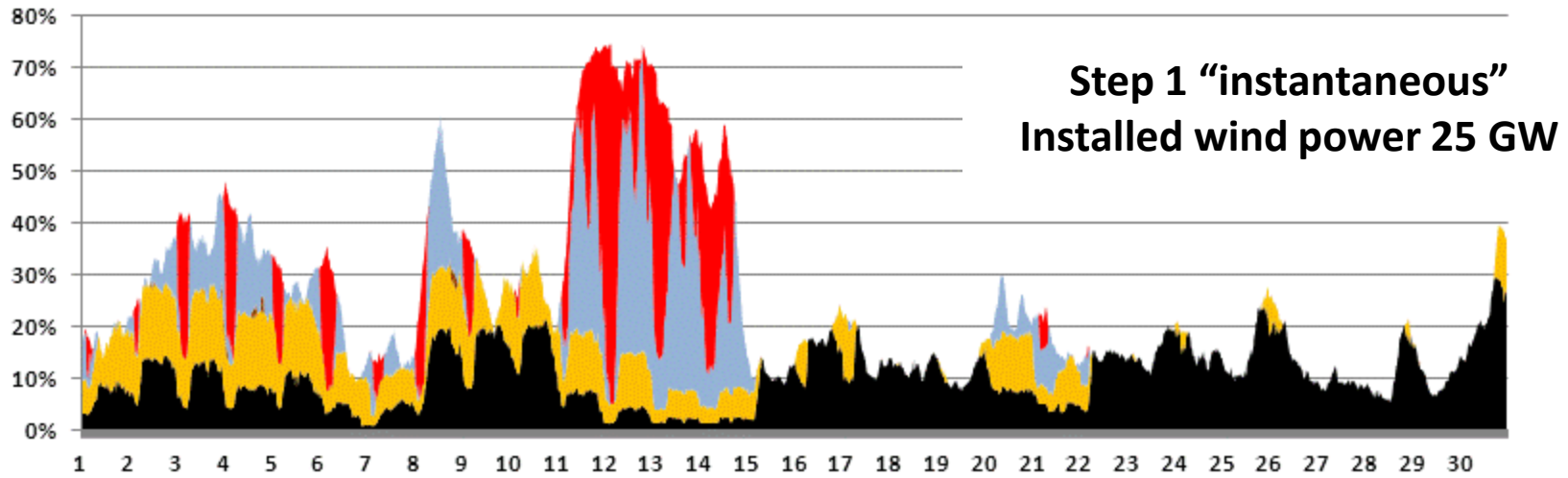
1) One uses it to pump water in French pumping stations (~5 GW and ~100 GWh capacity
2) This "pumped-through wind" water , is used later to stop any "coal" , "gas" and "oil" power which is not saved at steps 1 and 2

After Step 3, if there still remains some "unused" wind power,
one has to stop nuclear power plants
which does not lead to CO_2 emission reduction

Testing the ecological potential of the wind "Grenelle" plan

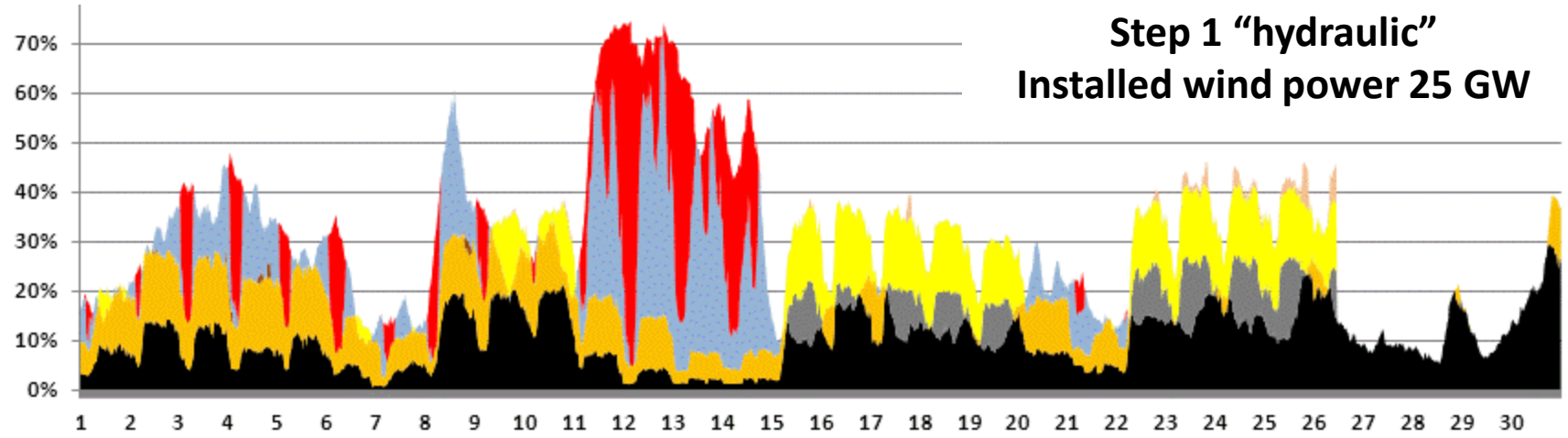
Illustration of steps 1 to 3 for the data of November 2010

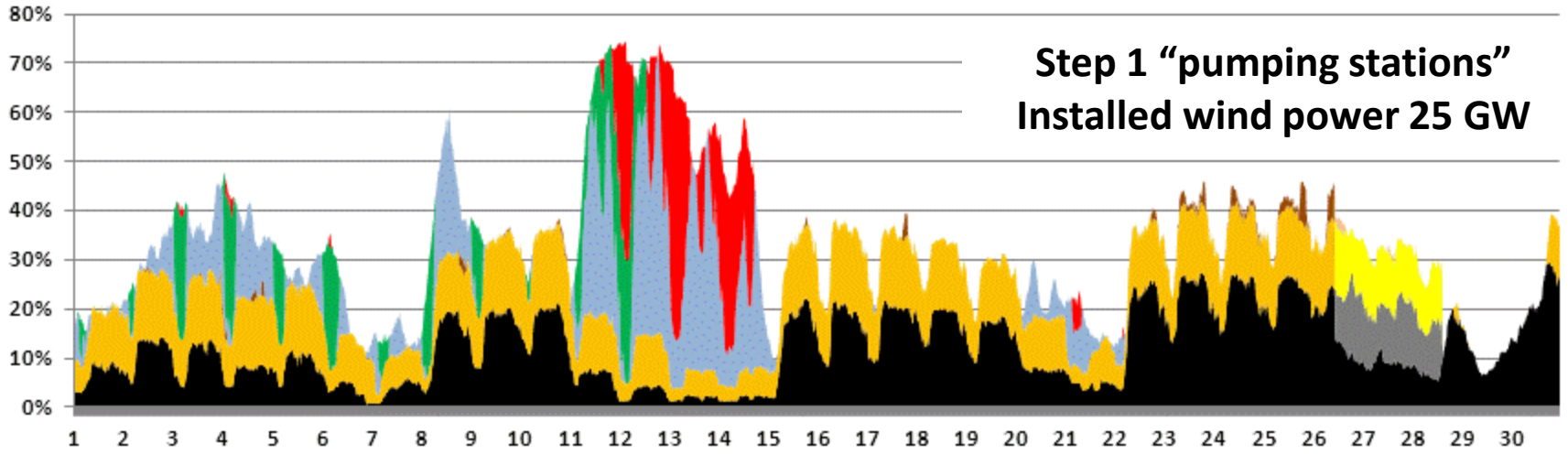




Testing the ecological potential of the wind "Grenelle" plan

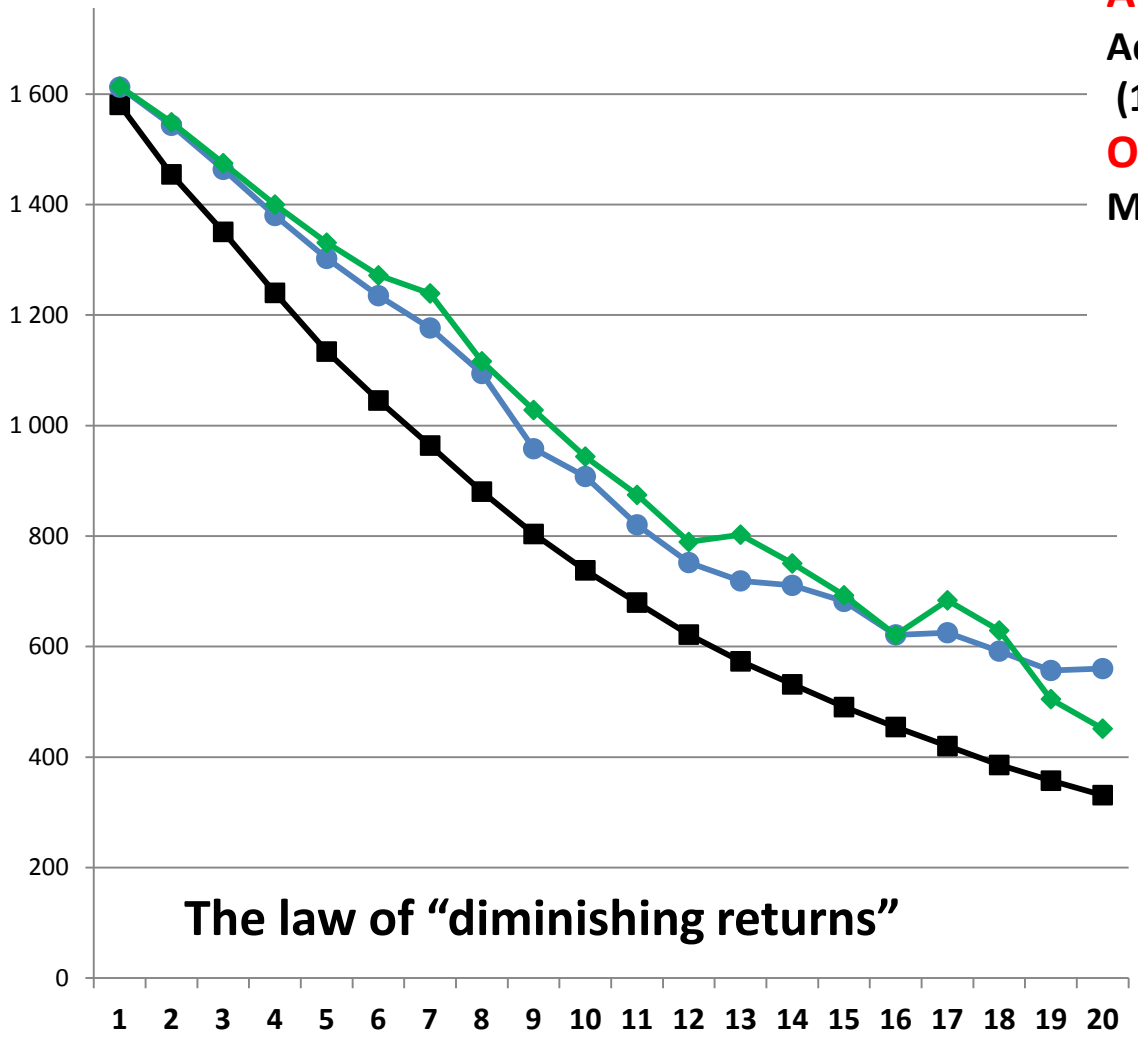
Illustration of steps 1 to 3 for the data of November 2010





Testing the ecological potential of the wind "Grenelle" plan

Maximal reduction of CO_2 emissions per additional wind power GW



Abscissa :

Additional wind power GW
(1 GW to 20 GW)

Ordinate:

Mass (kt) of "electric CO_2" avoided

Step 1 "Instantaneous" (black)

Step 1+2 'Hydraulic" (blue)

Step 1+2+3 "pumping stations" (green)

Integrated gain with 25 GW

16Mt (1=Instantaneous)

19Mt (1+2=hydraulic)

20 Mt (1+2+3=pump. Stat.)

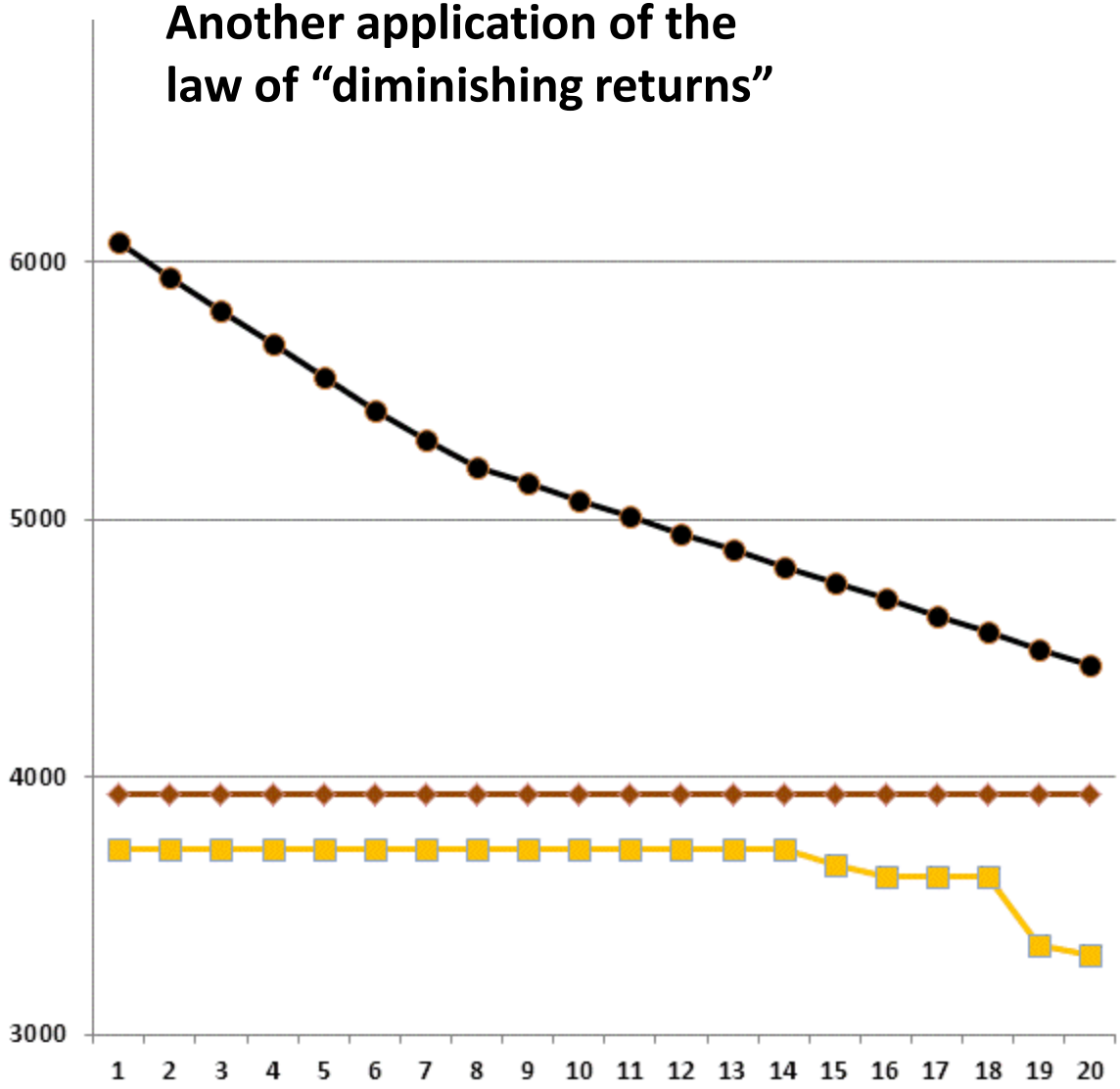
A limited positive impact.

The CO_2 emission reduction can't exceed 4-5% of French emissions while French government states " factor 4" (75%) as its goal.

Testing the ecological potential of the wind "Grenelle" plan

Maximal "fossil fired" power avoided per additional wind GW

Another application of the law of "diminishing returns"



Abscissa :

Additional wind power GW (1 GW to 20 GW)

Ordinate:

Power (PW) which it is still necessary to keep

- **"Coal fired power plant" (black)**
- **"Gas fired power plant" (yellow)**
- **"Oil fired power plant" (brown)**

The first additional wind GW allows pulling out 130 MW of coal fired power.

The twentieth additional GW allows pulling out 110 MW of coal and gas fired power

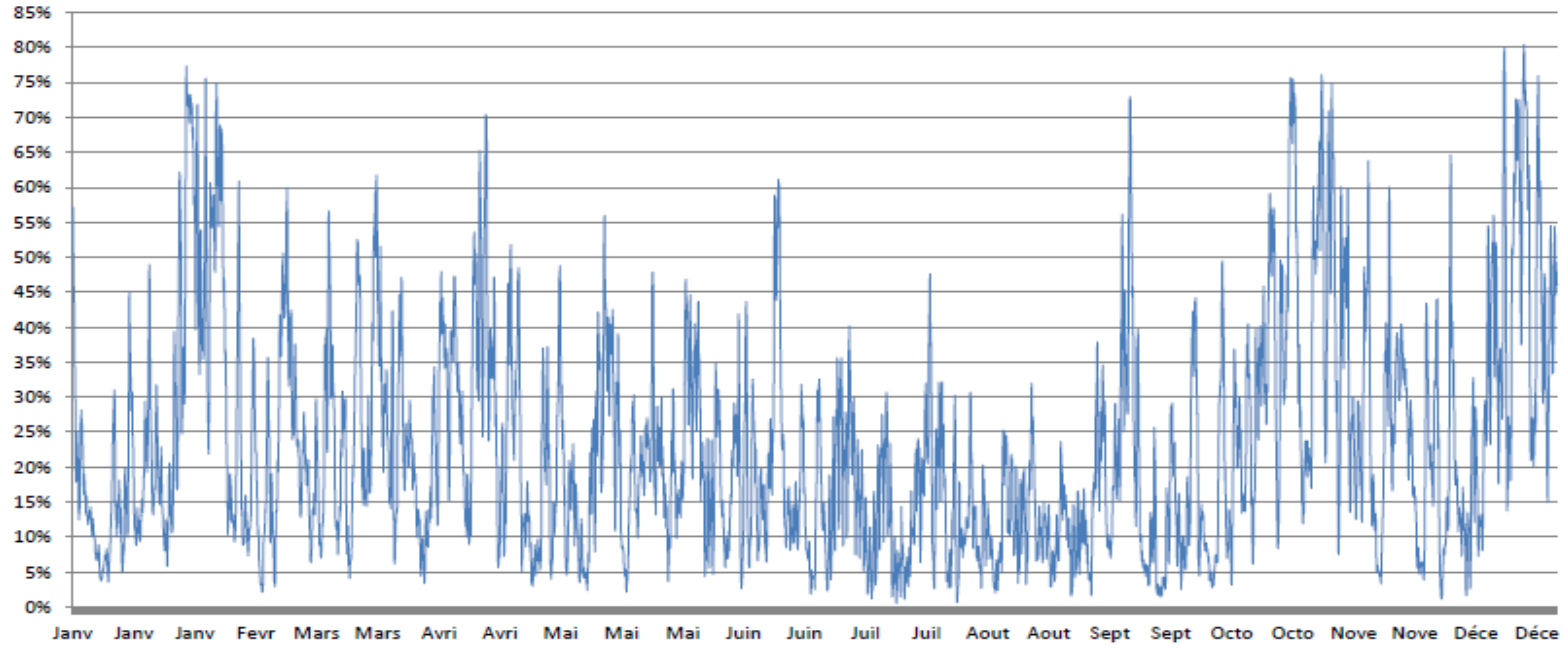
European wind energy production smoothing via increased trans border transfer capacity

The « Foisonnement »

In a French-English dictionary or in a French-French dictionary "foisonnement" corresponds to the word "proliferation" and only that.

But, presently, for some French major institutions such as the ADEME agency or the grid operator RTE , it means now: "Smoothing of the wind power time evolution generated by a geographical extension of the production area".

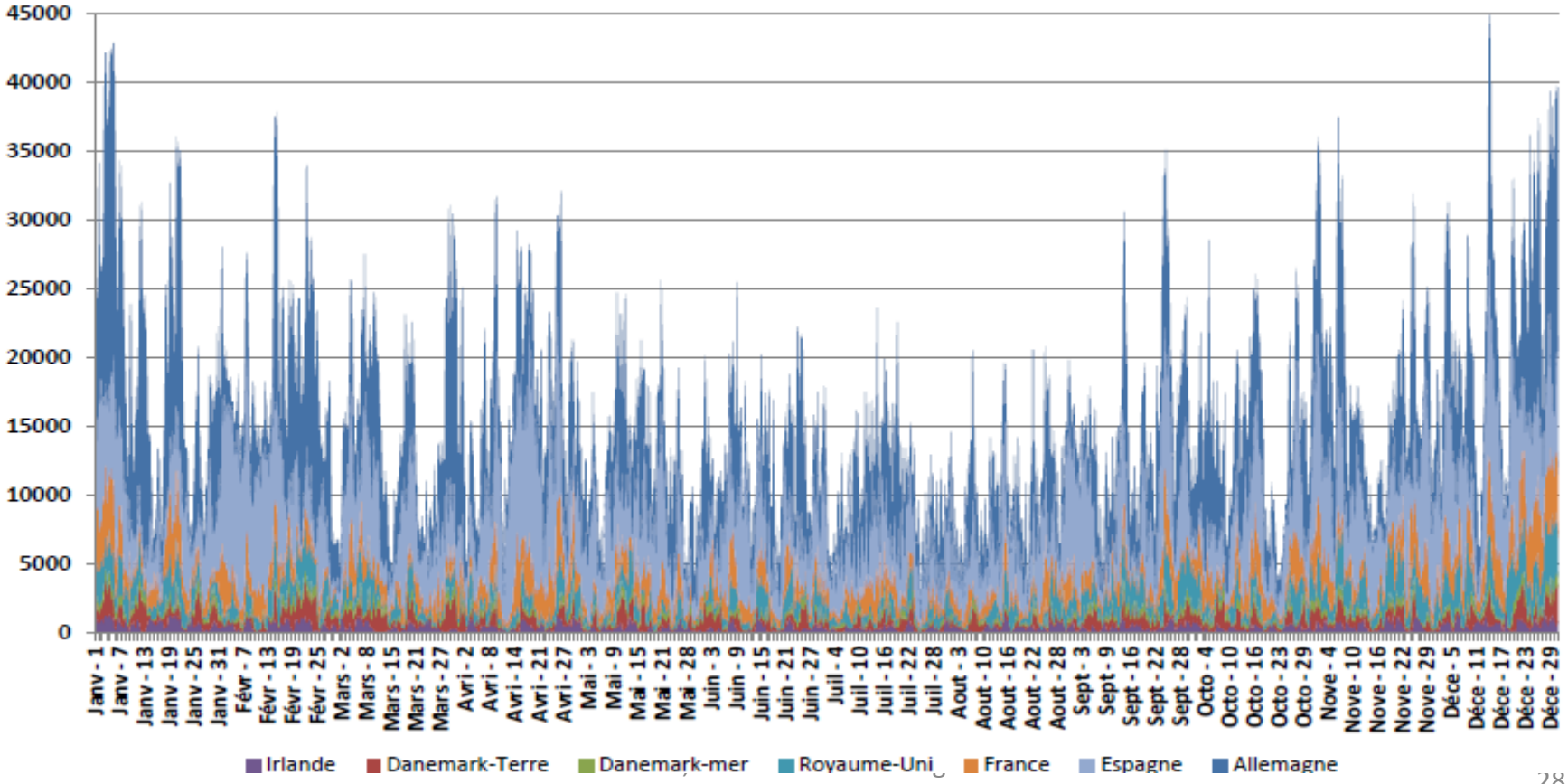
In their documents one can for instance read : "The foisonnement associated with the three French distinct wind zones leads to a much smoother time production curve", by which, in fact, this curve is meant:



“Foisonnement” at the European level

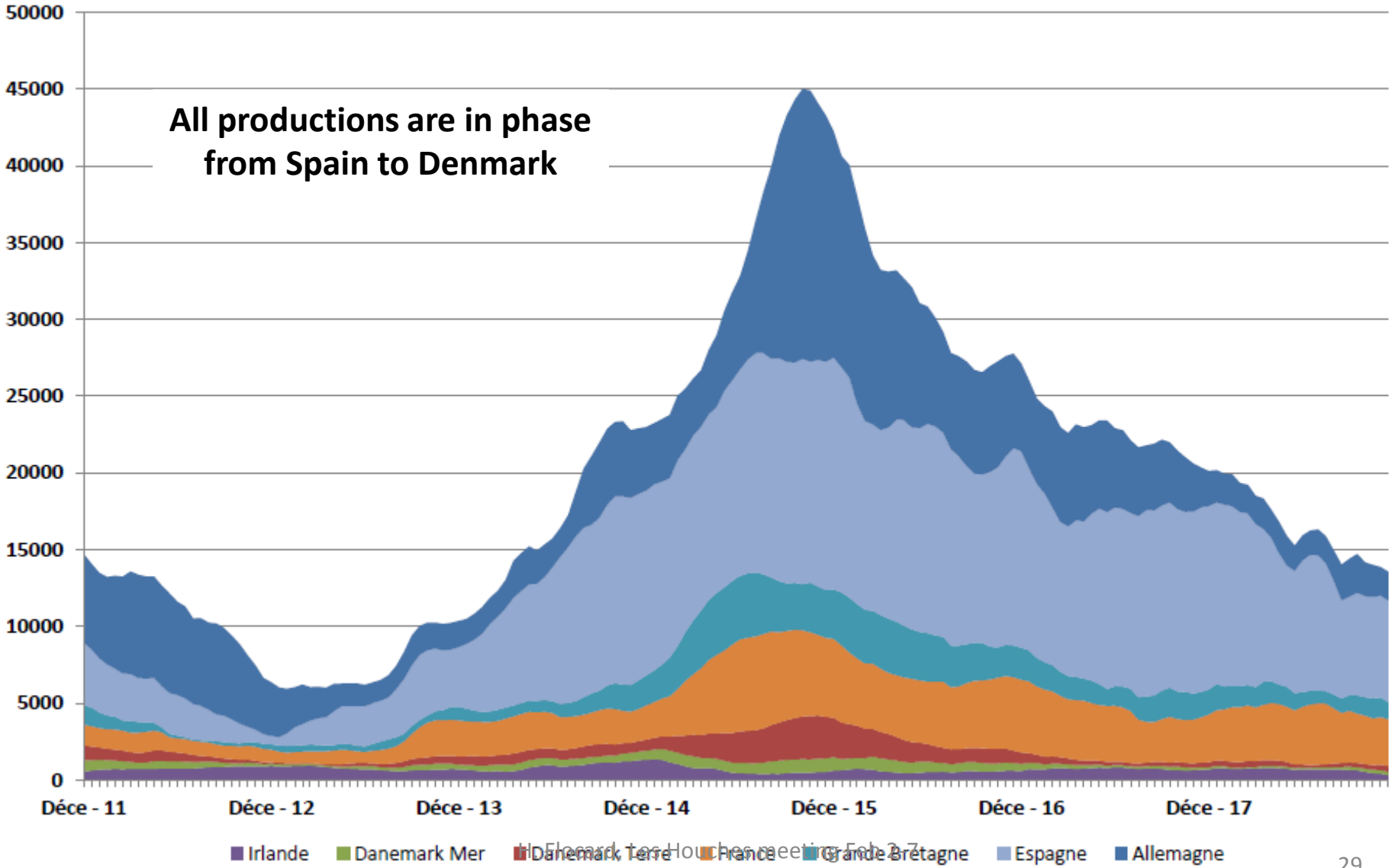
In Brussels, one of the arguments for EU funding of long HV transmission lines within countries and across borders corresponds more or less to stating :
“There is always wind somewhere”.

Hourly data collection for the year 2012 in seven countries
Spain, France, Ireland, UK, Denmark, Germany, Austria (D=D+A)
Total installed power varied over the year from 69GW to 75 GW



“Foisonnement” at the European level

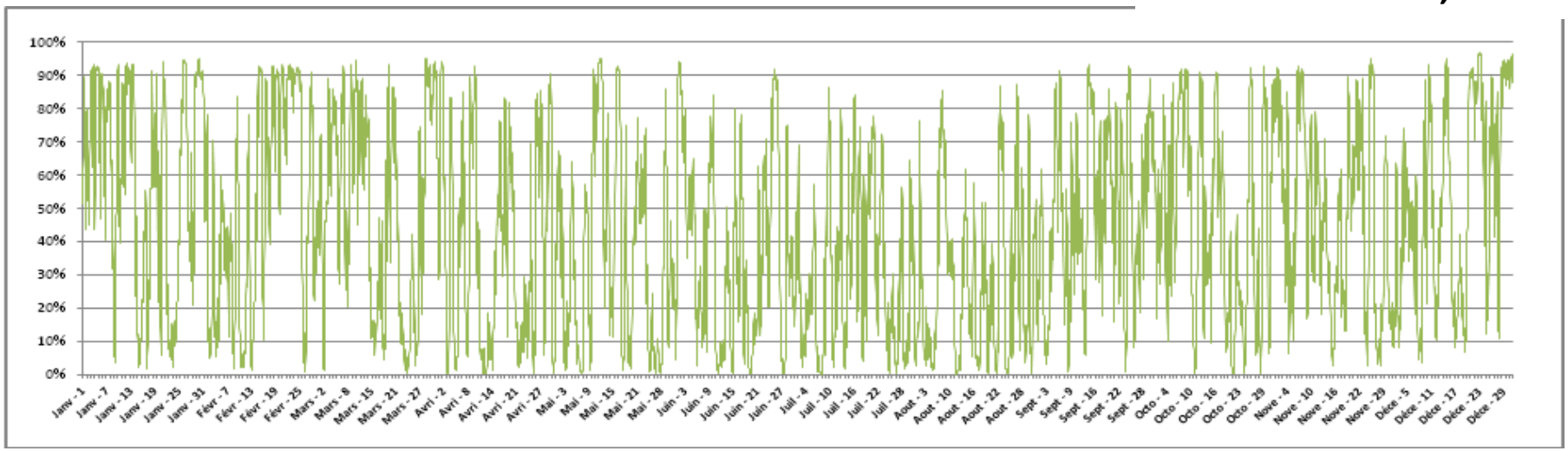
Seven countries : 2012 peak of European production 15 –December 2012: 45 GW
Total installed power this day was 75 GW



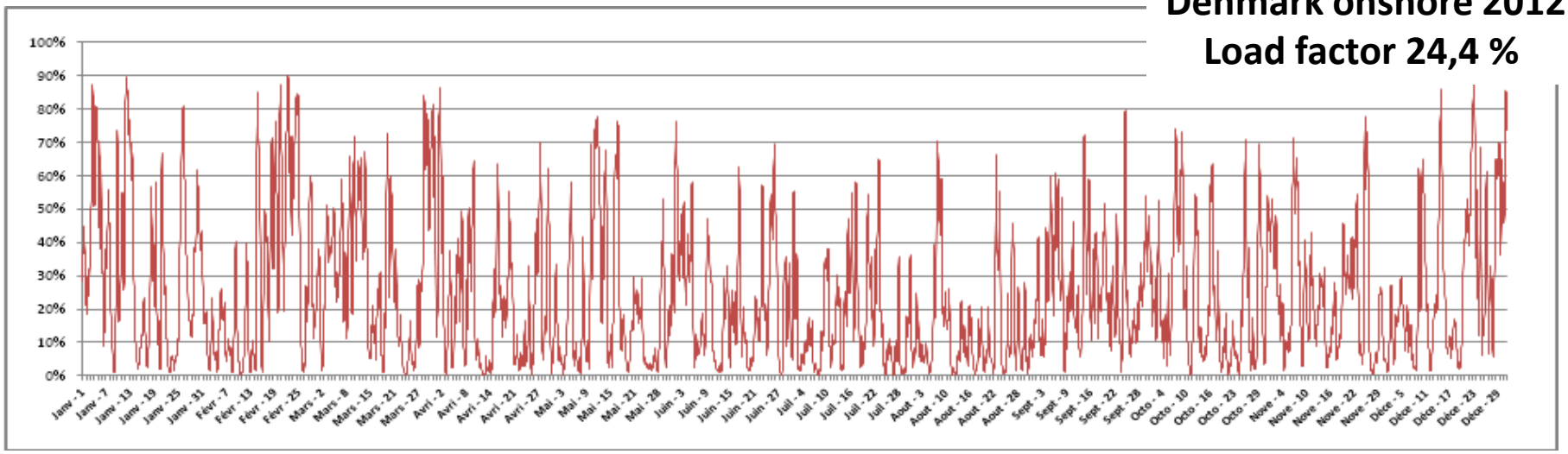
Nature and limit of “foisonnement”

Denmark as a “no-foisonnement” zone

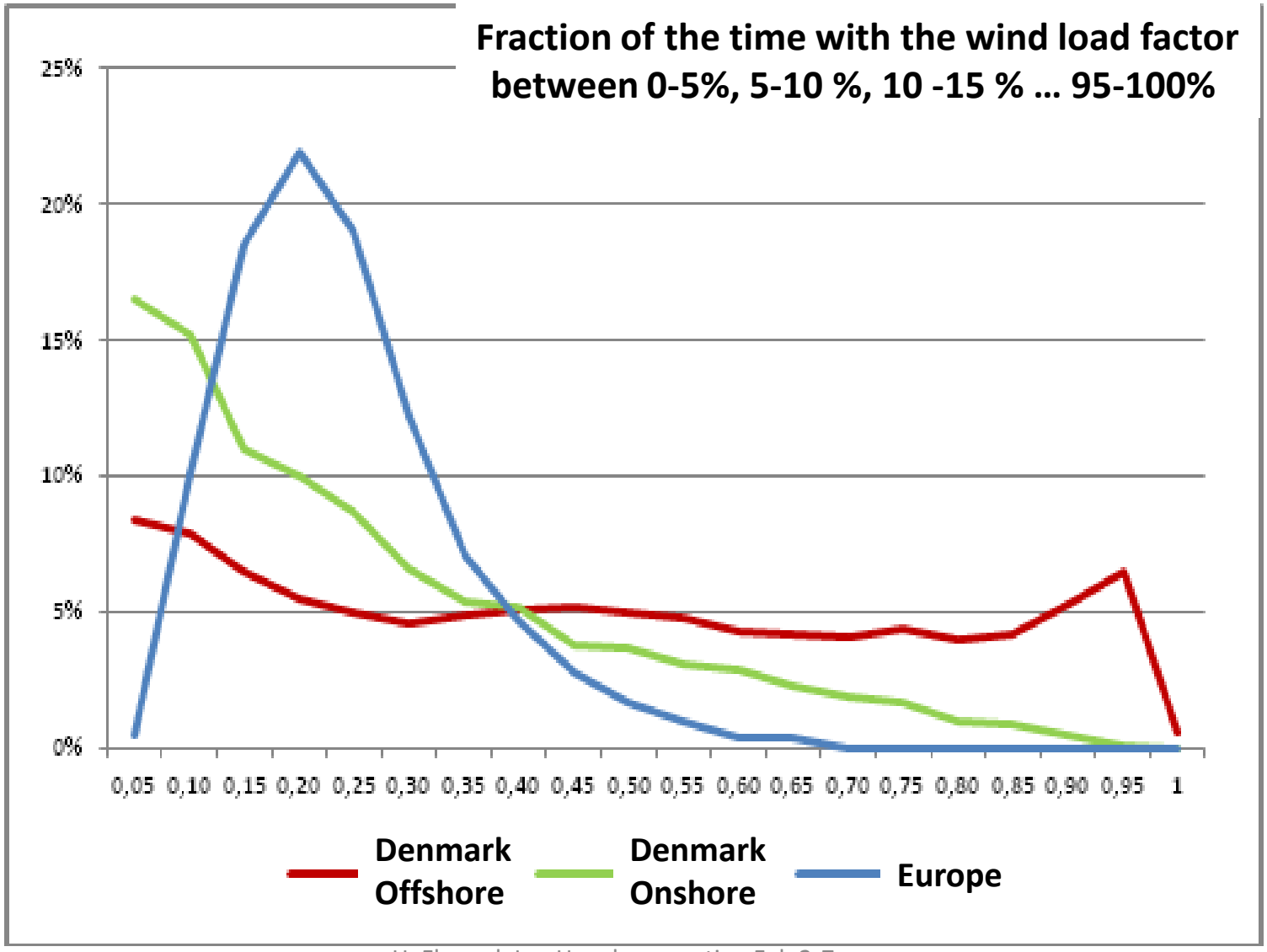
Denmark offshore 2012
Load factor 44,1 %



Denmark onshore 2012
Load factor 24,4 %



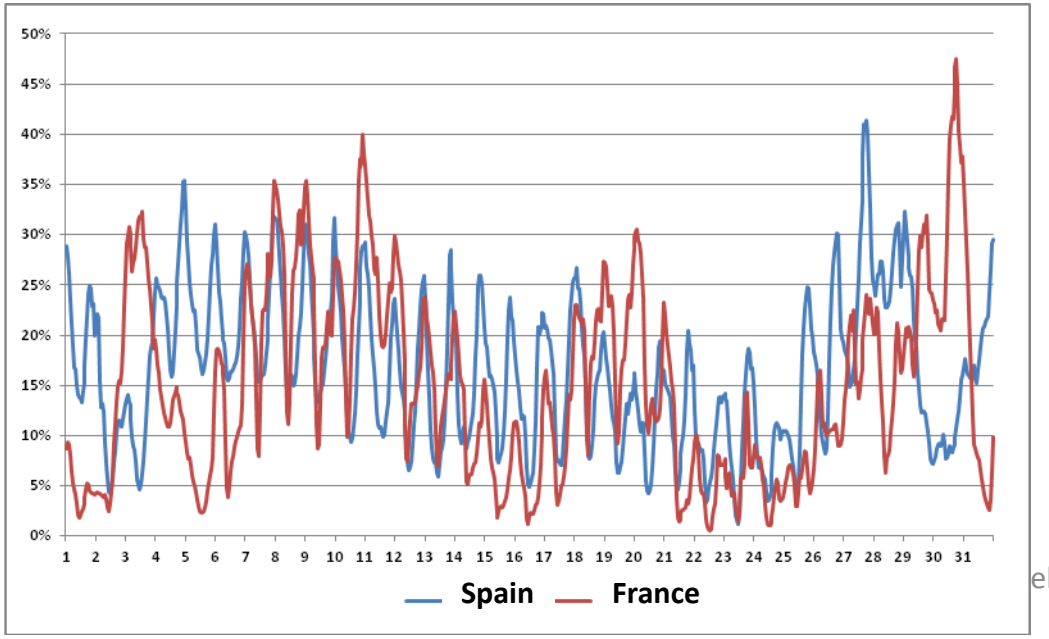
Nature and limit of “Foisonnement”
Observed distribution properties



Nature and limit of “Foisonnement”
Interpretation via a purely stochastic model

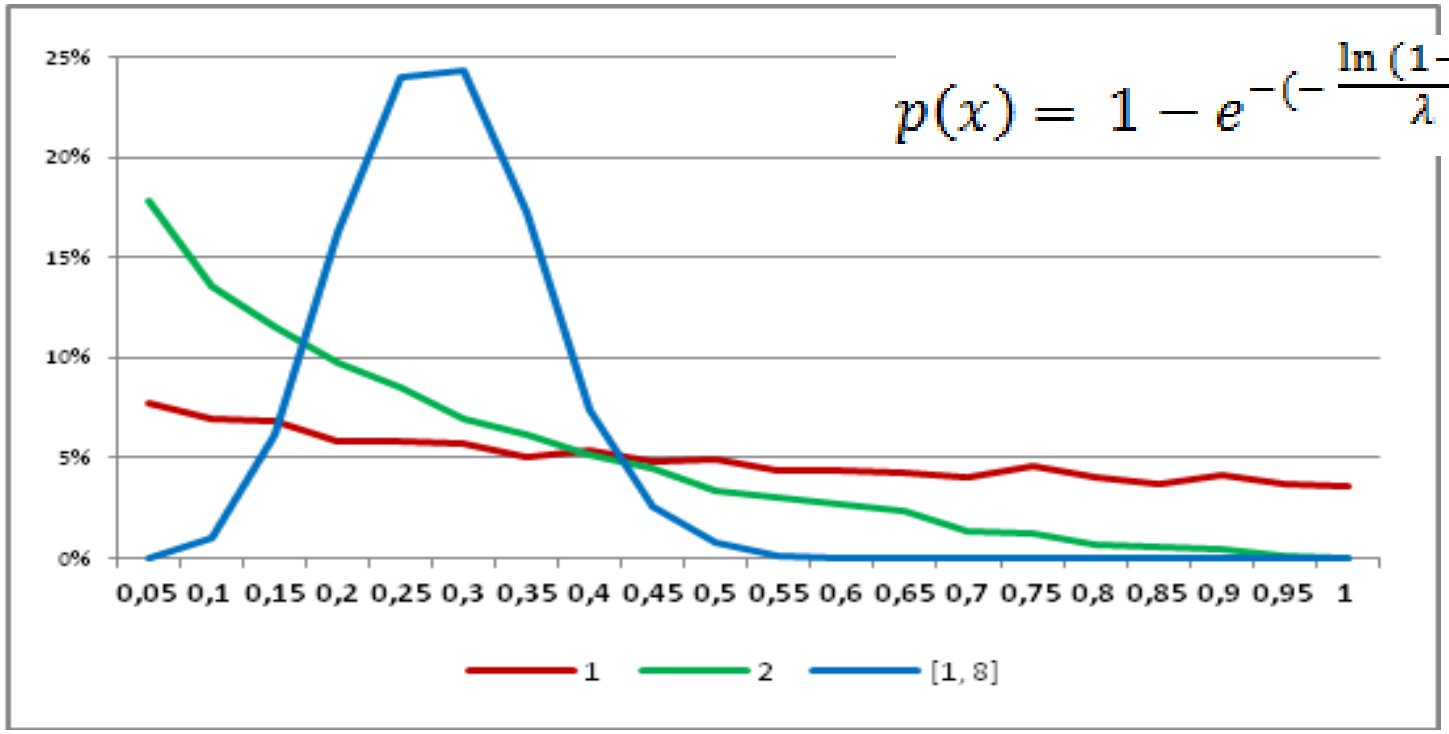
Assumptions of the model of a numerically simulated “Europe of the winds”:

1) “Europe” is divided into a limited number of zones where wind patterns are independent
2) Wind is highly correlated geographically at a scale of 500 km and even more
3) Within Europe there can’t be more than 7-9 wind independent zone
4) 8 zones, 500 km 2D extension – 2 million km^2 4 offshore and 4 onshore
5) Wind production in a given zone can be described as a purely random variable
6) Total “European” wind is the sum of the production in the 8 “independent” zones
7) Denmark offshore and onshore are good indicators of the distributions to be used for random number drawing.
8) The wind of this “Europe” is thus represented by 8x 8760 = 70080 random numbers



July 2013
Wind production
of French and Spanish
Wind fleets which are more
than 1000 km apart

Nature and limit of “Foisonnement”
Interpretation via a purely stochastic model



1) European wind production is well described as the sum of a limited number of random numbers. Such a sum is still a random variable.

2) As random variables are added, the shape of the distribution changes according to what the central limit theorem predicts. No more, no less.

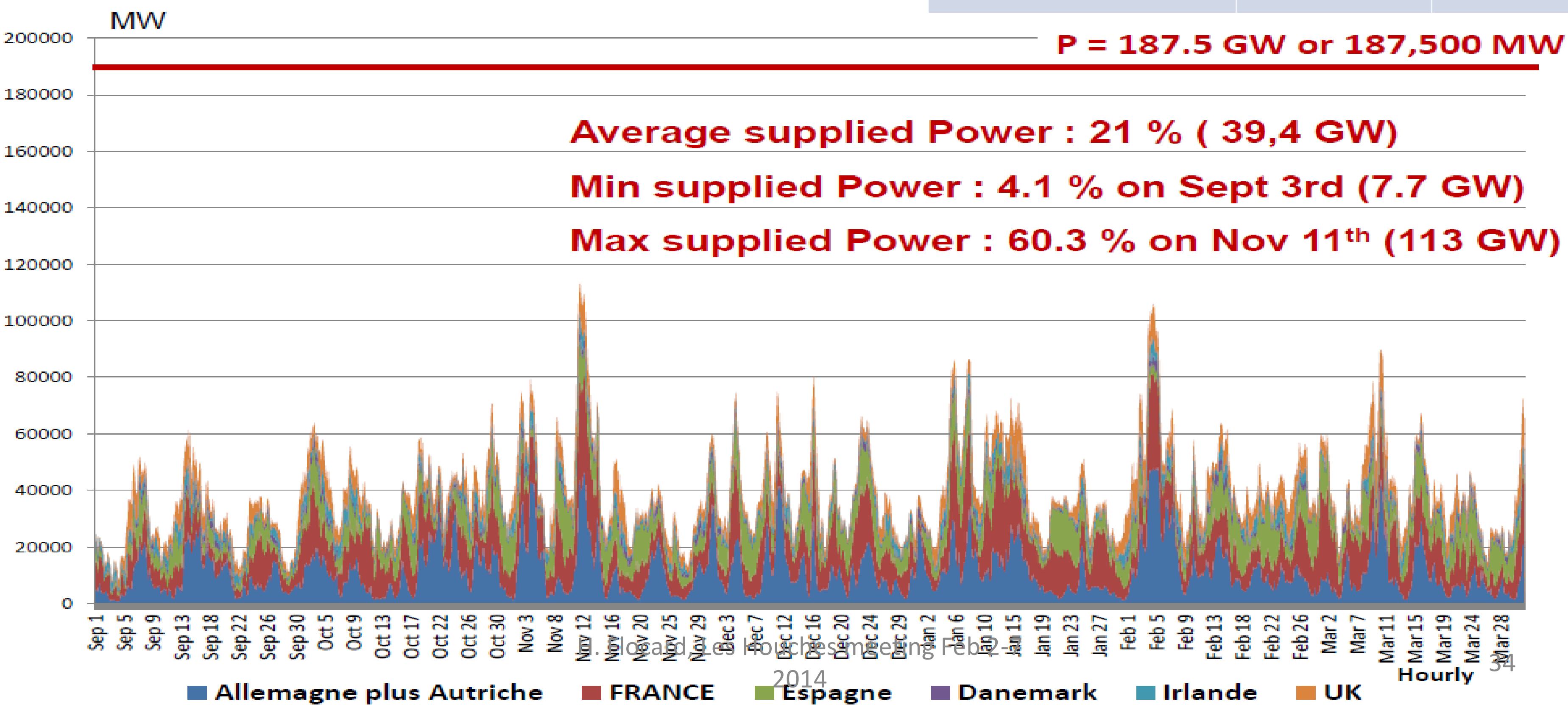
The number of independent zones over Europe is certainly no greater than 8.

Adding contributions of many European countries will not reduce significantly the wind power fluctuations

The future of the united Europe of wind

Rescaling 7 European countries productions observed over 6 months of 2010
To the installed powers as announced in official national plannings

MW	2010	2030 est.
France	5660	53000
Germany/Austria	28200	60000
Spain	20700	30000
Denmark	3800	4500
Ireland	1430	10000
Great Britain	5200	30000
Total	65000	187500



An analysis of the ADEME 2030 electric scenario

(Published 2012-13)

ADEME
« Agence De l'Environnement et la Maitrise de l'Energie »
is a French public entity
whose activities concerns environment and energy economies.
As it depends directly on
« Ministère de l'Ecologie du Développement Durable et de l'Energie »
ADEME contributions are thus much in line with government views .

The hypotheses of the ADEME 2030 electric scenario

This scenario is of great interest because, for each type of electric production, it specifies both the installed powers and the expected annual energy production, thus allowing a thorough analysis of its consequences.

Voluntarist scenario organized around 3 very original (for France) trends

1) Decrease by 21% of electric consumption (cf Negawatt)

This correspond to close to -25% per capita (population grows)

Deep reorganization of French way of life in less than 20 years

Consumption = 83% of production -> already need to export 17%

2) Strong reduction of nuclear energy (electoral promise of our president)

Power of nuclear fleet drops from 63 GW to 32 GW.

Production is now baseload (49 % production). Load factor (6800h/an)

3) Strong growth of intermittent electric renewables

Solar 33 GW (assumed to 20% more efficient than that of Germany 2012)

Wind 46 GW (assumed to be 3% more efficient than that of France 2012)

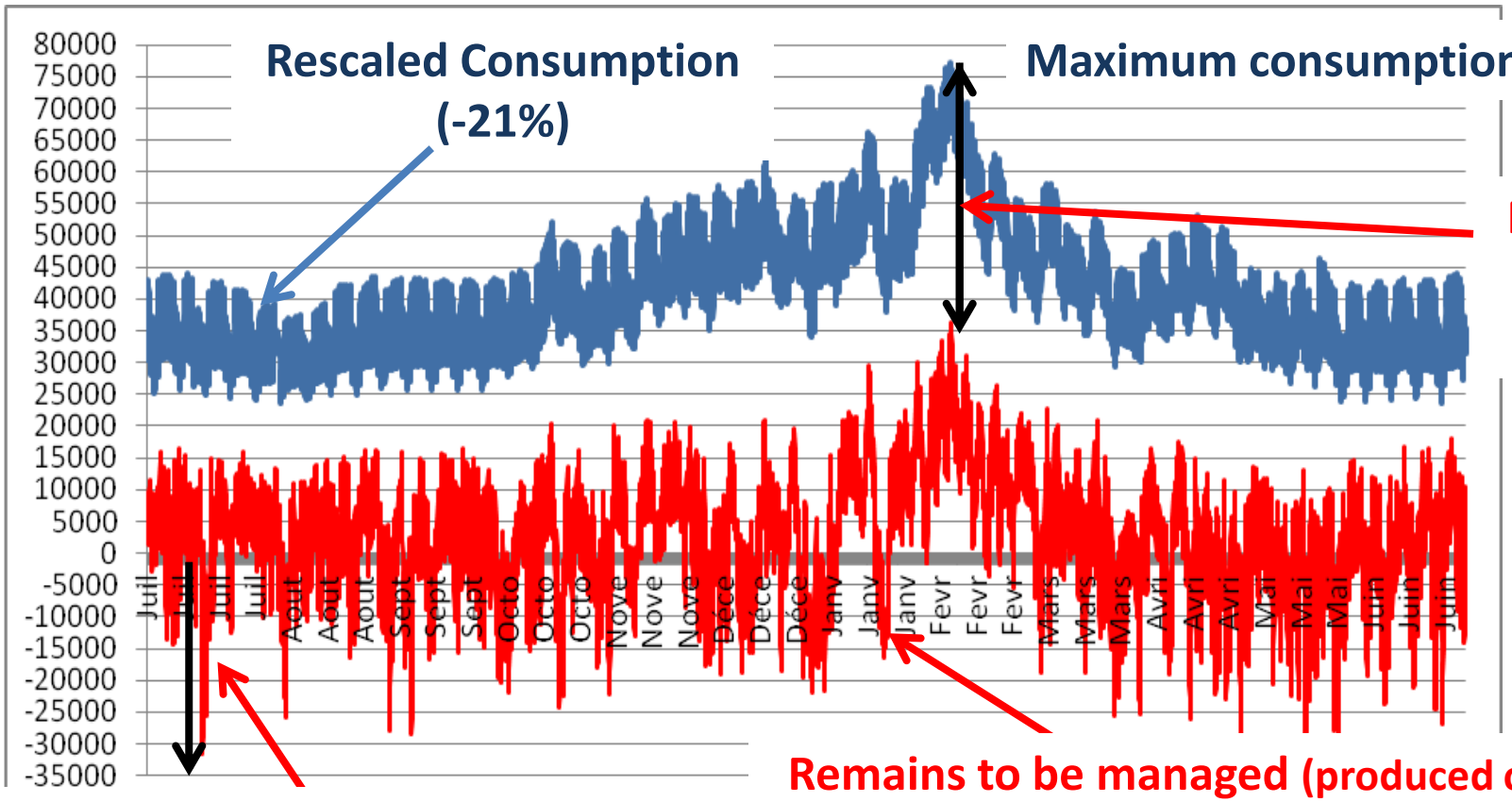
These 79 GW ensure 29,6 % of production

Nuclear + Solar + Wind = 95 % of consumption

Additional : hydraulics 15% of production, Almost no increase of storage means, Other renewables and waste 4,7 % ; Gas & Oil 1,7 % (3% ???)

Time analysis of the consequences of ADEME electric scenario
Period : 1er July 2011- 30 June 2012

Observed French 2011-12 consumption then reduced by 21%.
Observed French 2011-12 wind production then rescaled to 46 GW and 3% more efficient.
Observed German 2011-12 solar production rescaled to 33 GW and 20 % more efficient.
Nuclear turned to baseload : summer 17GW, winter 32 GW, average 24,8 GW.



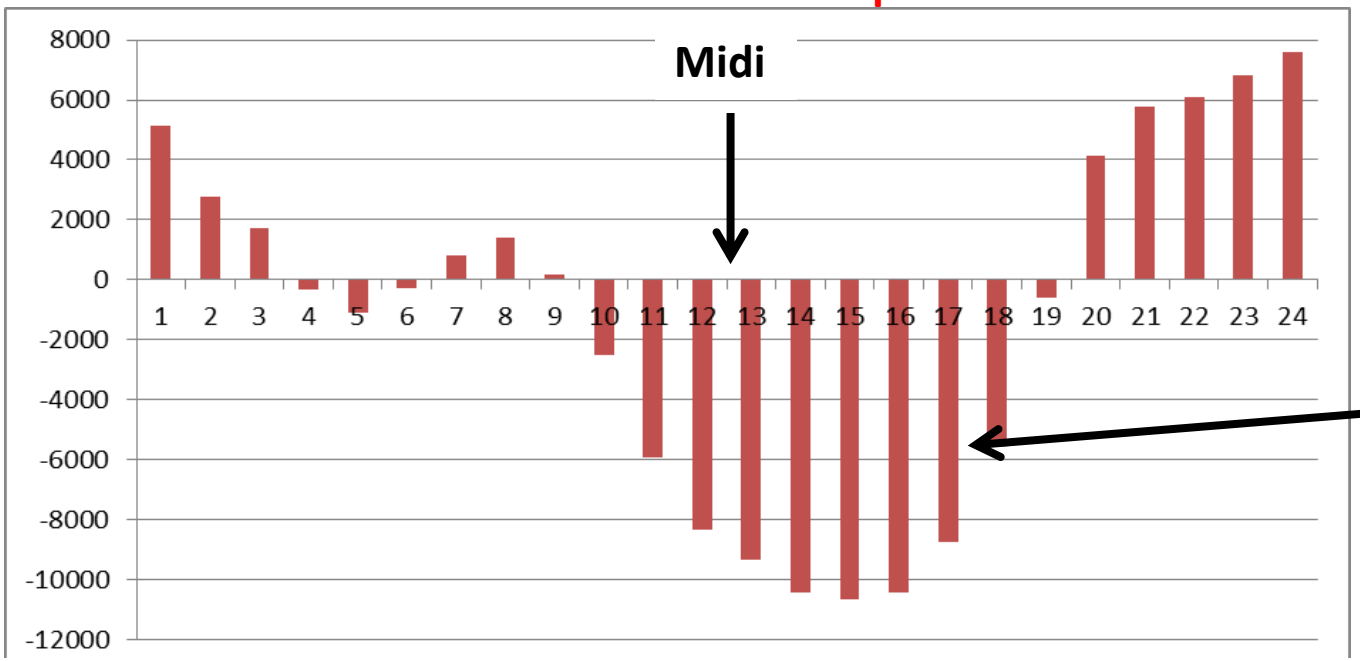
Time analysis of the consequences of ADEME electric scenario

Global summary :

- Over a year the scenario "consumes" 369 TWh (average power 42 GW).
- With 111 GW of nuclear + wind + solar, the scenario "produces" already 354 TWh.
- However, with these sole productions followed each hour over the year, 45 TWh are still missing and 29 Twh have to be exported

IN ADDITION to the 75 TWh of export included from start in the ADEME 2030 scenario.

Hourly structure (from 1 to 24h) of the difference = Consumption- (Nucl+Wind+Solar)
Period : 1st April- 30 June2012



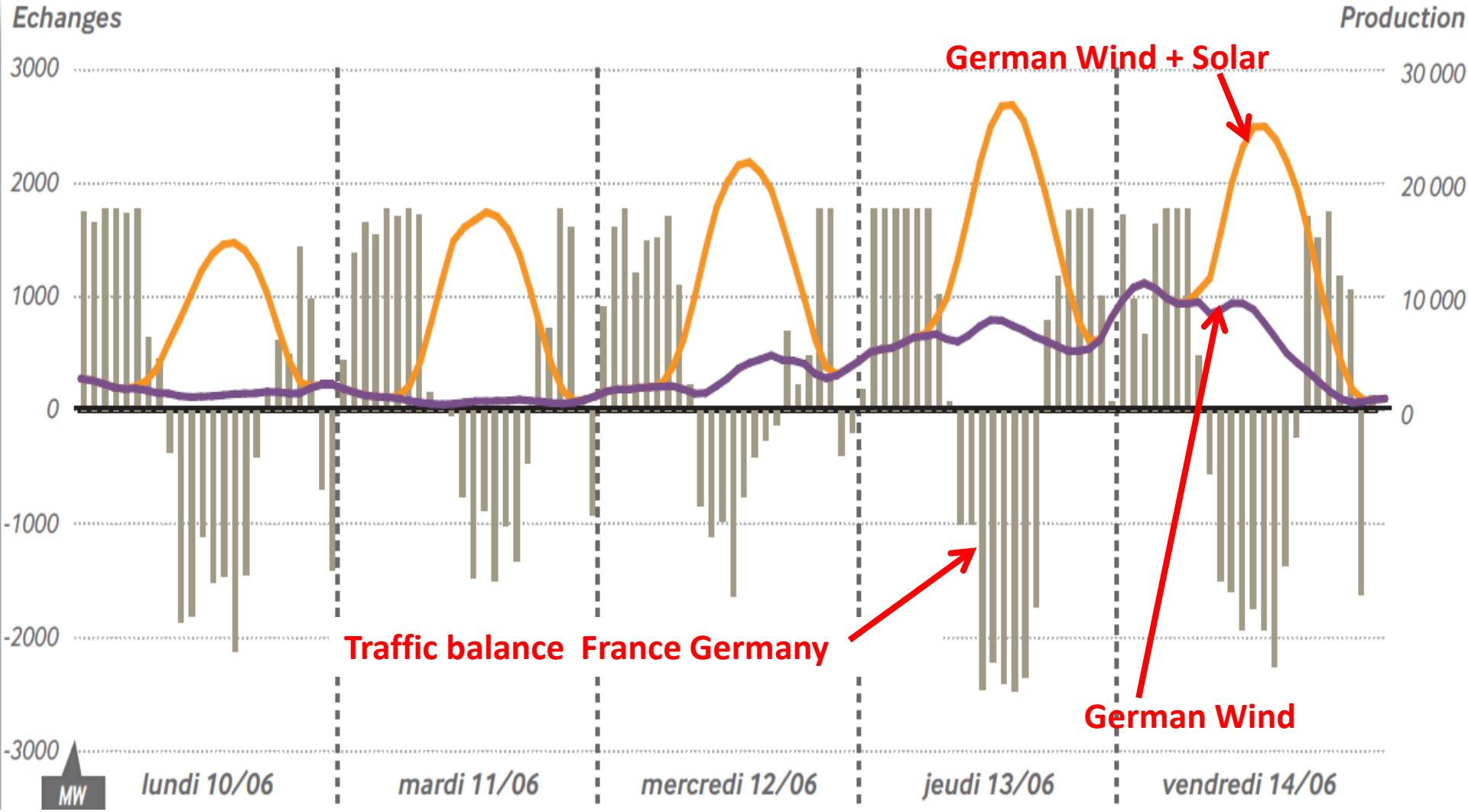
Night deficit Production is missing.

Day excess Excess production must be exported.

In the ADEME 2030 electric scenario France must export at the same time our neighbors (Germany, Italy, Spain) are doing the same.

Observed effects on France of German renewable growth

Correlation of German renewable production with electric flux at the German border from (positive) and towards (negative) France



How well does one predict today renewable intermittent productions (day-ahead predictions)

Prediction error on intermittent production

A perfect prediction of intermittent productions allows ahead programming

- of backup power (capacity reserve) if it exists,

- of storage systems when they exist,

- of physical fluxes on HV lines if they exist,

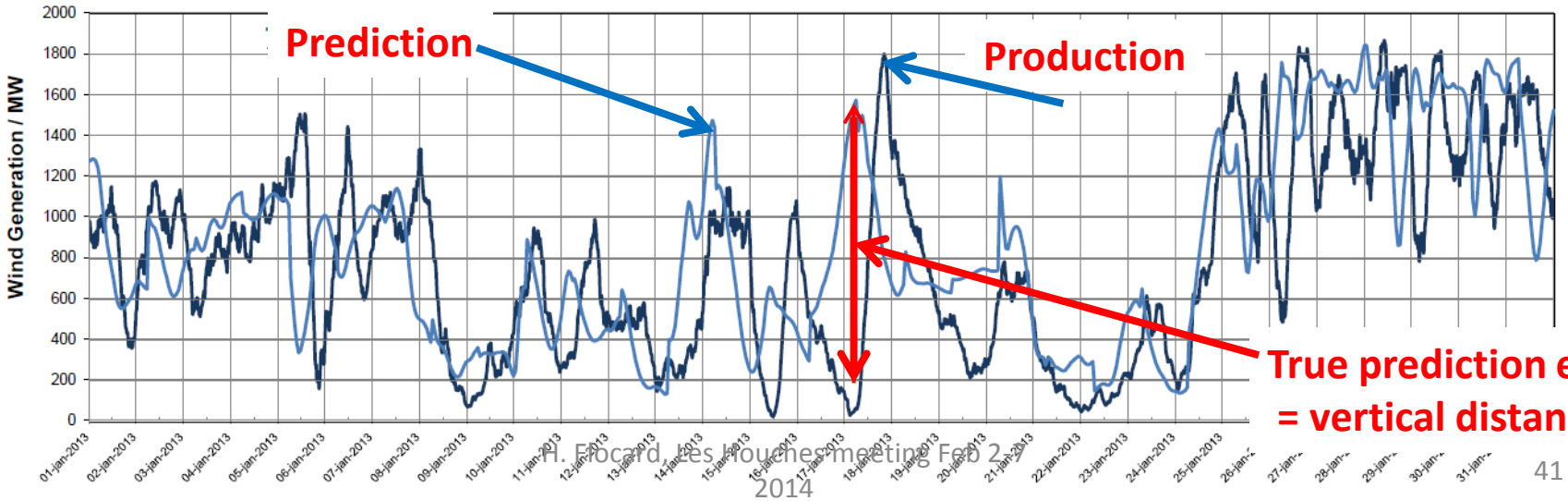
- of negotiated international fluxes ,

in order to satisfy the basic relation

consumption (x, t) = production (x, t).

Any quality deficit in the prediction of intermittency requires scenarios to increase stand-by backup reserves from one day to the next by an amount equal to day-ahead error prediction.

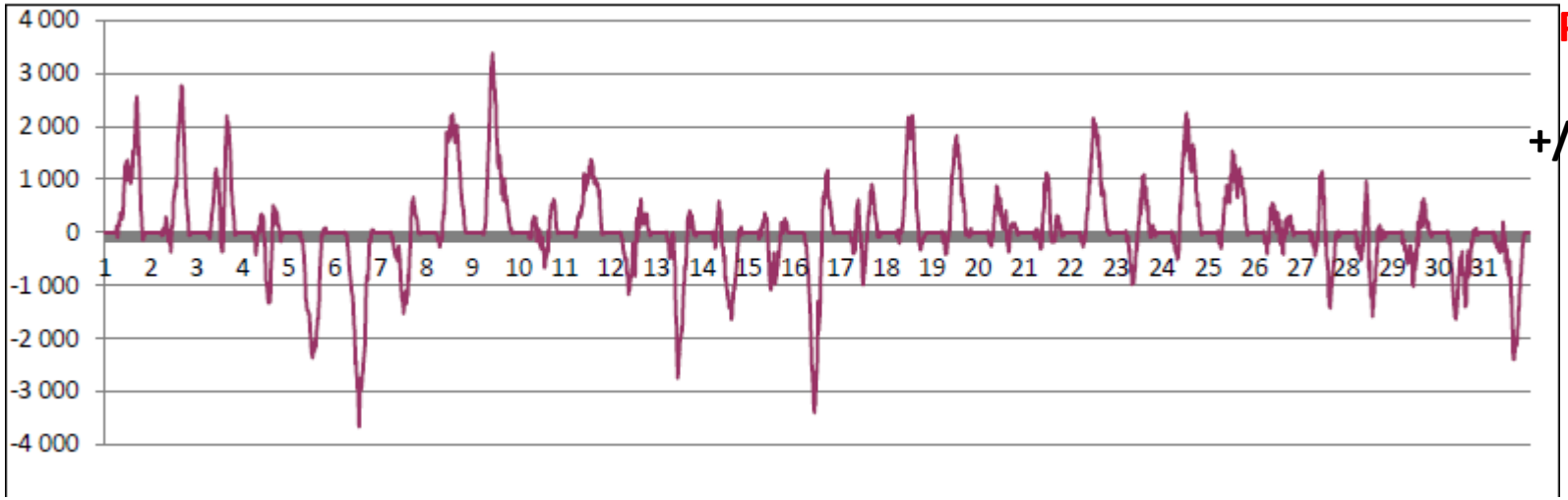
A standard although BIASED presentation of predictive capacity : Ireland January 2013



Prediction error on intermittent production

Germany; prediction18h30 for the next day

Solar May 2012 : Production-Prediction (MW) (installed P ~27 GW).

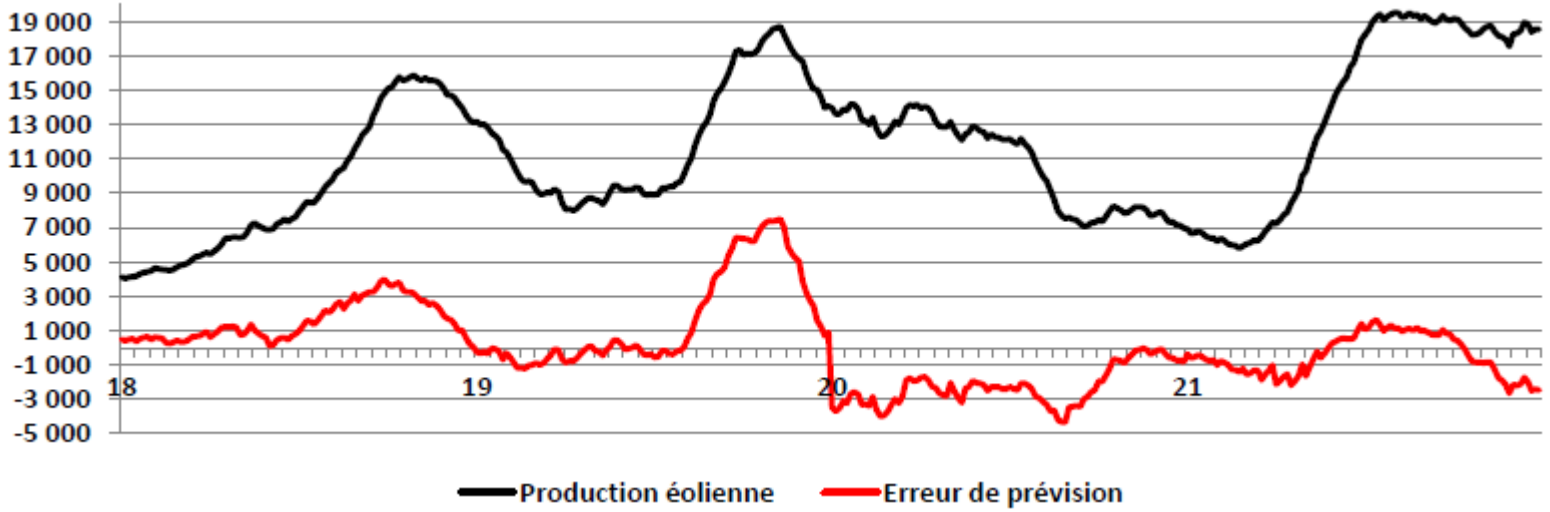


Prediction error

+/- 3000 MW

~ 10 %

Wind 18-21 January 2012 : Production-Prediction (MW) (installed P ~29 GW).



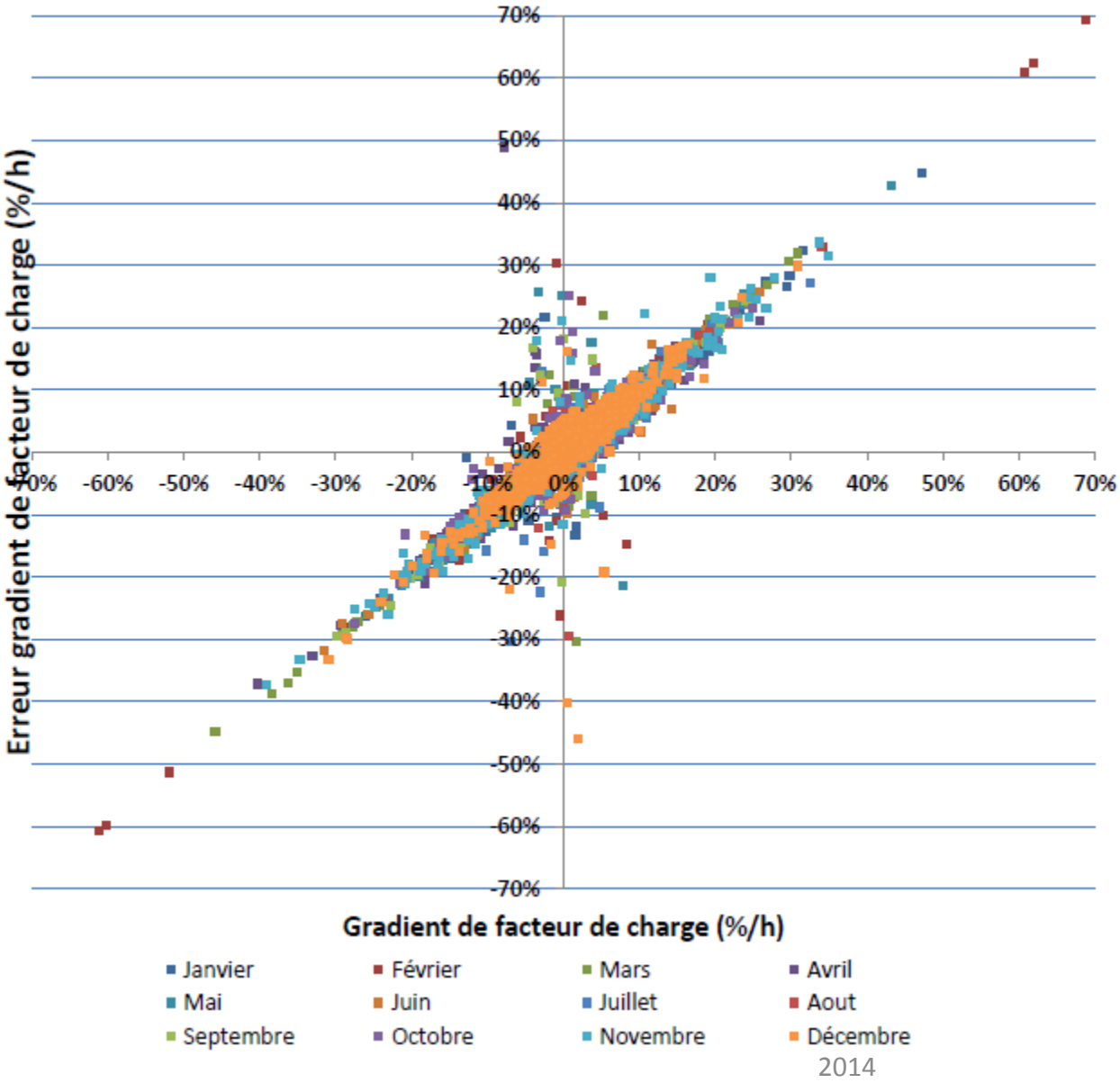
Prediction error

7 GW; -4 GW

~ 15 %

Prediction error on intermittent production

Belgium offshore 2012; prediction18h for the next day



Data from
Grid manager ELIA

Power gradients corresponding to variations up to 25 % installed power within 1h occur frequently

For a 25GW iinstalled power (Grenelle environnement) gradients up to 6 GW/h (~four EPRs to be started Or stopped within 1 hour

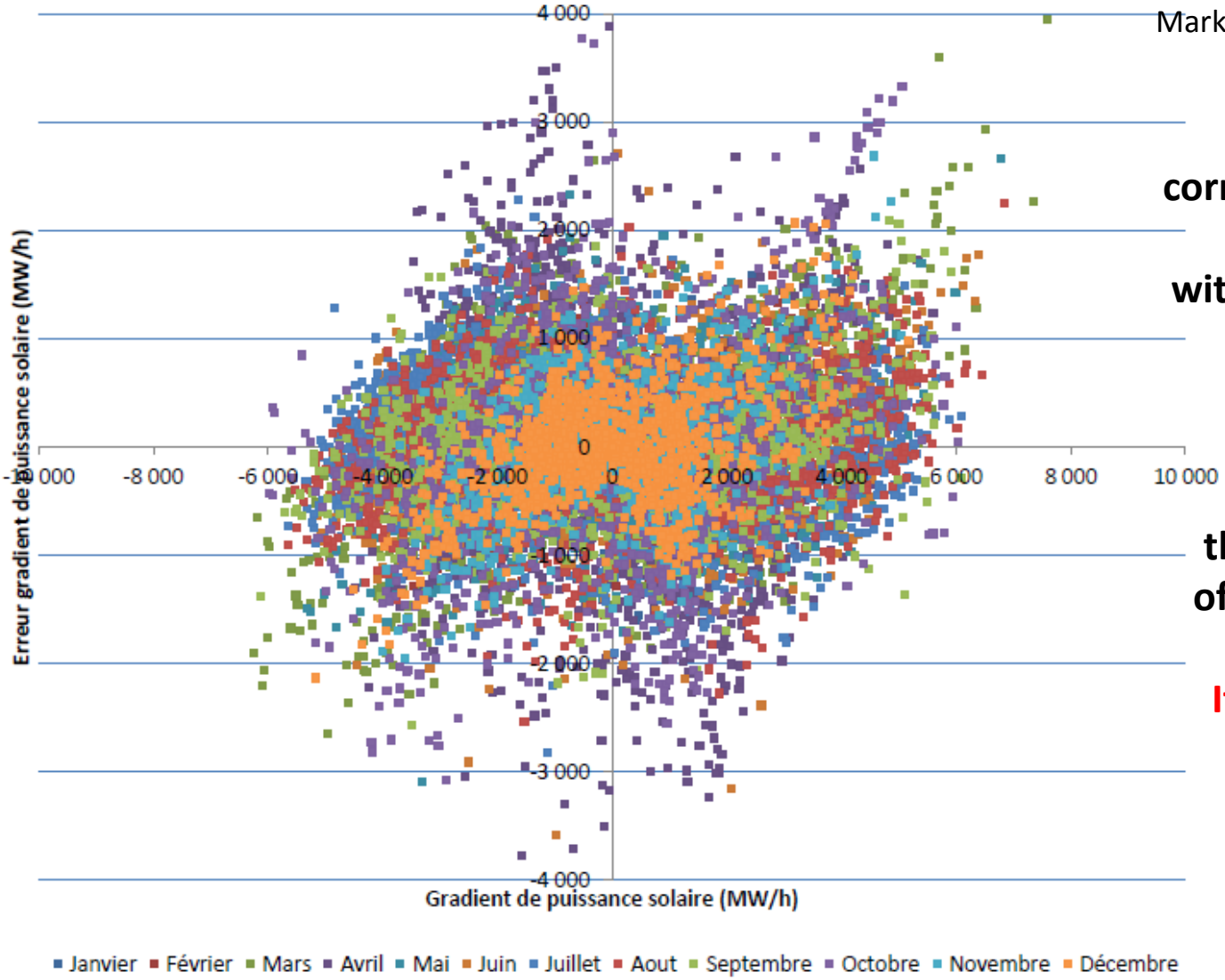
On the average, predictions underestimate the gradients by a factor 20

For 25 GW of wind power It amounts to keeping about three EPRs as a standby backup.

Prediction error on intermittent production

German solar 2013; prediction18h30 for the next day

Data from
Market manager EEX



Power gradients corresponding to variations up to 5 GW within 1h occur frequently

Error on estimating these power gradients often exceeds 1.5 GW/h

It amounts to keeping about one EPR as a standby backup.

My own solar wind turbine

A present from my grand daughter
note that the object is also antinuclear

Could this influence
future energy scenarios ?

A new addition to German language
(Duden Wörterbuch 2013):
Die Verspargelung
Wortart : Substantiv, feminin
Gebrauch : Meist abwertend

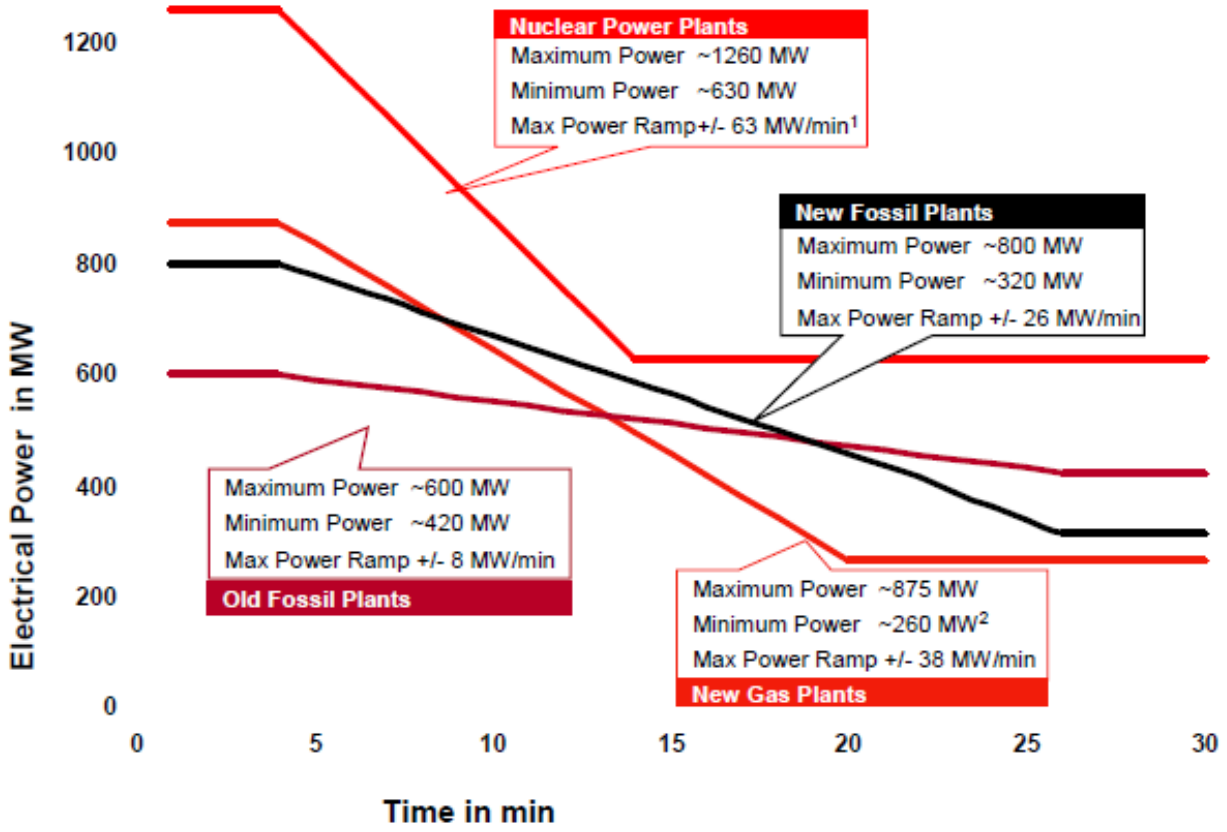
Thank you

Additional slides

Status of load balancing by nuclear plants

Load balancing
Power ramps of various dispatchable plants

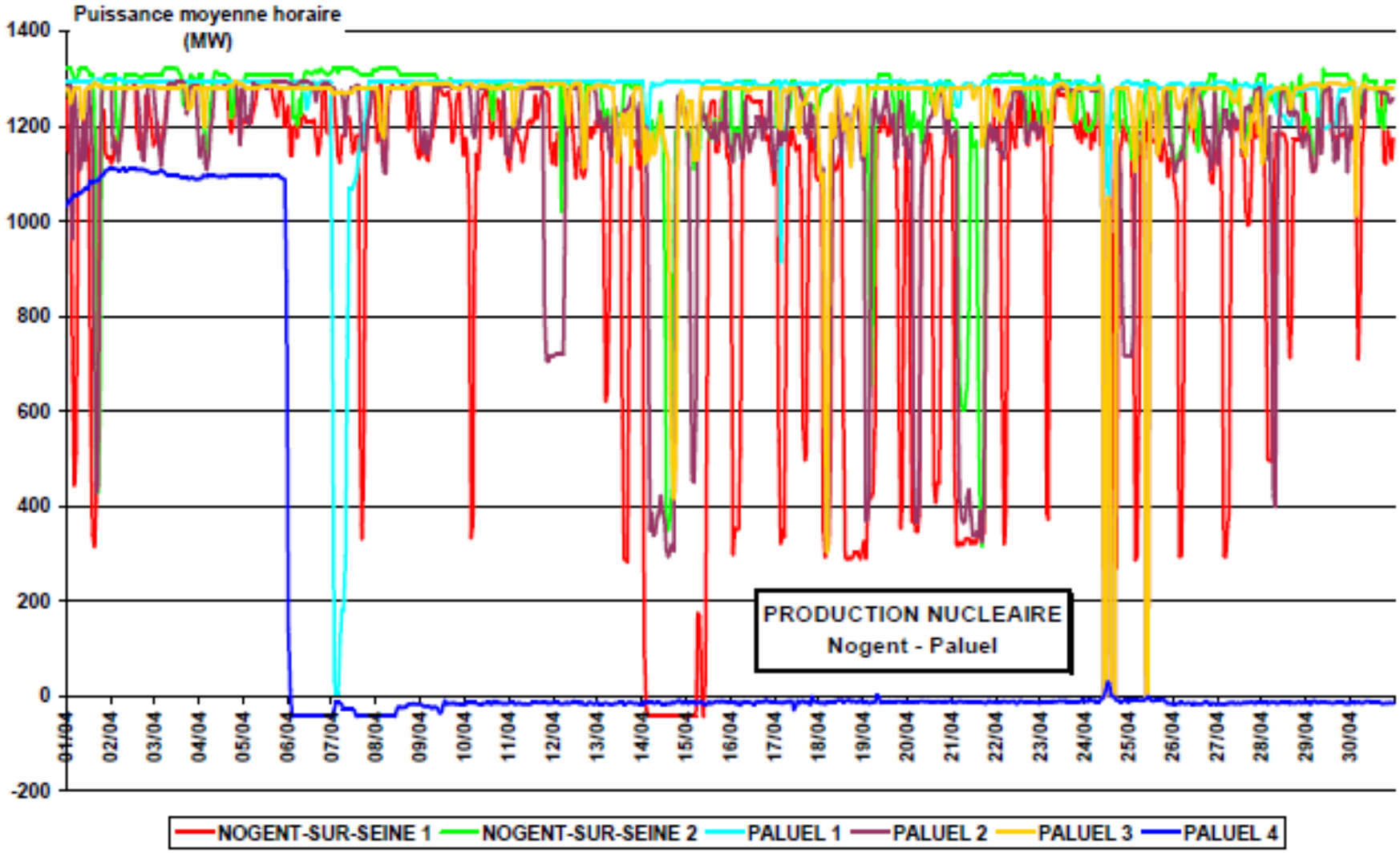
Comparison of power ramps



Nuclear Power Plants belong to the most flexible plants in the grid!

Load balancing

How the French nuclear fleet had to adjust its production to cope with strong French (European ?) wind production April 2013



Load balancing
French situation – "Gray operating mode"

1) Primary reserve : time scale second

- **+/- 2 % Pn (+/- 20 MW for a 1 GW reactor)**

2) Secondary reserve : time scale minute to twelve minutes

- **+/- 5,5 % Pn (+/- 50 MW for a 1 GW reactor with a max ramp 7 MW/mn)**

3) Tertiary reserve : twelve minutes and further

- **+/- 20 % Pn (+/- 200 MW for a 1GW reactor with a max ramp 30MW/mn)**

On the average, EDF provides ~1300 MW of reserves to the grid manager (650 MW primary reserve, 650 MW secondary reserve)

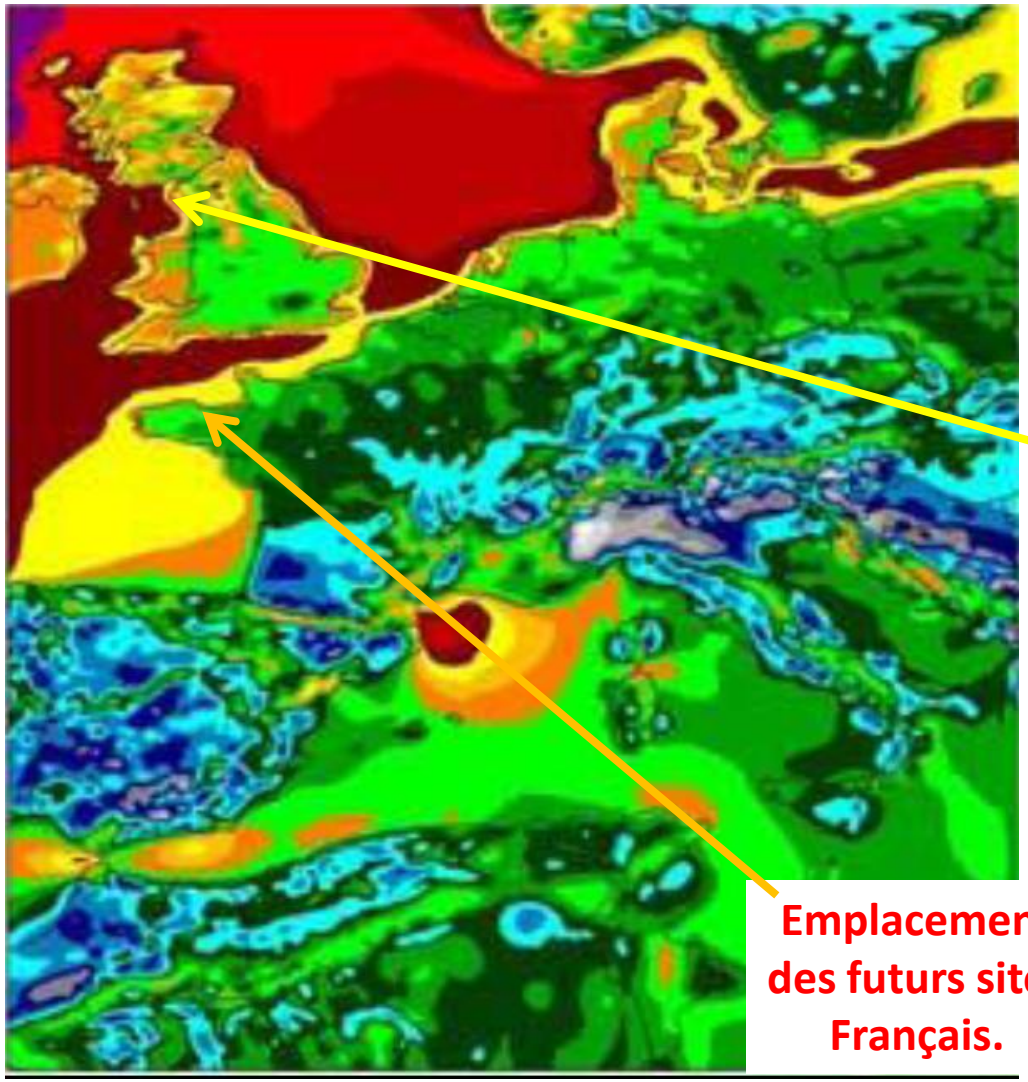
On a typical year

- **nuclear fleet (78 % production) provides about 50 % of the balancing**
- **hydraulics (12 % production) provides about 32 % of the balancing**
- **oil-fired plants (1% production) provides about 18 % of the balancing**

Source : GR21 meeting- SFEN 22/05/2010
M Debes, EDF R&D nucléaire/Direction Production Ingénierie

Offshore

En mer, le vent est plus fort et plus irrégulier



Emplacement des futurs sites Français.

Carte d'Europe des vitesses de vent à 80 m de hauteur. (Vestas)

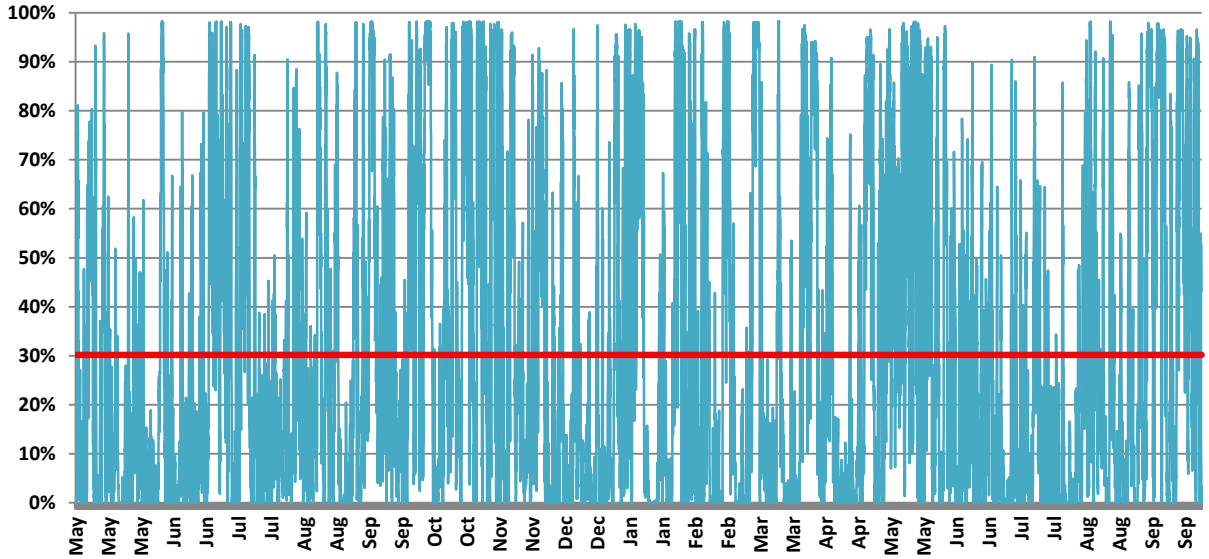
Le parc offshore Robin Rigg

180 MWc; turbines Vestas 3MWc
Opérateur E.ON Renewables
Mise en service Avril 2010.
Analyse de 17 mois de production.

Emplacement de Robin Rigg

Vue d'ensemble du parc Robin Rigg

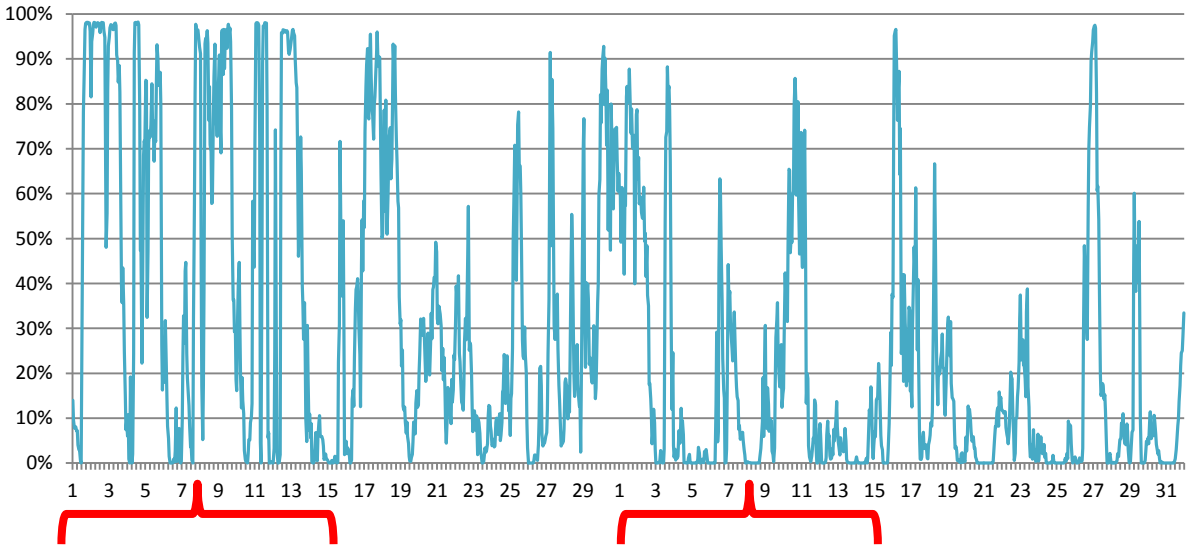
En mer, le vent est plus fort et plus irrégulier



Parc Robin Rigg
Données horaires 17 mois
Mai 2010-Sept 2011.
Efficacité moyenne 30 %.

A cause de sa compacité géographique, le parc de 180 MW se comporte presque comme une seule éolienne de 180 MW.

La France prévoit des parcs offshore jusqu'à 750 MW.



Agrandissement Novembre Décembre 2010

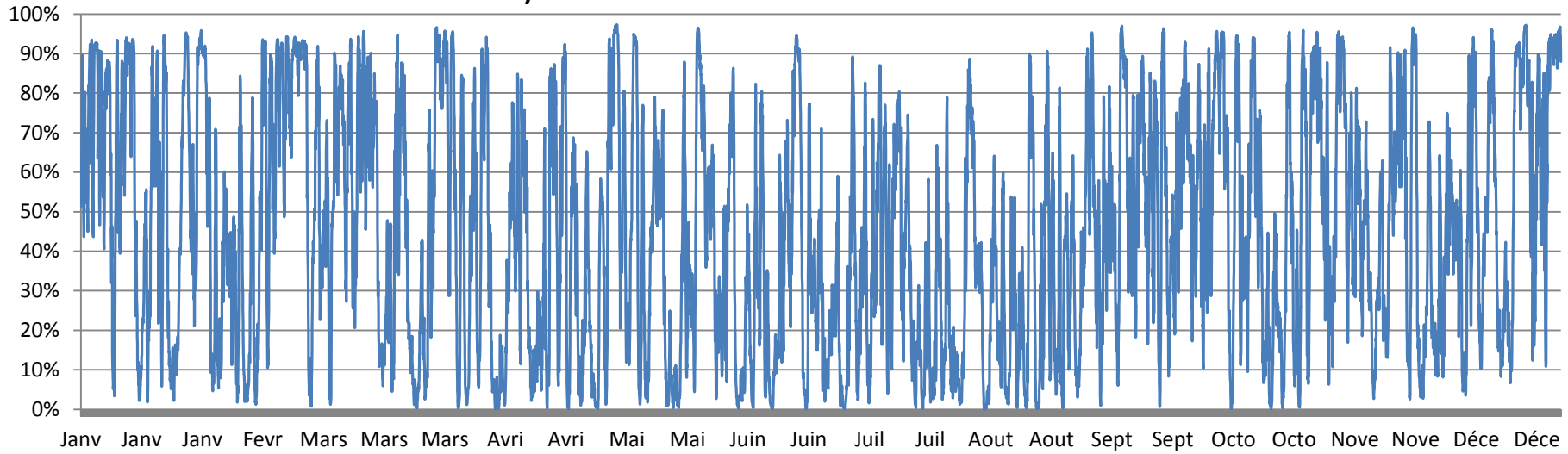
1ère moitié Novembre Record de production éolienne France.

1ère Moitié Décembre. Vague de froid exceptionnelle sur l'Europe : cœur de la vague de froid 13/12/2010 Record de consommation en France battu : 97 GW.

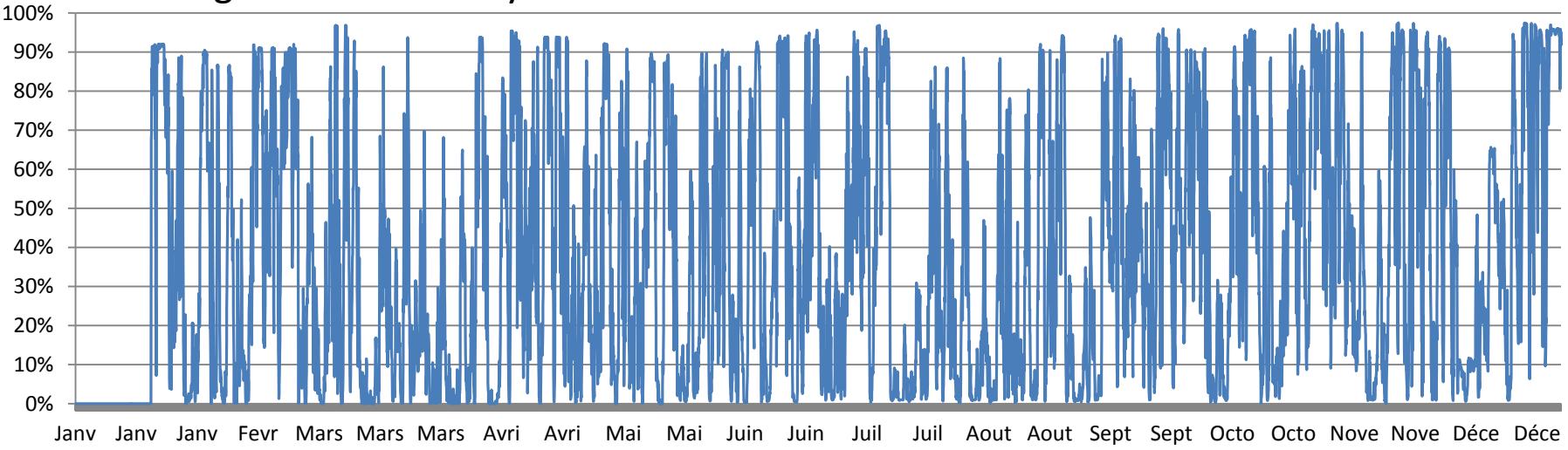
En mer, le vent est plus fort et plus irrégulier

Eolien offshore : exemples européens Année 2012

Offshore Danois : efficacité moyenne annuelle **45 %**



Offshore Belge : efficacité moyenne annuelle **39 %**



Quelle efficacité moyenne raisonnablement espérer pour le futur éolien offshore français ?