

Storage Demand for an Electricity Supply based on Wind and Sun

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Ladies and Gentlemen,
let me introduce myself and give you some information about my office.

Dr.-Ing. Matthias Popp

- born 1958
- Wunsiedel in Fichtelgebirge, Bavaria
- 1983 founding of Engineering office Popp during study
- 1983 diploma in mechanical engineering at Fachhochschule Coburg
- Engineering Office Popp, software development for automotive industry
- 1989 diploma in mechanical engineering at Technical University Munich
- Member of city council (CSU) and from 2002 to 2008 honorary deputy mayor of his home- and festival town Wunsiedel in Fichtelgebirge as well as member of supervisory board of the regional energy provider SWW Wunsiedel GmbH

Thereby intensive involvement with questions of energy supply

The proposal for a pumped hydro power station in the Fichtelgebirge was leading to the research of answers to the question:

How can energy storage plants deliver a contribution to a sustainable regenerative power supply?

- 2010 doctor-engineer at Technical University of Braunschweig
- 2011 finalist at the RWE Future Award 2011

MATTHIAS POPP Engineering office
Renewable Energies, Energy Storage
Simulations, Software-Development

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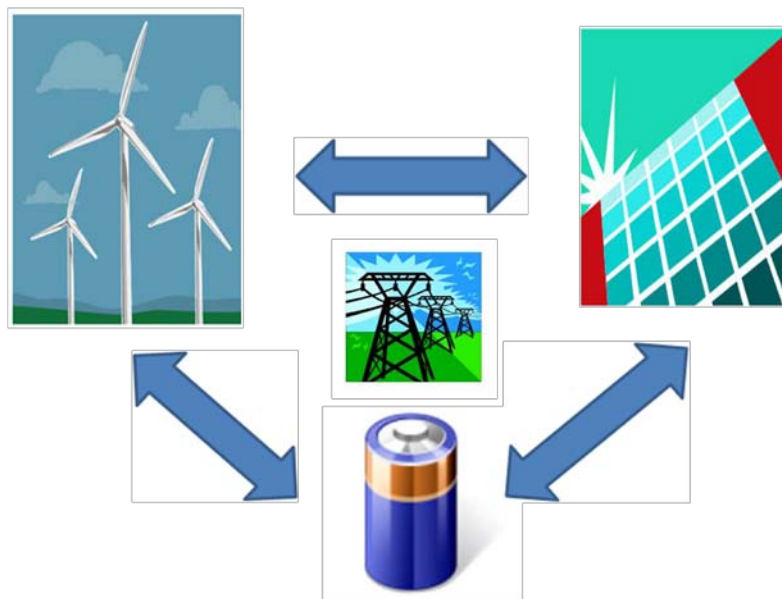


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Last year I made a doctorate with the title „Storage demand for a power supply with renewable energies“.

This doctoral thesis is published as book by Springer in German language.

Wind, Sun and Storage



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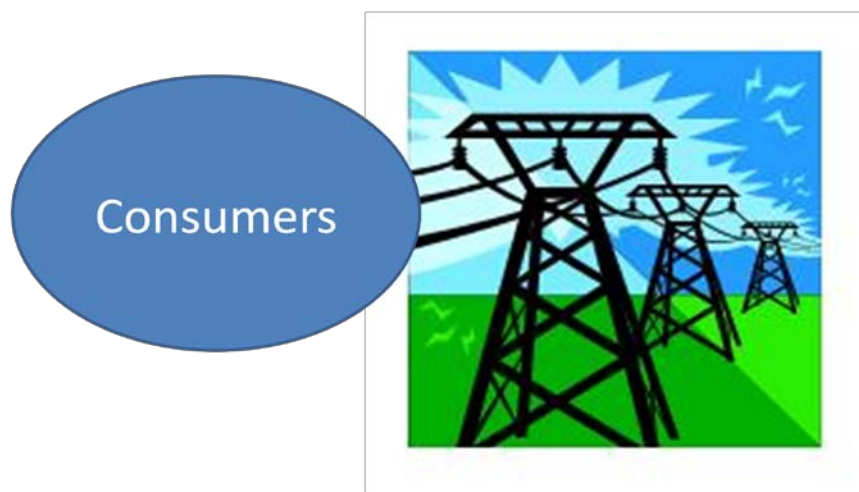
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In most of the dense populated countries of Europe, a regenerative electricity supply has to concentrate on the huge energy potentials of wind and sun, if the electricity demand shall be served sustainable.

These energies are only available volatile, depending on the weather.

In cooperation with storage systems, these volatile energy sources can be adjusted to meet the demand.

Electric Power Demand



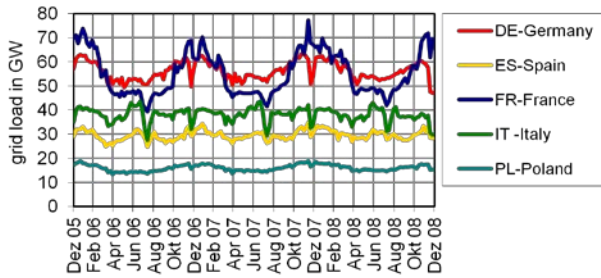
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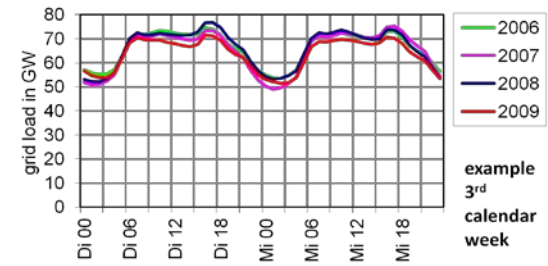
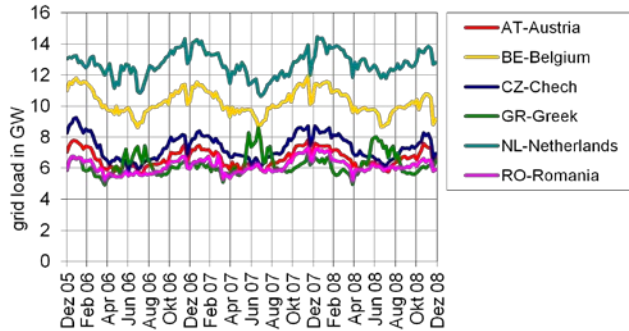
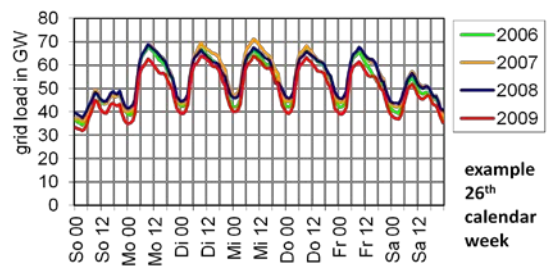
Let's have a short view on the electric power demand.

Consumption of electric Power

weekly power consumption in European countries



daily power consumption in Germany



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In European countries, the consumption of electric power during winter time is normally higher than during summer time.

It shows a typical sequence over the days of a week, according to the time of the year.

A power supply has to fulfil this task precisely in every moment.

Wind Energy



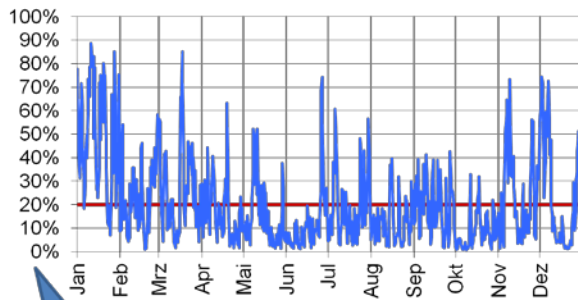
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What can wind energy contribute to this task?

Characteristics of Wind Energy

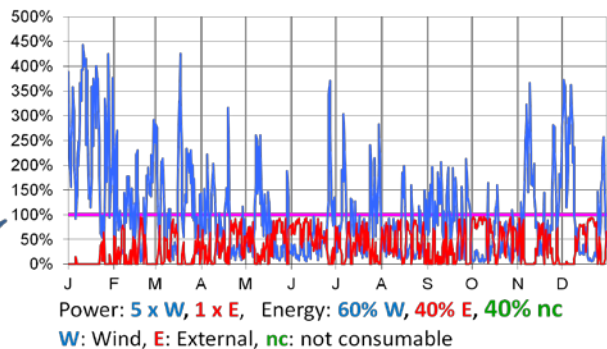
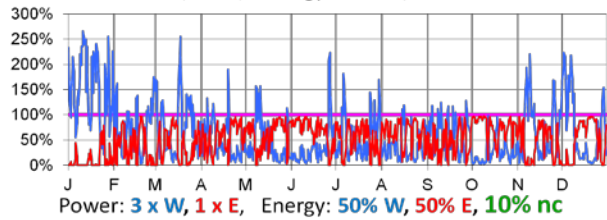
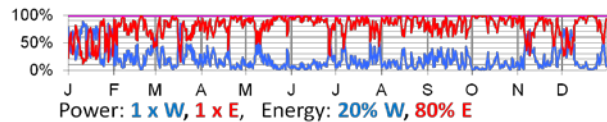
real wind power input
in Germany
exemplary for 2005 (blue)
capacity factor about 20%



100% = installed
rated power

100% = average
consumption

expansion without storage



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The maximum installed generating power of the wind power plants in Germany is never produced because there is hardly a constant strong wind across the whole country.

Sometimes, there are countrywide weak wind phases, where the wind power production goes down to zero.

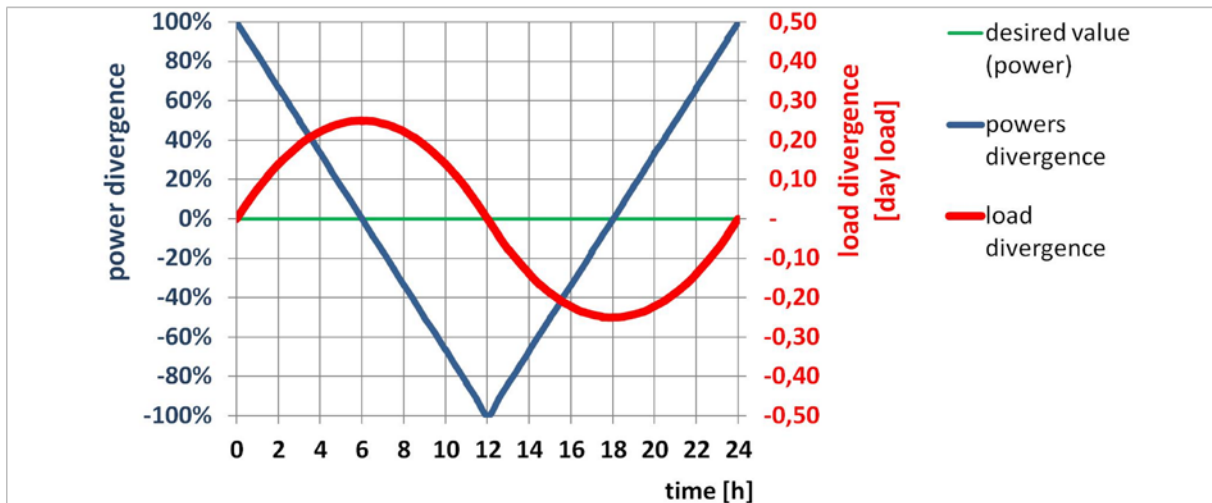
When wind power production isn't enough, to fulfil the intended power supply task, other external power stations have to help out to balance the deficit.

In average, wind power plants in Germany deliver about 20% of there installed power.

To determine the necessary storage properties for balancing between surpluses and deficits, the load divergence is introduced.

Load Divergence

as characteristic feature of volatile power sources



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It shows, how an ideal storage system without losses has to be operated, to transfer a volatile power production into a constant power supply.

Overshooting power charges the storage system and power deficits discharge it.

At the end of the analysis period, the storage system has the same zero load level as at the beginning.

Mathematical, it is the power divergence from the average power, integrated over the time.

Wind Energy in Europe – Data Basis



Raster areas
90 km x 90 km

Wind speed
100 meters above
ground

1970 to 2008

3-hourly time steps

Source:
anemos Gesellschaft für
Umweltmeteorologie mbH

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With the concept of load divergence, the wind energy of Europe was analysed.

In three hourly time steps, available wind power for all European countries was calculated by using characteristics, orientated on real wind power stations.

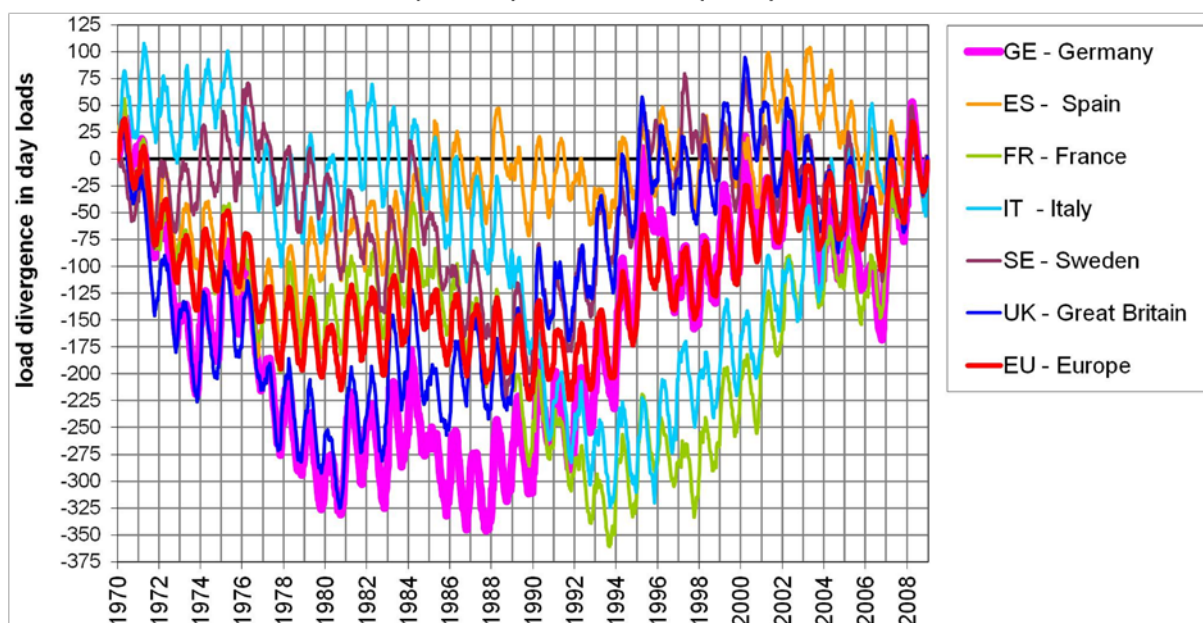
The comparison of these calculated values, with the real wind power inputs in Germany, showed good conformance.

This validation created confidence in the used procedure.

Let's now have a look on the identified load divergences.

Load Divergence of Wind Energy in Europe

for wind power plants with capacity factor 20%



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Shown are the load divergences for some large European electricity consuming countries and for whole Europe.

In weak wind periods, storage devices would have been discharged, in strong wind periods, they would have been charged.

At the end of the analysed period, where the same amount of electrical energy would have been produced as consumed, the load divergence is zero, like at the beginning.

The curves show drastic differences in the yearly availability of wind energy in different countries.

The load divergences increase and decrease during this period in some countries to values as large as the power consumption of a whole year.

Special attention should be given to the observation, concerning all European countries.

Because of average stronger winds during winter time, an increase of load divergence can be observed.

Because of average slower wind speeds during summer time, a decrease of load divergence can be observed.

The load divergence, caused by the wind power, depends strongly on the design of the wind power plants.

Increasing the Capacity Factor (number of full load hours)

- larger rotor diameters
- larger hub height in air layers with higher wind speeds

wind power

- increases with the square of the rotor diameter
double diameter => fourfold power
- increases with the third power of the wind speed
double wind speed => eightfold power

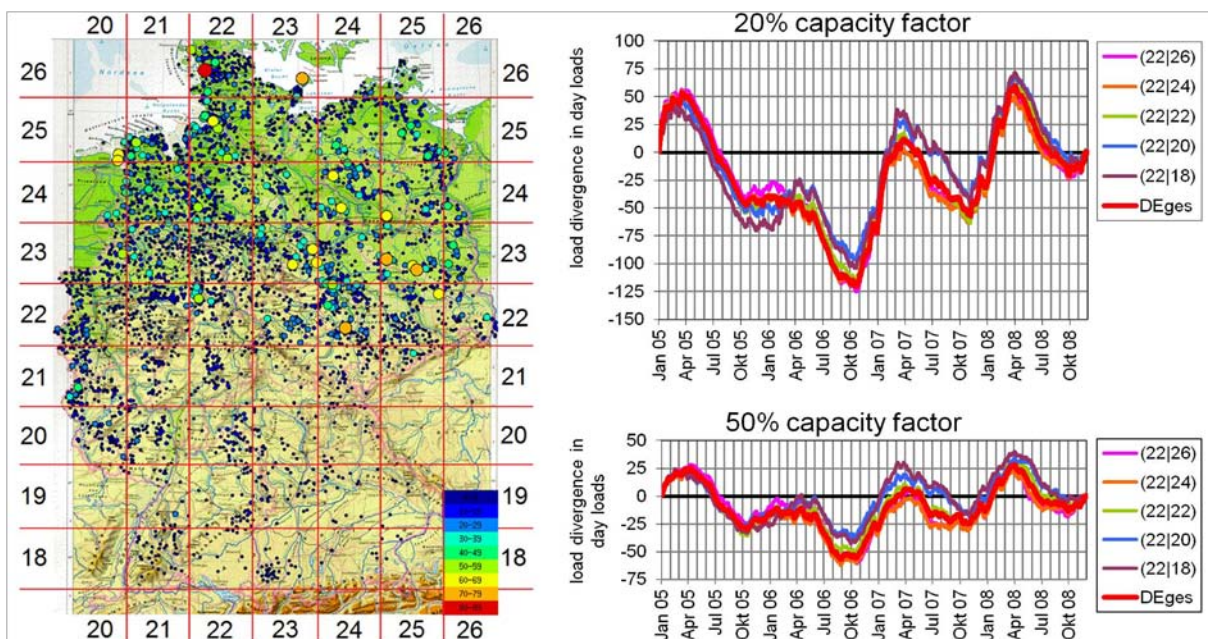
When keeping the rated power of a wind power station and increasing the rotor diameter as well as the hub height, the average power and therefore the capacity factor will increase **at a clearly reduced load divergence.**



If wind energy plants are designed for a larger number of full load hours, or meaning the same, for a higher capacity factor, the load divergence of the transformed wind energy can be reduced drastically.

Some manufacturers offer wind power stations, who lead to this direction.

Capacity Factor and Load Divergence



Broken down to the conditions of Germany, the map shows the raster areas of the used European wind atlas.

Comparing the load divergences of the single areas of Germany, it can be seen, that the curve shapes are very similar.

The diagrams show exemplary for four years, from north to south, the load divergences of some areas.

The similarity of the curve shapes comes from the observation, that wind conditions normally follow the weather conditions of greater areas, surpassing far over the borders of single countries.

The balancing effects of powerful electricity grid in a national solo run will therefore stay within borders.

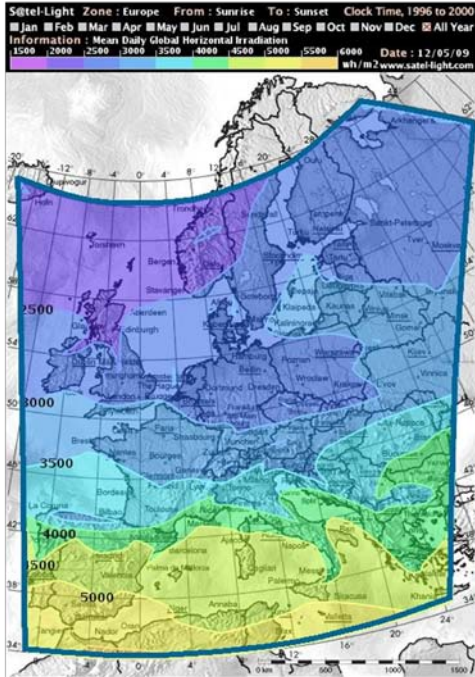
However, a higher capacity factor would have a much bigger balancing effect.

Solar Energy

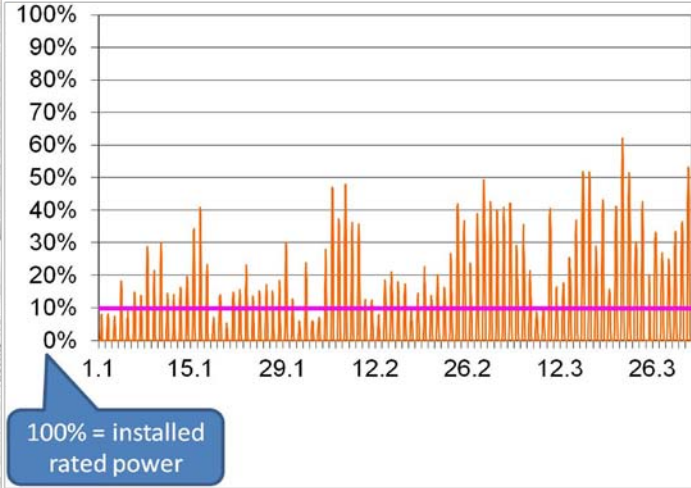


Let's now look, in an analogy way, on solar energy.

Solar Energy Offer

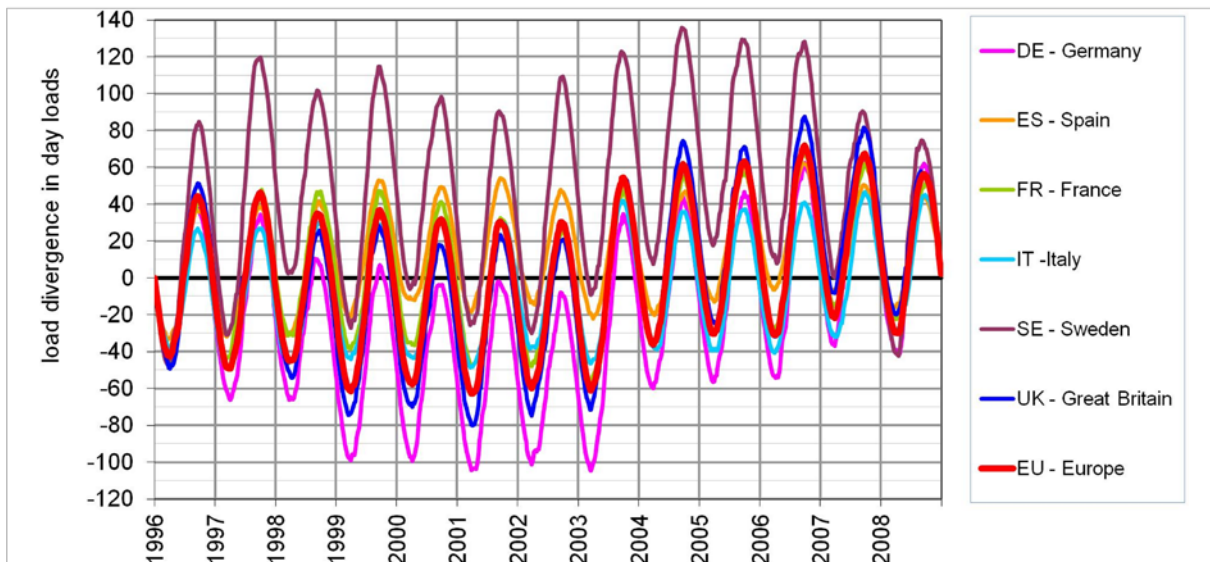


real solar power input in Germany
 in the 1st quarter of 2005 (orange)
 capacity factor, applying to the whole year ca 10%



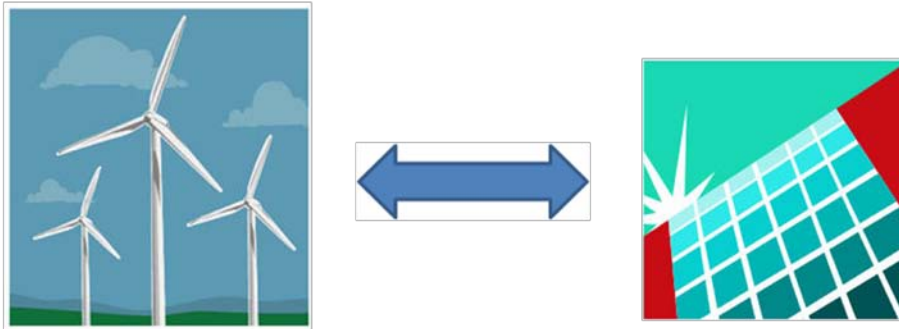
For these studies, global irradiation measurements from Meteosat satellite were available. The known curves of sun power, as daily pulses, reach in Germany in long term average about 10% of the installed peak power of solar modules. Also for the solar energy input, the load divergences were calculated.

Solar Energy Load Divergence



As awaited, the diagram shows, storage systems would fill up in summer time and would empty in winter time. Thereby, the load divergence of solar energy behaves about in opposite direction to the load divergence of wind energy.

Combination of Wind and Sun



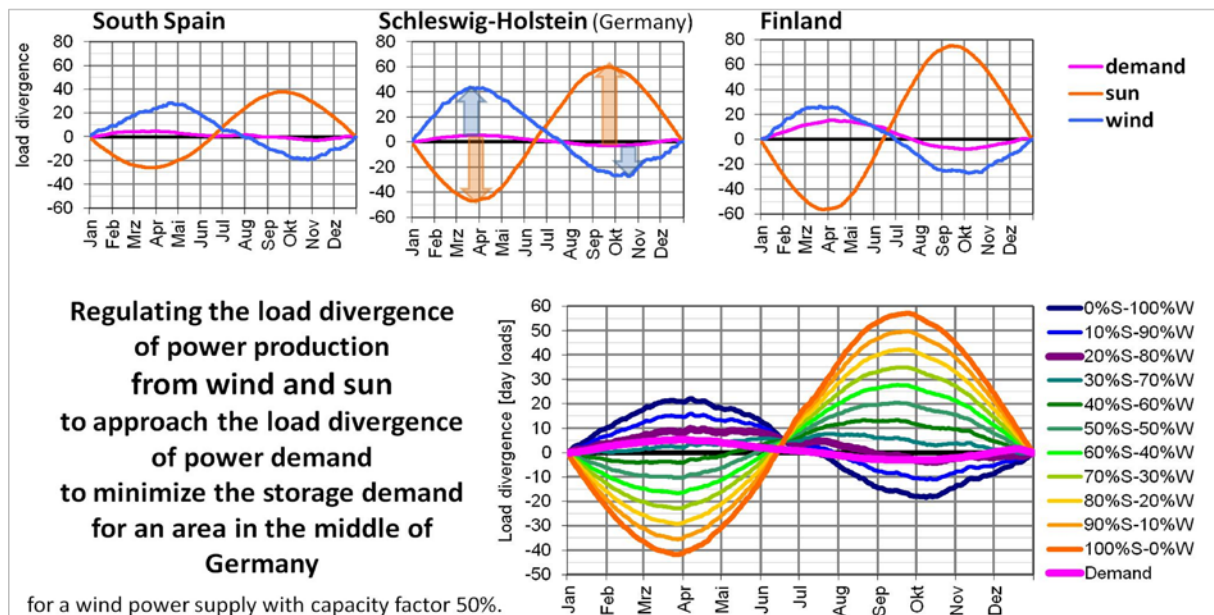
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Therefore it's obvious to think about a combination of both energy sources.

Yearly Average of Load Divergence

for the power demand as well as for the solar and wind power availability in example regions



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To illustrate those circumstances, the analysed period is merged together to one year for the three load divergences of power demand, wind power and solar power.

The sum of the blue arrows in the example for Schleswig-Holstein gives the storage capacity, necessary to balance the wind energy for a power supply, meeting the demand, in this region.

The sum of the orange arrows shows analogical the storage capacity for balancing a pure photovoltaic power supply, meeting the demand.

The production contribution of wind and sun can be tuned for every region and for every country so, that in sum a minimum of divergence from the regional demand would result.

With the, on this way discovered, optimal mixture of energy production, the necessary storage capacity can be minimized.

Real Power Supply and Storage Demand



Real power supply systems must get along with lossy storage systems and with lossy power transmission grids.

Storage systems can furthermore only dispose over a limited capacity and transmission grids can only dispose over a limited transmission power.

Secure Power Supply with Production Reserves

Production reserves

serve beside the

balancing of storage- and transmission losses

also the

ability to bridge over years with higher power demand and/or lower production with limited storage.

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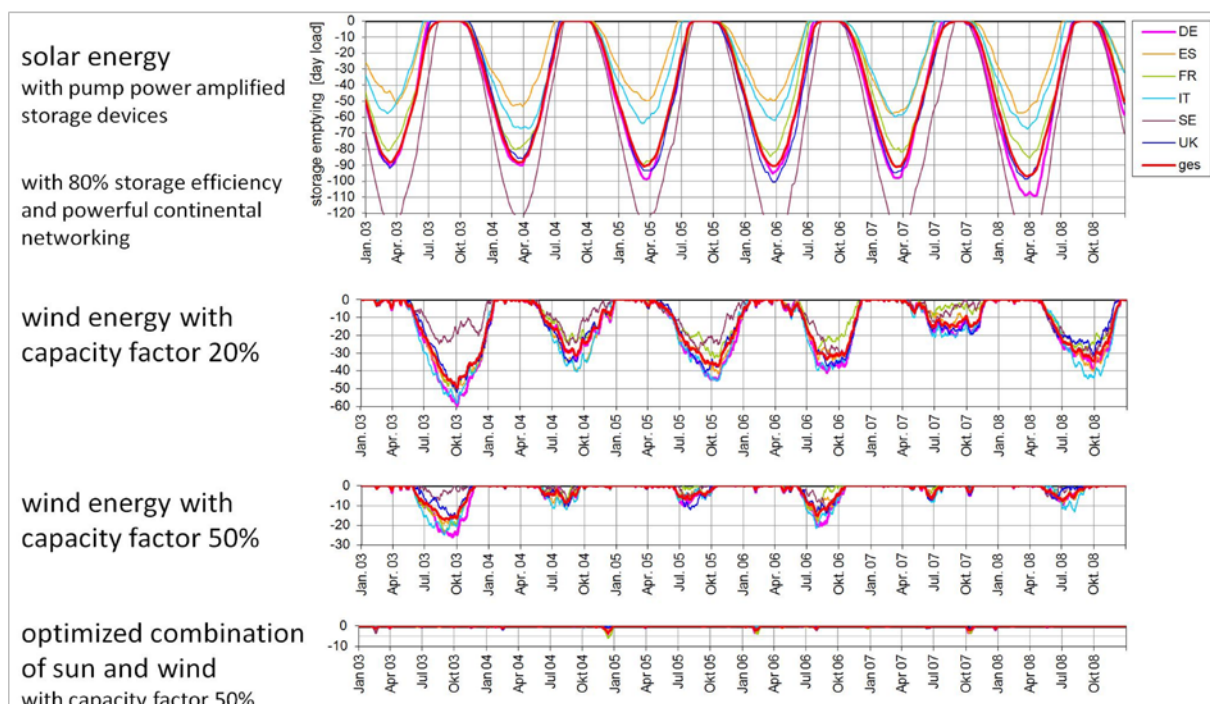
In order to establish a secure and always meeting the demand power supply, production reserves are required.

They allow, in average, to transform more volatile power to electrical power, as really requested.

Production reserves are necessary, to fill up a storage system again, after a shortage of wind power or after low production periods.

The storage management, that would arise under real, technical realisable conditions, is shown in the following storage emptying curves.

Storage Emptying Curves with 30% production reserves



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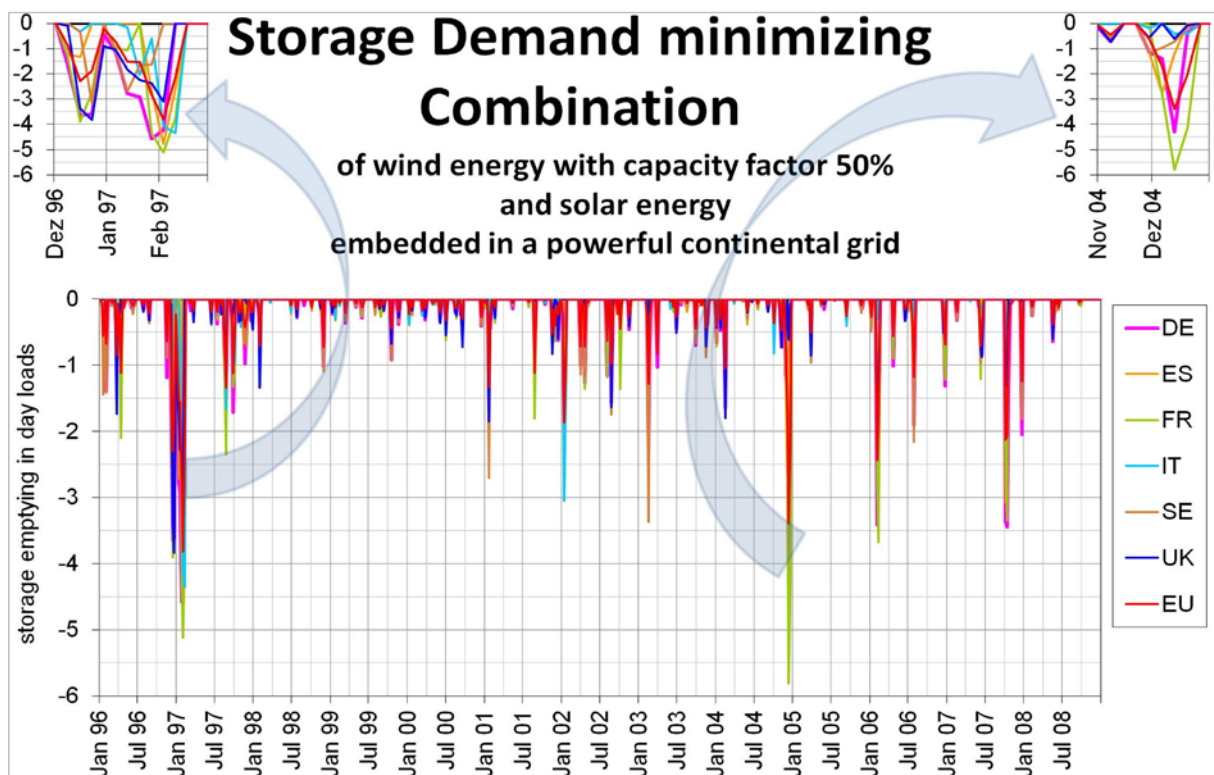
Assuming a given pure photovoltaic production system, the maximum discharge of a storage system would account more than 100 day loads at the end of the winter.

A pure wind energy production, which has in the moment a capacity factor of about 20% in Germany, would lead to a maximum storage discharge of 60 day loads at the end of the summer.

Using wind energy with a higher capacity factor, the storage demand could be reduced to about 26 day loads.

An optimized mix of both types of energy production would drastically reduce the maximal necessary storage capacity.

Those circumstances are shown in the next diagram in a larger scale and for a longer period of time.



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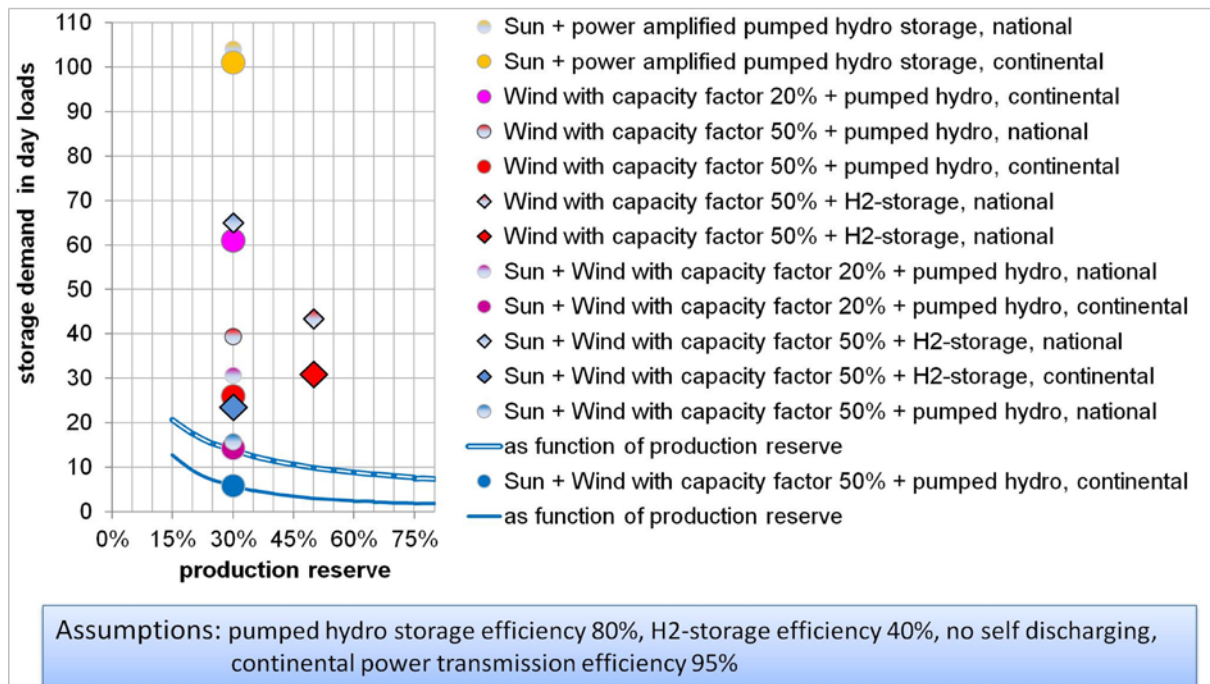
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It can be seen, that only after a couple of years, during winter time, a significant use of the storage capacity would occur.

Often, storage systems would be stressed less than a half day load over many months.

Mostly, the storage systems would be well charged.

How large has to be the „battery“?



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A wide range of analysed results are shown in this diagram.

Every entry in this figure shows a solution for a regenerative electric power supply system, that meets the demand.

The required storage capacity varies from more than 100 day loads in pure solar power scenarios, downwards to some day loads in scenarios with an optimized mix of wind and sun and highly efficient storage systems.

The better the tuning between wind and sun and the cooperation of countries across borders and the higher the chosen production reserve and the higher the storage efficiency, the lower the required storage capacity will be and vice versa.

For example, at 30% production reserve, a storage capacity minimizing combination of sun and wind with a high capacity factor would require about 14 day loads of storage capacity in a national solo run and about 6 day loads in a European cooperation.

=====

more detailed:

A range of analysed results are shown in this diagram.

Pure solar energy would require the largest storage systems. A powerful continental transmission grid could barely reduce it.

Wind energy with capacity factor 20% would work in combination with normal pumped hydro systems only in a powerful cooperation across countries with a storage demand of about 60 days.

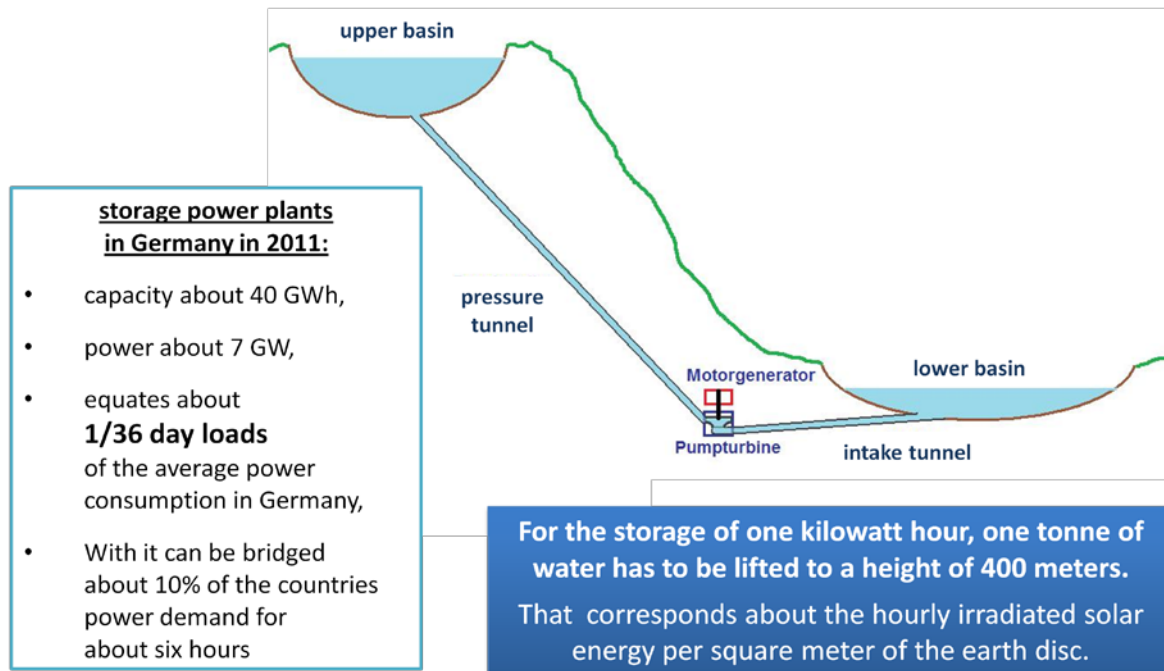
Wind energy with capacity factor 50% would require about 26 day loads with clearly less storage capacity and would also allow a secure power supply in a national solo run with about 40 day loads.

A storage capacity minimizing combination of sun and wind with capacity factor 20% would need about 30 day loads in a national solo run and about 14 day loads in an European cooperation.

A storage capacity minimizing combination of sun and wind with a high capacity factor of 50% would require about 14 day loads of storage capacity in a national solo run and about 6 day loads in an European cooperation. Storage systems with a lower 40% efficiency would require, with 50% production reserve, about 43 day loads in a national solo run and 31 day loads in an European cooperation, when using wind energy with capacity factor 50%.

With an optimized production, a power supply, meeting the demand can still function in a national solo run with about 65 day loads at this low degree of 40% storage efficiency.

Pumped Hydro Storage



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The available pumped hydro storage capacity of Germany correlates to about the 36-th part of a day load of the average power demand.

(To store one kilowatt hour of energy, which comes for a price of about 20 Cent for a private household, a tonne of water has to be lifted to a height of 400 meters in a pumped hydro storage system.)

For a regenerative power supply of Germany, based on wind and sun and without fallback to fossil or nuclear energy carriers, that would mean, ...

Required Storage Capacity

Storage demand in an isolated national initiative of Germany:

in an optimized production structure with electric power, alone from wind and sun, with 30% production reserve

capacity about 20 TWh, power about 90 GW
corresponds to about **14 day loads** of the average consumption,
requires about **500 times the existing storage capacity**

Storage demand of Germany in an European cooperation:

in an optimized production structure with electric power, alone from wind and sun, with 30% production reserve

capacity about 9 TWh, power about 90 GW
corresponds to about **6 day loads** of the average consumption,
requires about **200 times the existing storage capacity**,
efficient upgrading of the European power grid and a complete upgrade of wind- and solar energy in all countries of Europe

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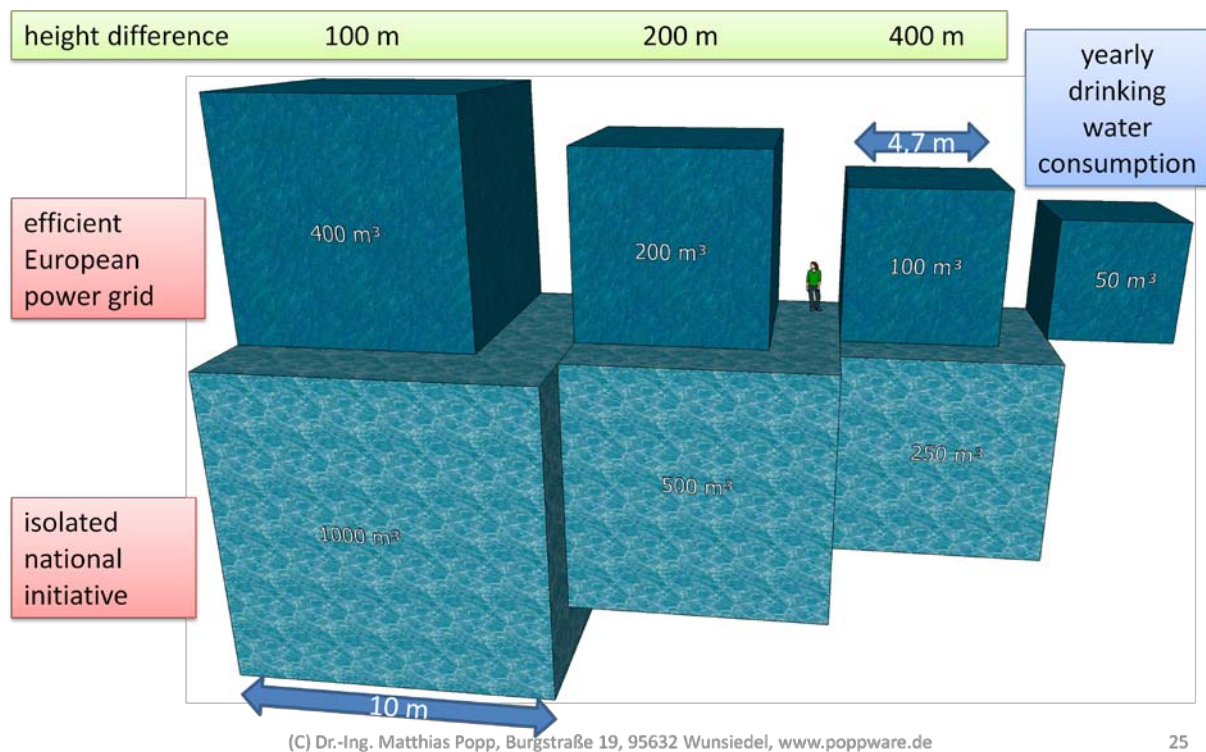
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... , that in a national solo run, the actually available storage capacity would be required about 500 times as large.

In an optimized European cooperation, which unfortunately can't be expected today, the required storage capacity would still reach about 200 times of the existing capacity.

The thereby required water volumes of pumped hydro systems per person of the German population are shown on the following sheet in a true scale.

Water Demand for Energy Storage per Person



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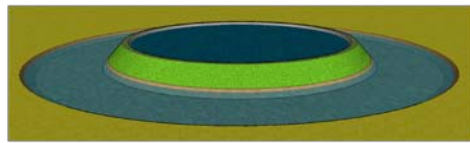
The required storage capacity per person would be between 100 and 250 kilowatt hours, depending on the reachable cross country balancing effects.

Depending on the reachable average height differences of the water surfaces of the pumped hydro storage systems, the necessary exchange volume per person would be between 100 m³ and 1000 m³.

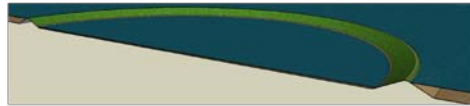
A thinkable geotechnical option to realize such storage systems is a Ringwallspeicher, which I can present you at the poster exhibition.

Ringwallspeicher

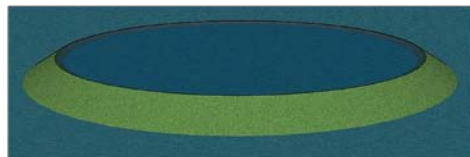
as geotechnical option to create large storage capacities



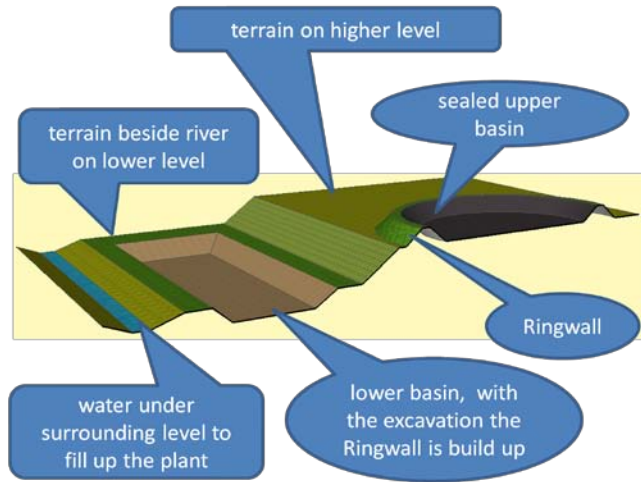
for the flat land



for deep waters



for flat waters



with natural height differences

doubling geometric dimensions 16-folds the storage capacity

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Therewith, large storage capacities with a high degree of efficiency can be built also in areas, where classic pumped hydro systems wouldn't be considered, because large height differences can be established and natural existing height differences can be increased.

You are welcome to visit me at the poster exhibition, to get written information about this storage system or to hear more about it, in a personal conversation.

Conclusion

A secure, robust and meeting the demand, 100% regenerative power supply requires today:

- one wind power station for about 1300 people,
 - about 20 m² solar module area per person,
 - about 40 m² water area per person
- for power storage plants with high efficiency, decentralized, distributed well over the country.

That requires in Germany about 1% of the countries area.

Compared to this, a 100% electrical power supply with biomass would require about 2200 m² per person or nearly half of the countries area.

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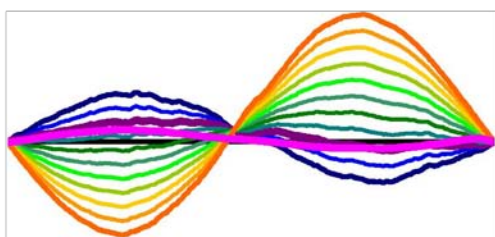
Today, a secure and 100% regenerative power supply, which meets the demand, is a real option for the future.

There are a lot of different possibilities to realize it.

It is less of a technical or financial challenge, than much more the question of winning acceptance in the society.

Also the establishment of appropriate public law and economical framework should be created to actuate the required investments.

Thank you for your Interest



You are welcome to contact me to find out a suitable energy mix for your preferred storage solutions and for a holistic approach to lay out your energy system.



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Please ask me now, if you have any questions.