Combining Wind And Solar With Energy Storage To Achieve The Greatest Economic Value

Presentation of Dr.-Ing. Matthias Popp

at

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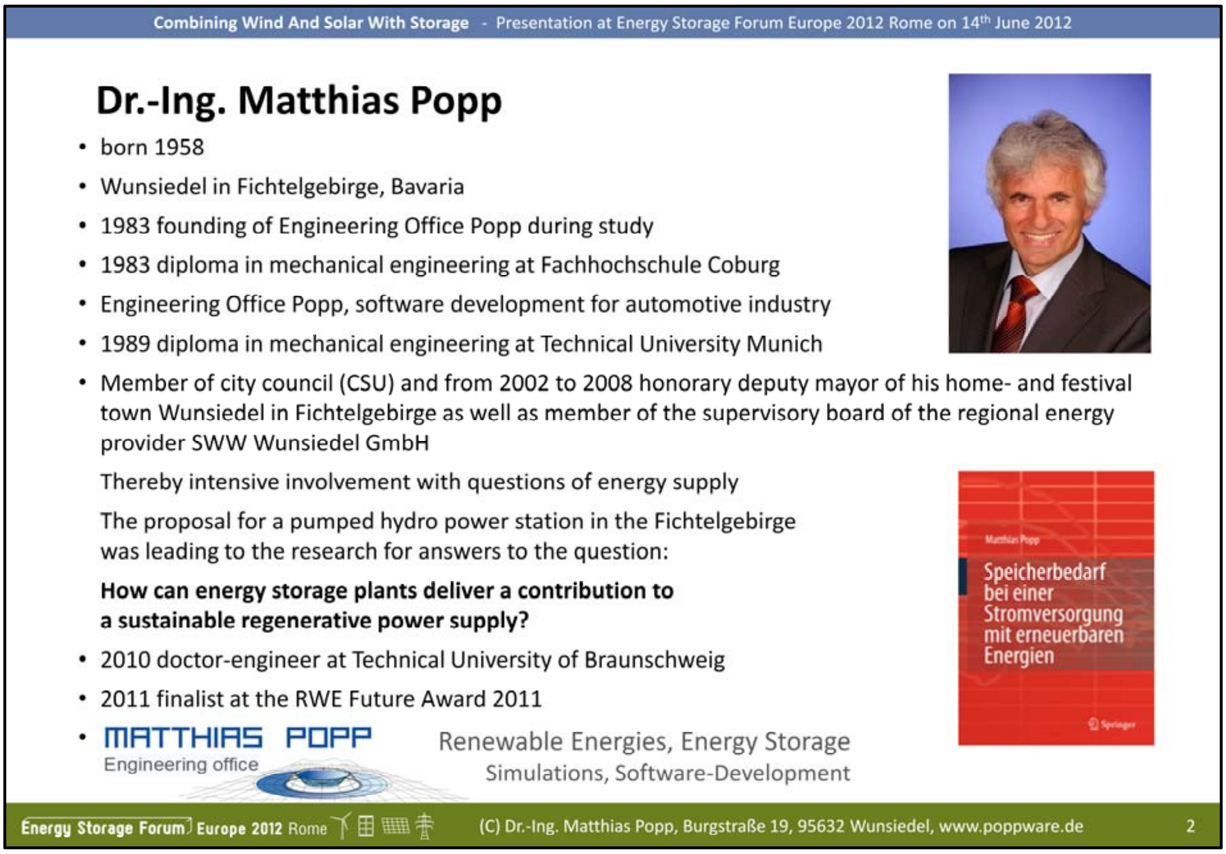
Ladies and Gentlemen,

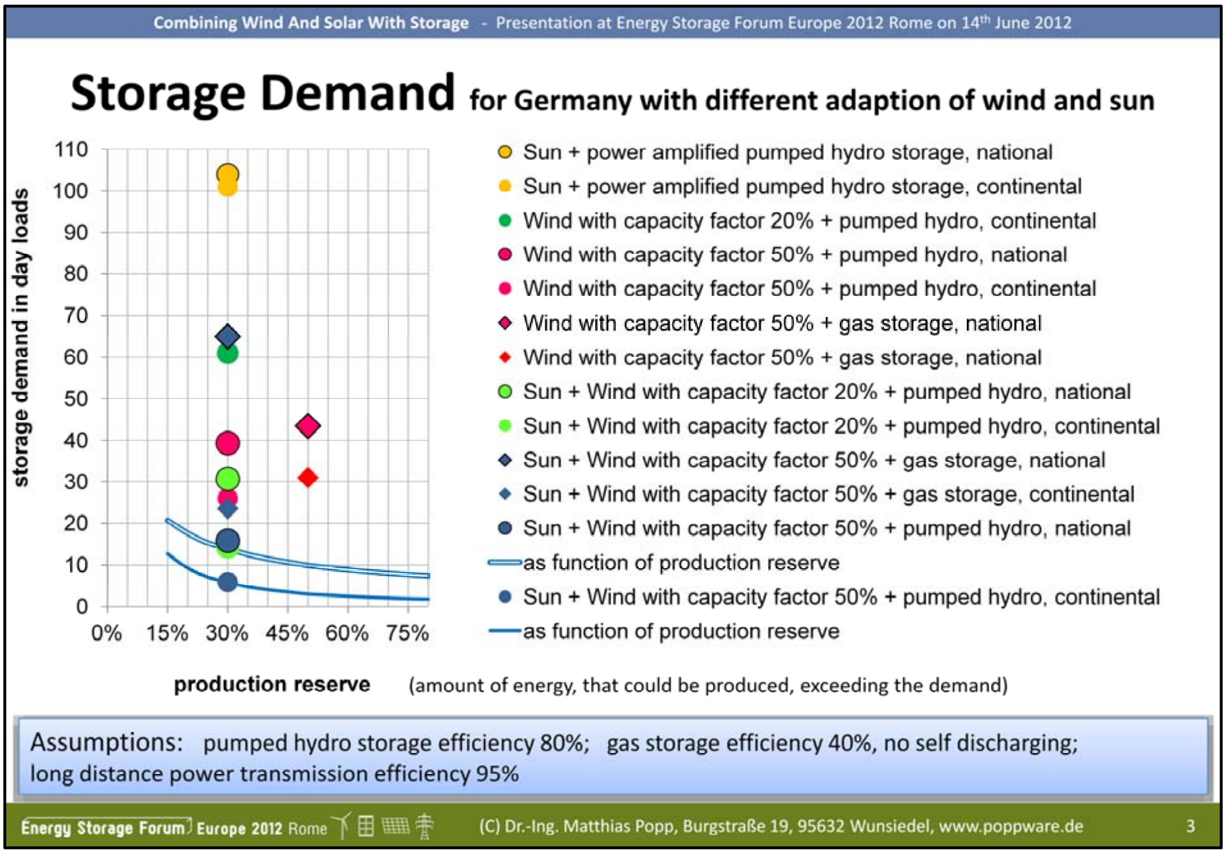
let me introduce myself and give you some information about my office.



In 2010, I made a doctorate with the title:

„Storage demand for a power supply with renewable energies“.

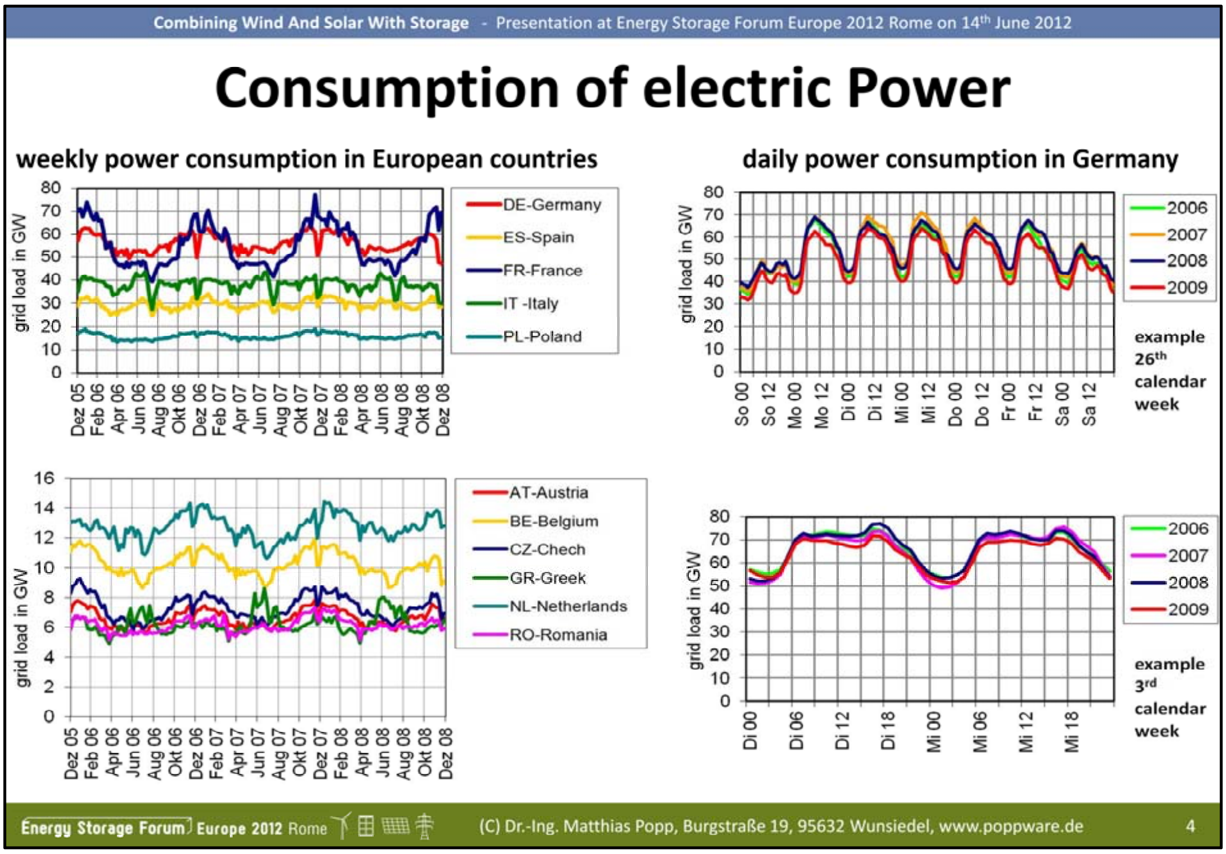
This doctoral thesis is published as book by Springer in German language.



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

A day load is the, in average, daily consumed, amount of energy in the supplied area.

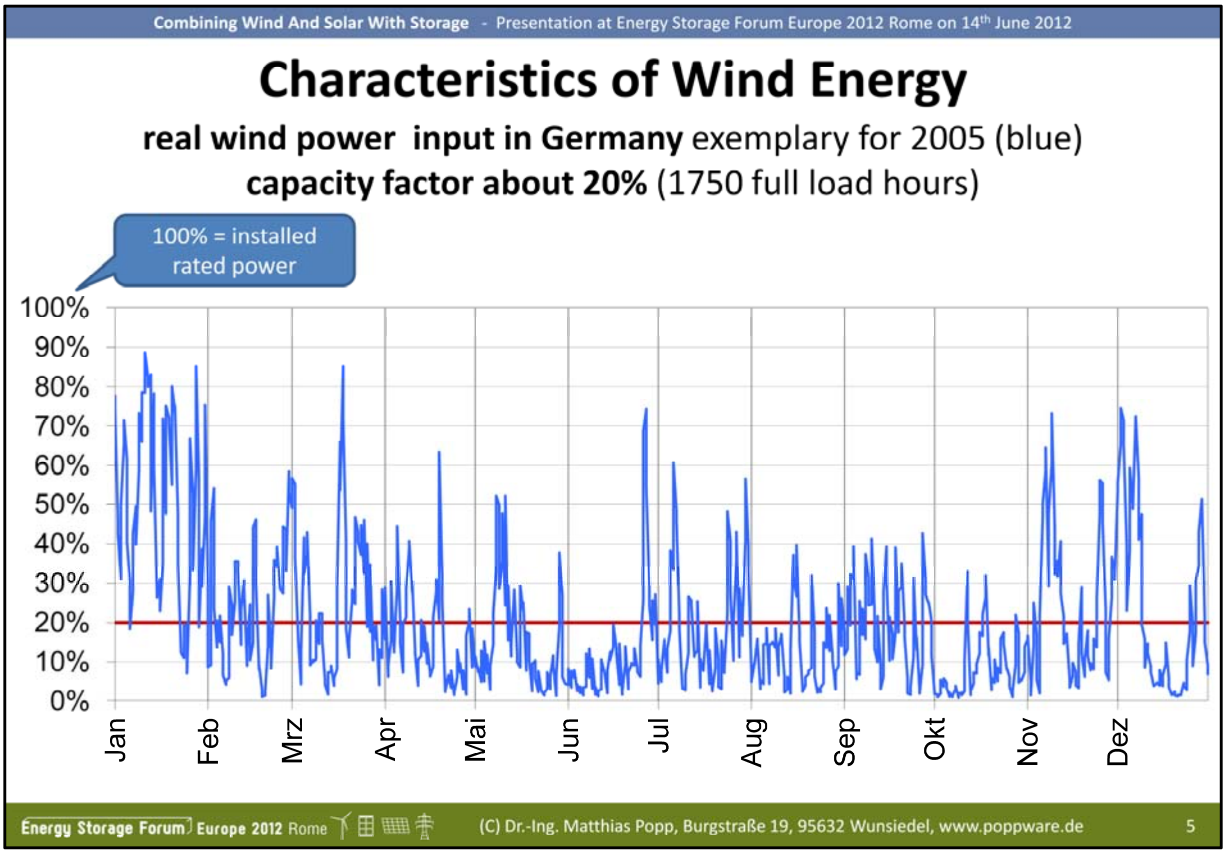
The better the tuning between wind and sun, the cooperation between countries, based on well developed transmission grids and the higher the chosen production reserve and the higher the storage efficiency, the lower the required storage capacity will be and vice versa.



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, independently from the power production system.



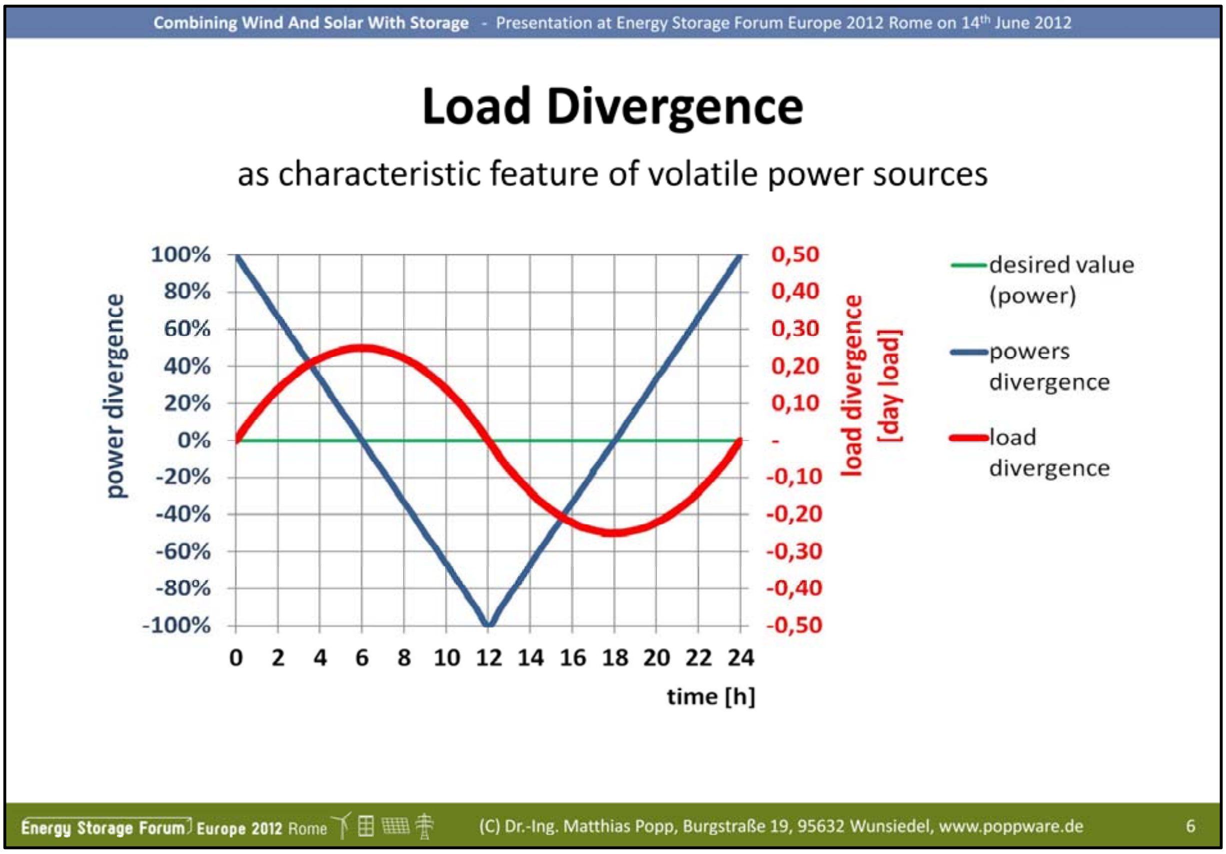
The maximum installed generating power of the wind power plants in Germany is never produced, because there is hardly a constant strong wind across the whole country.

Sometimes, there are countrywide weak wind phases, where the wind power production goes almost 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 their installed power.

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

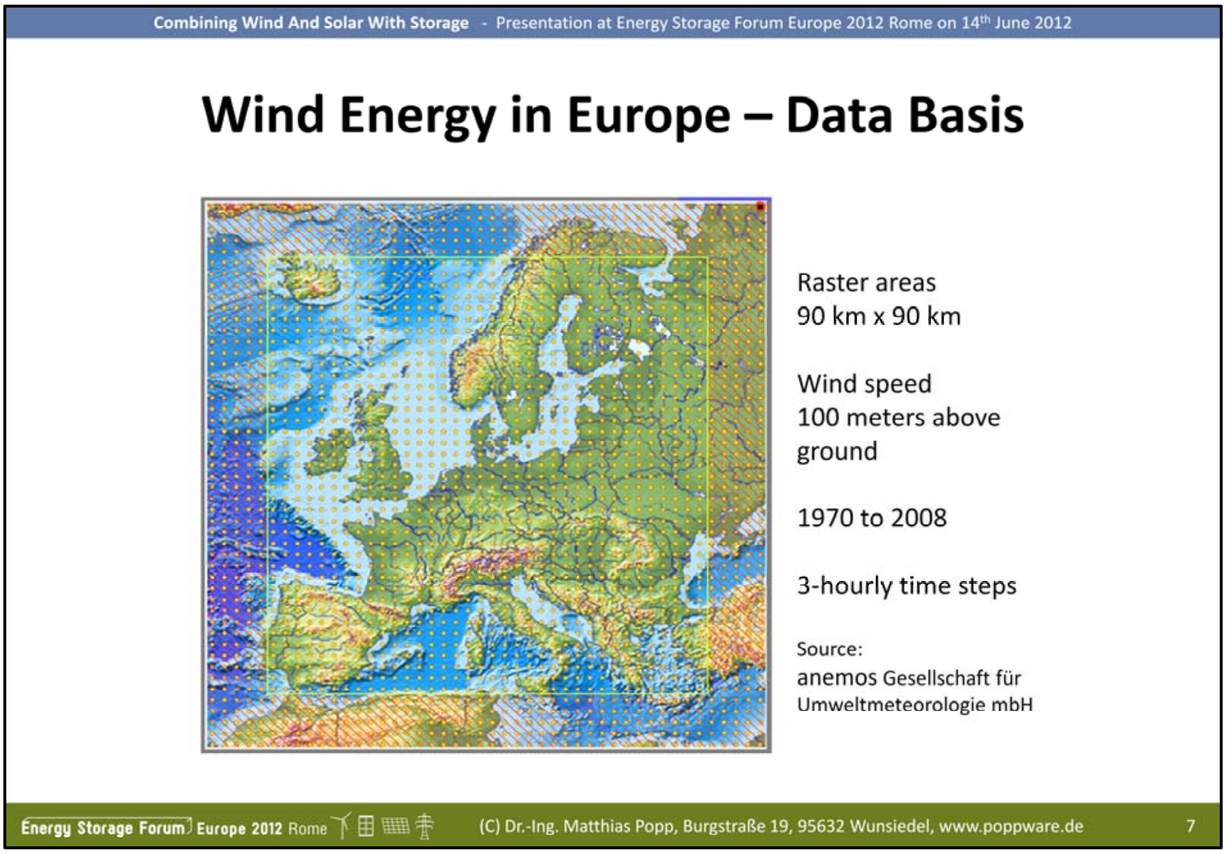


It shows, how an ideal storage system without losses has to be operated,
to transfer a volatile power production into a constant power supply.

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

At the end of the analysed 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.



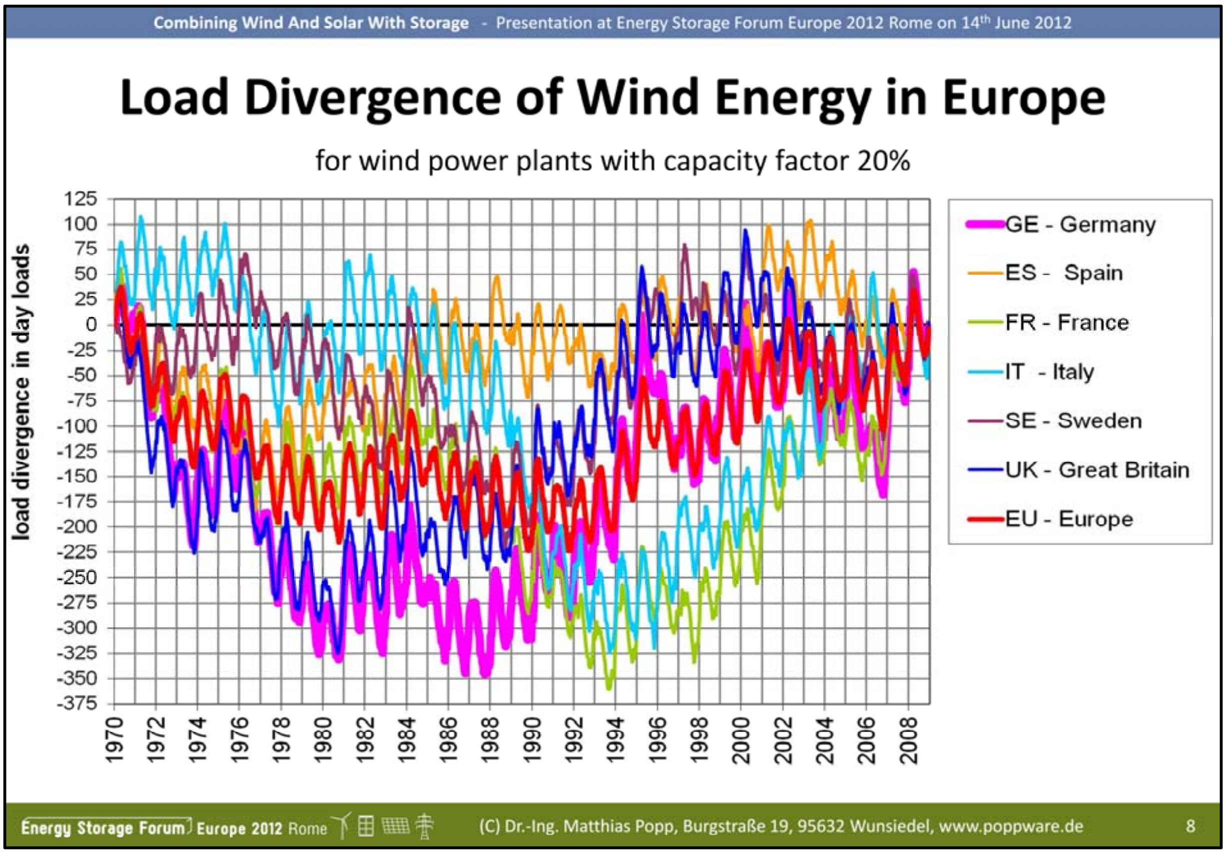
With the concept of load divergence, the wind energy of Europe was analysed.

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 at the identified load divergences.



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.

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.

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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.

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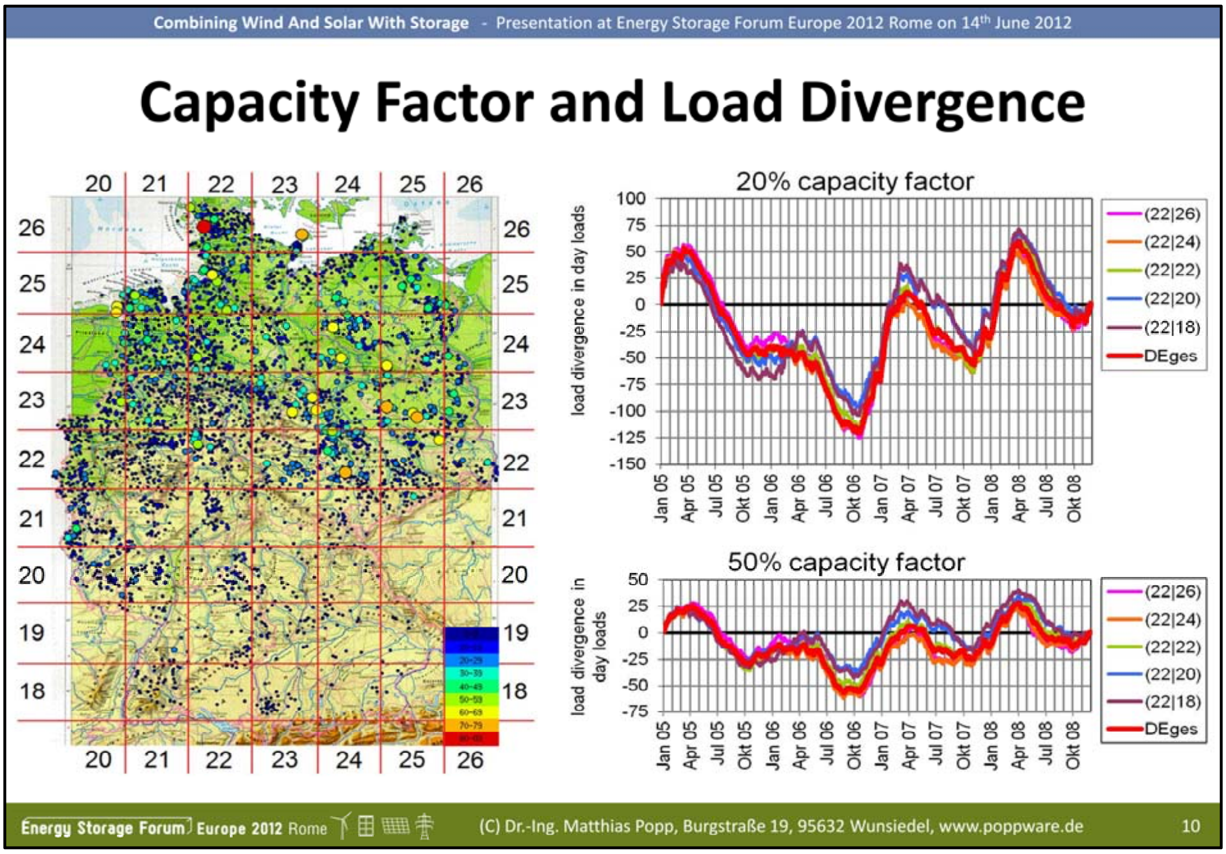
If wind energy plants are designed for a larger number of full load hours, or meaning the same, for a higher capacity factor, the load divergence of the transformed wind energy can be reduced drastically.

Some manufacturers offer wind power stations, leading into this direction.



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

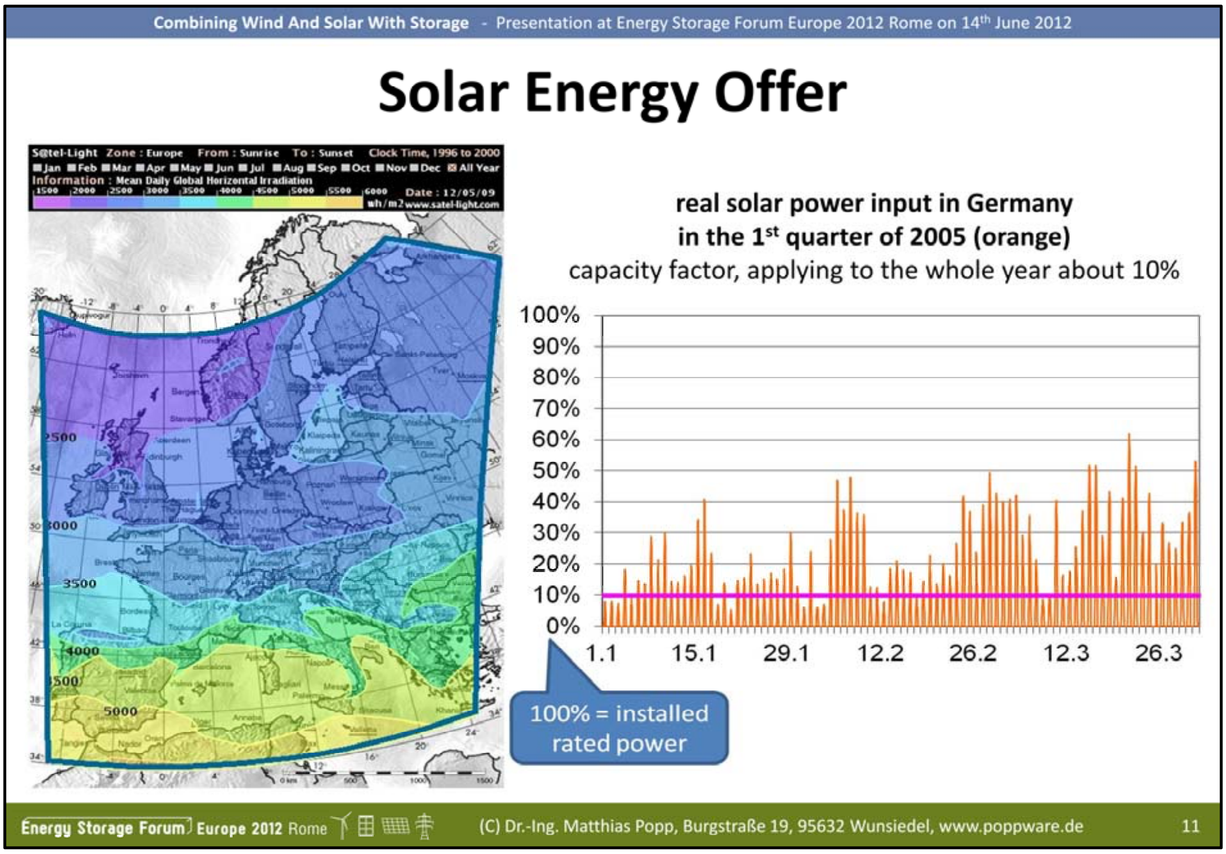
Comparing the load divergences of the single areas of Germany, it can be seen, that the curve shapes are very similar.

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 effect of a powerful electricity grid in a national solo run will therefore stay within borders.

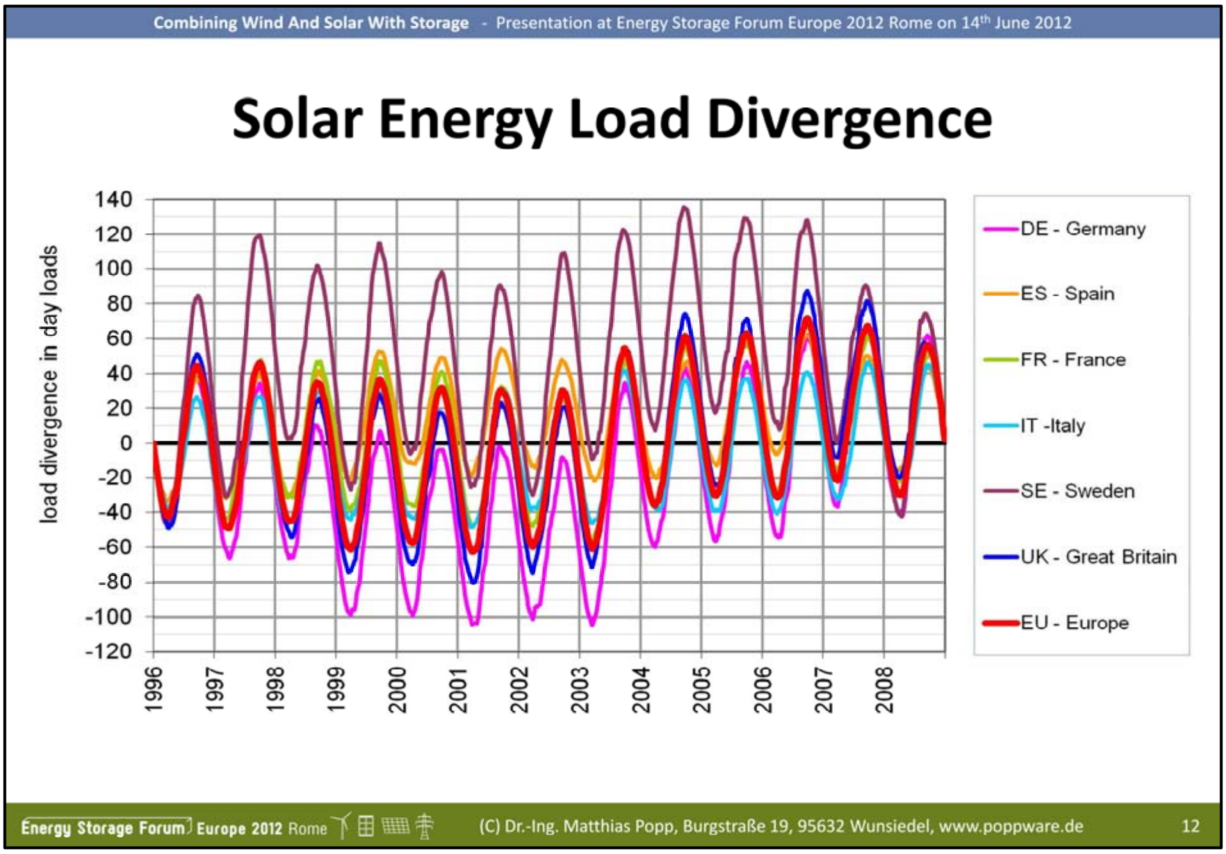
However, a higher capacity factor would have a much bigger balancing effect.



For these studies, global irradiation measurements from meteosat satellite where available.

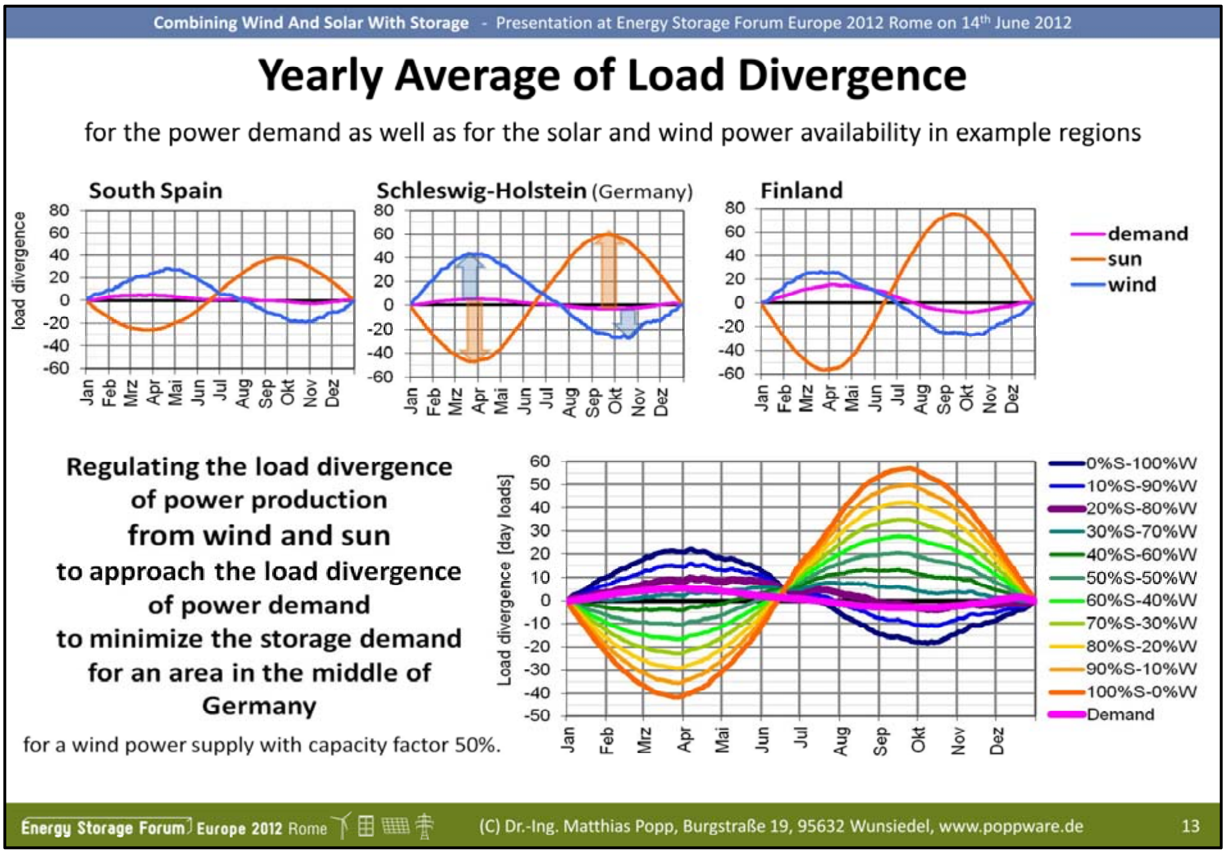
The known curves of sun power, as daily pulses, reach in Germany in long term average about 10% of the installed peak power of solar modules.

Also for the solar energy input, the load divergences were calculated.



As awaited, the diagram shows, that storage systems would fill up during summer time and would empty during winter time.

Thereby, the load divergence of solar energy behaves about in opposite manner to the load divergence of wind energy.



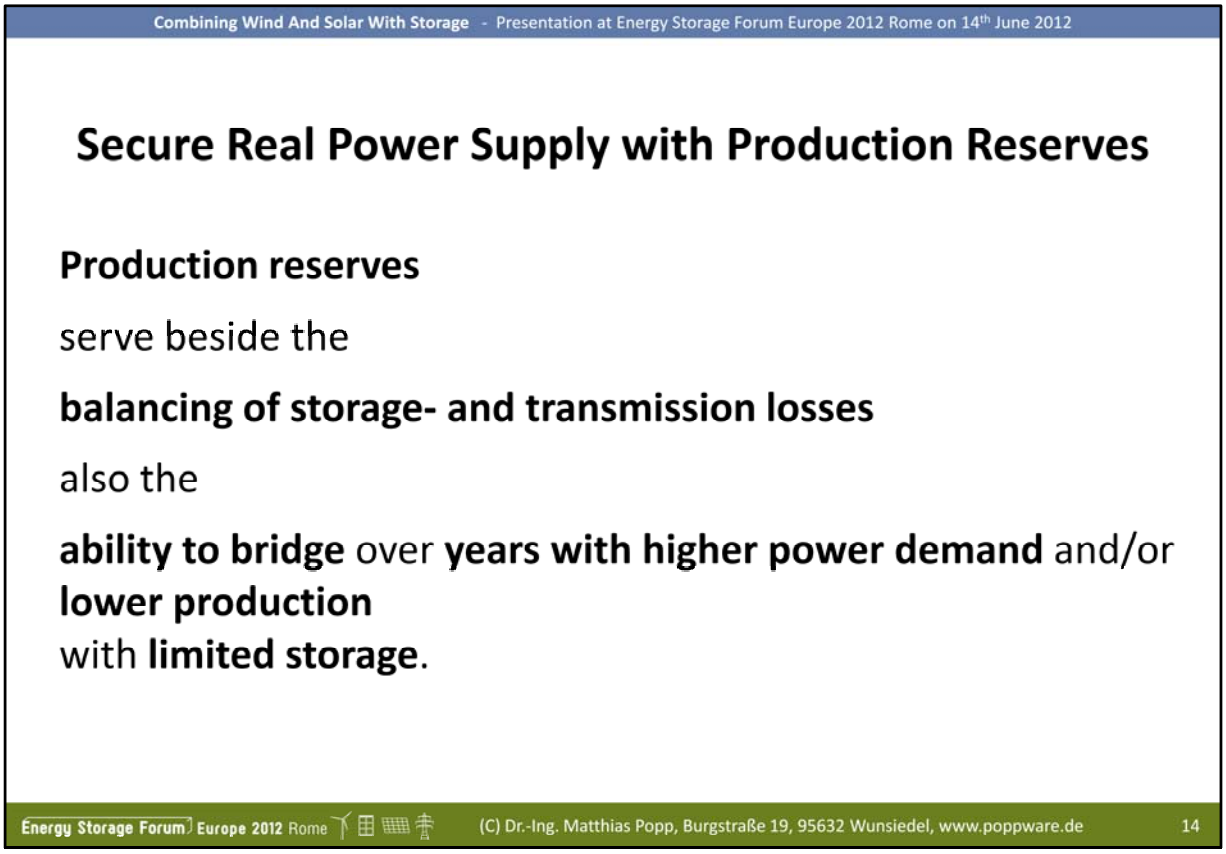
To illustrate those circumstances, the analysed period is merged together to one year for the three load divergences of power demand, wind power and solar power.

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 demand for balancing a pure photovoltaic power supply.

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 this discovery of an optimal mixture of energy production, the necessary storage capacity can be minimized.



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

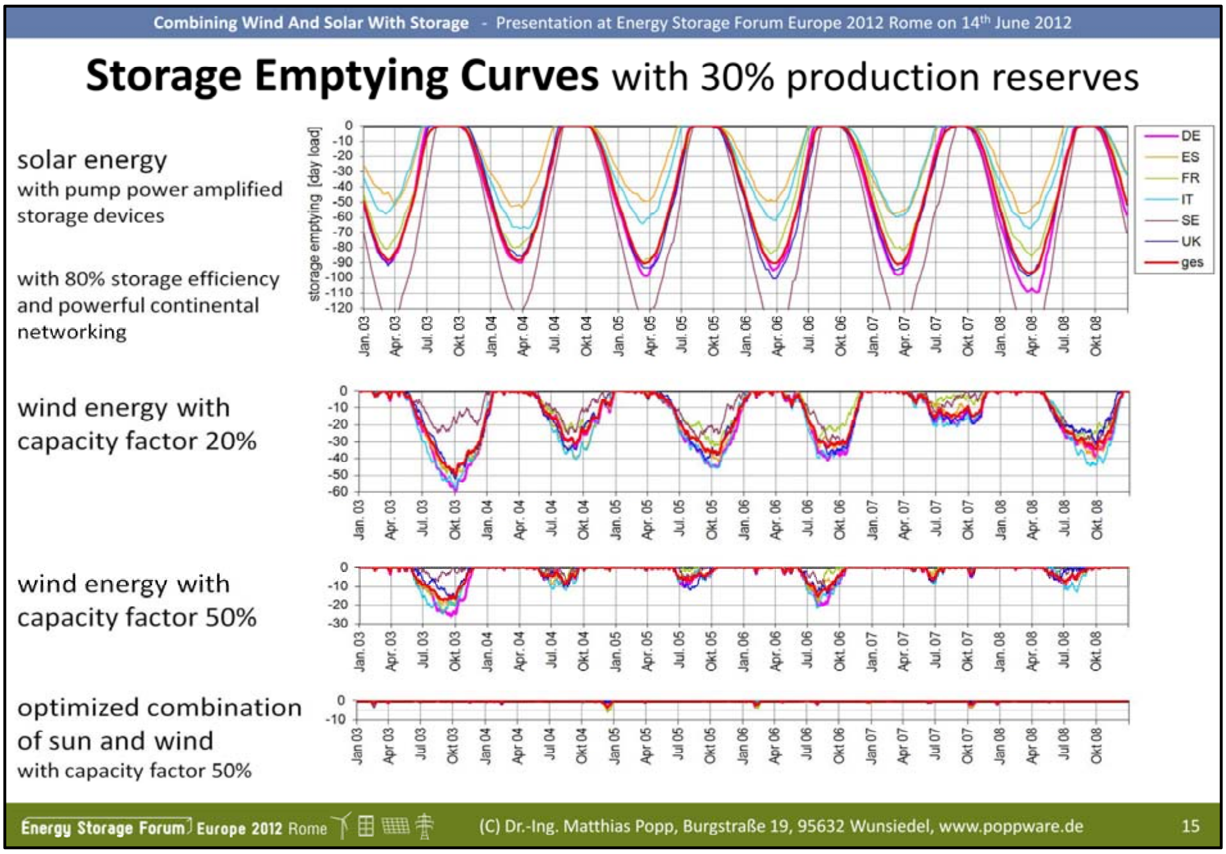
Storage systems can furthermore only dispose over a limited capacity and transmission grids can only dispose over a limited transmission power.

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 storage systems again, after low production periods.

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



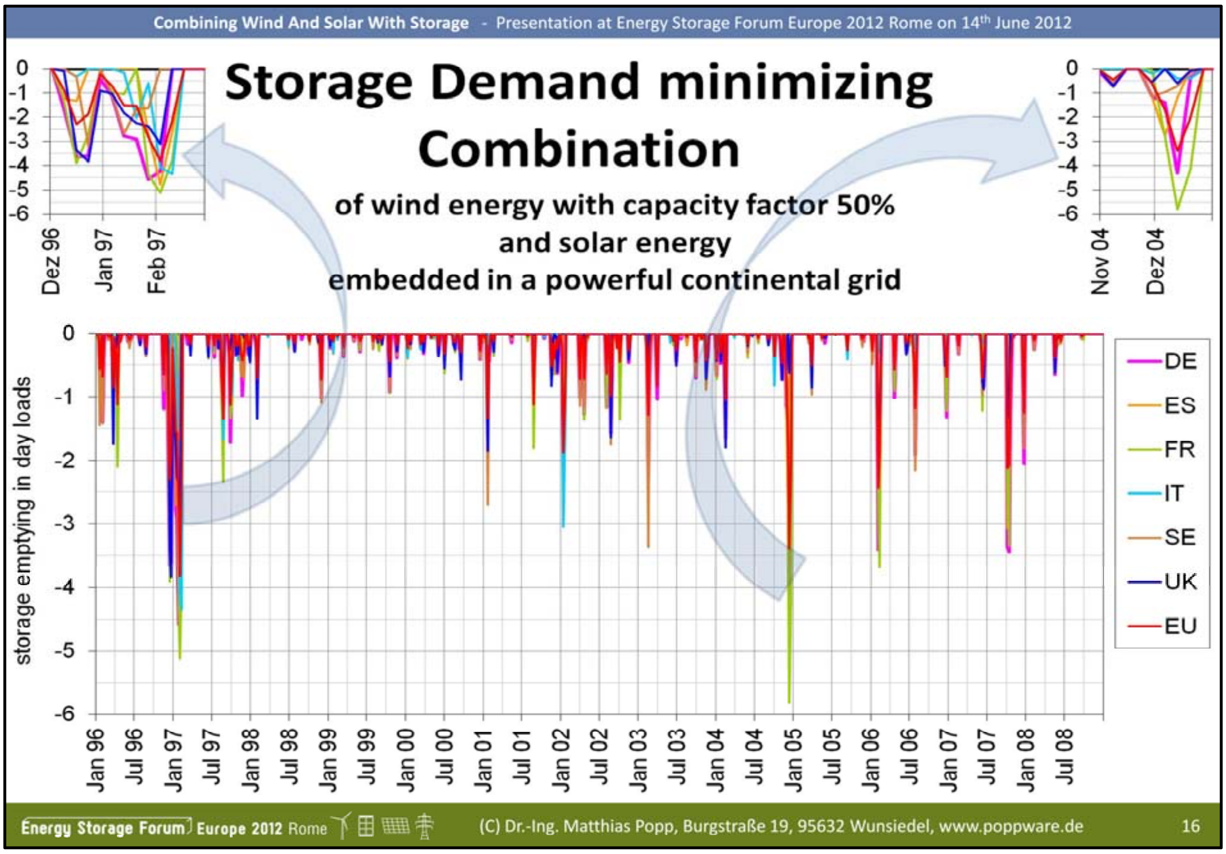
Assuming a given pure photovoltaic production system, the maximum discharge of a storage system would account more than 100 day loads at the end of the winter.

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.

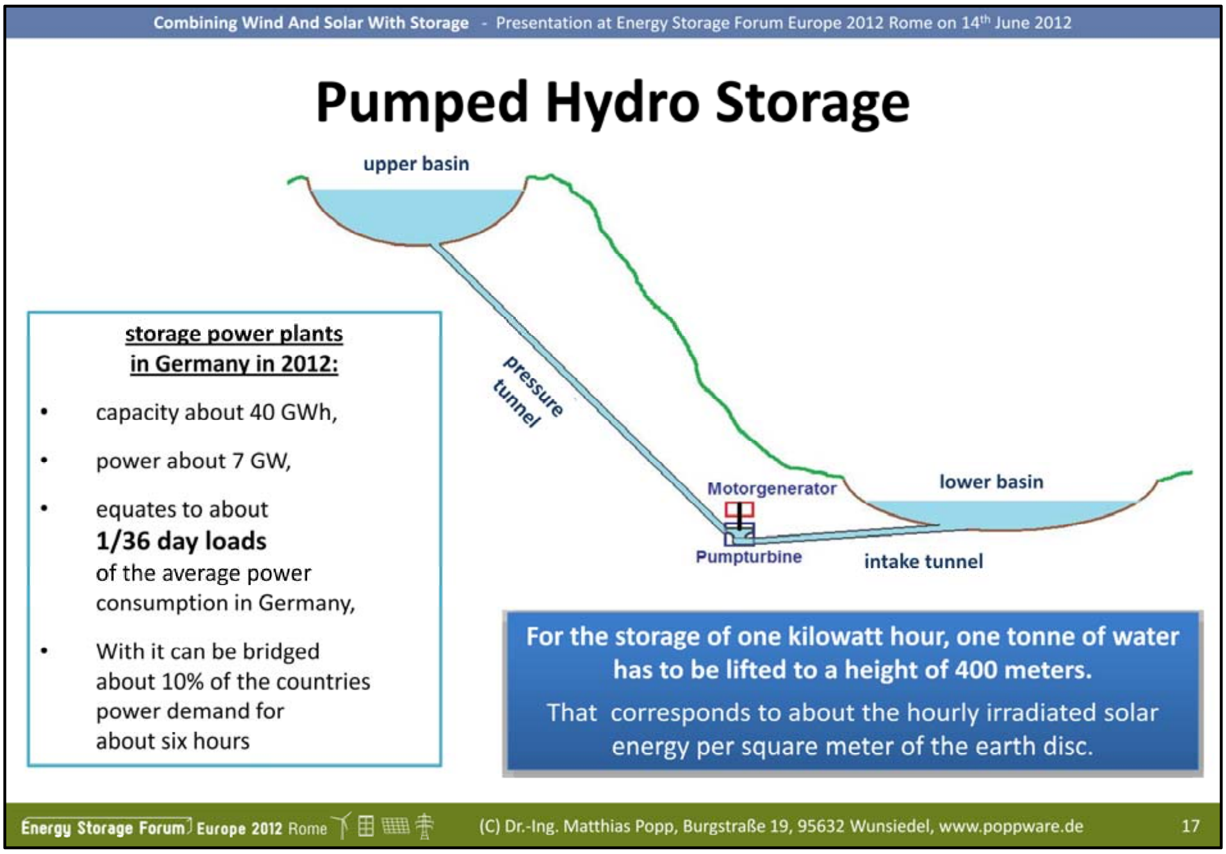
Those circumstances are shown in the next diagram in a larger scale and for a longer period of time.



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.



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

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

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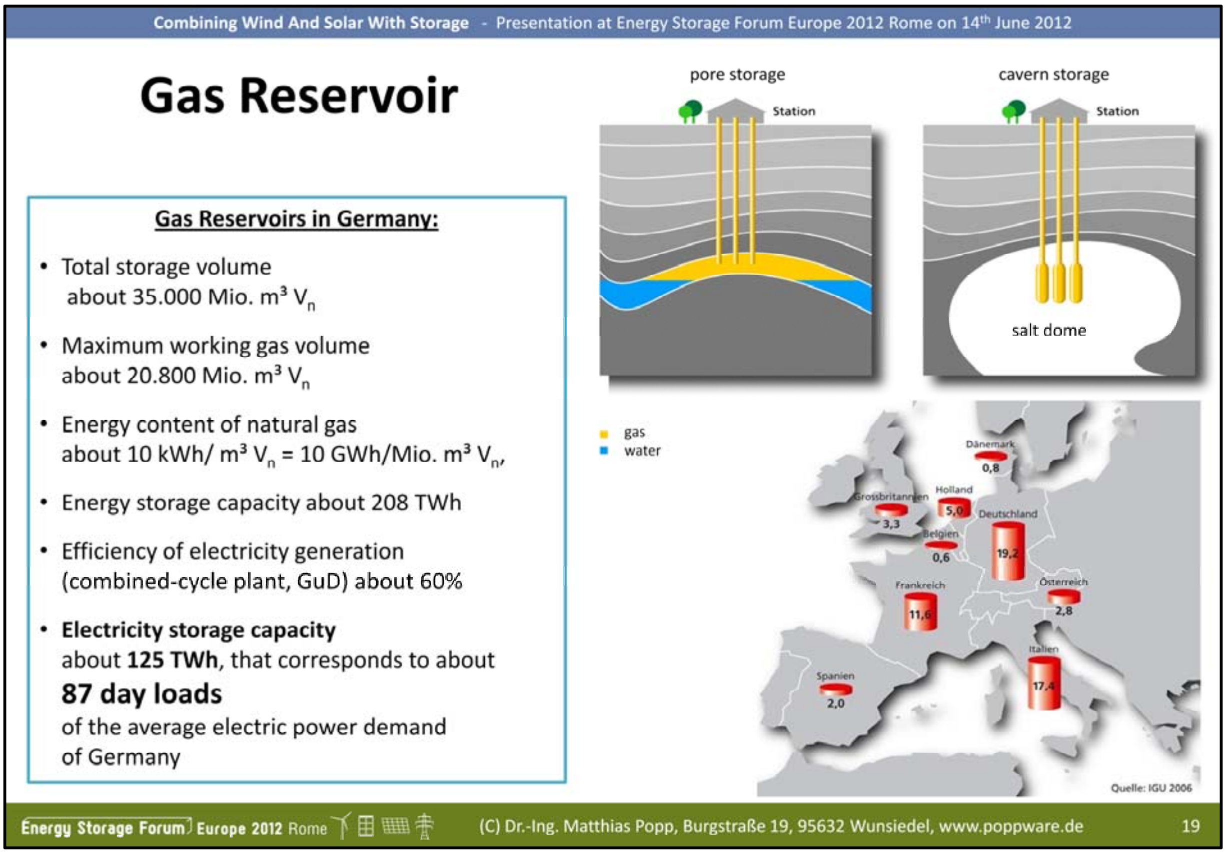
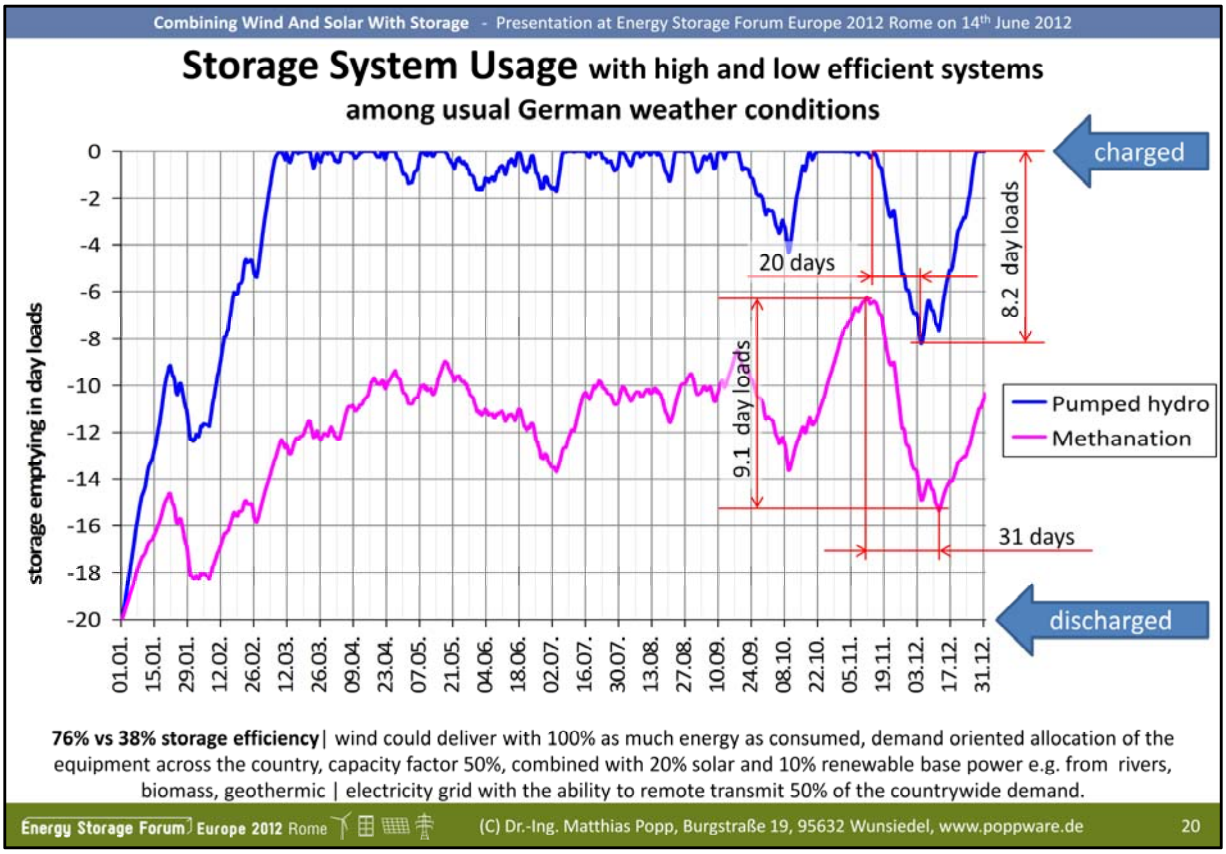
... , that in a national solo run, the actually available storage capacity would be required about 500 times as large.

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.



Because of the huge storage demand, caused by the future development of renewable power supply,
alternative storage technologies are considered, with hydrogen or methane as energy carriers.

In contrast to the approved pumped hydro technology, the required storage capacity seems to be no problem, but much larger power losses would arise.



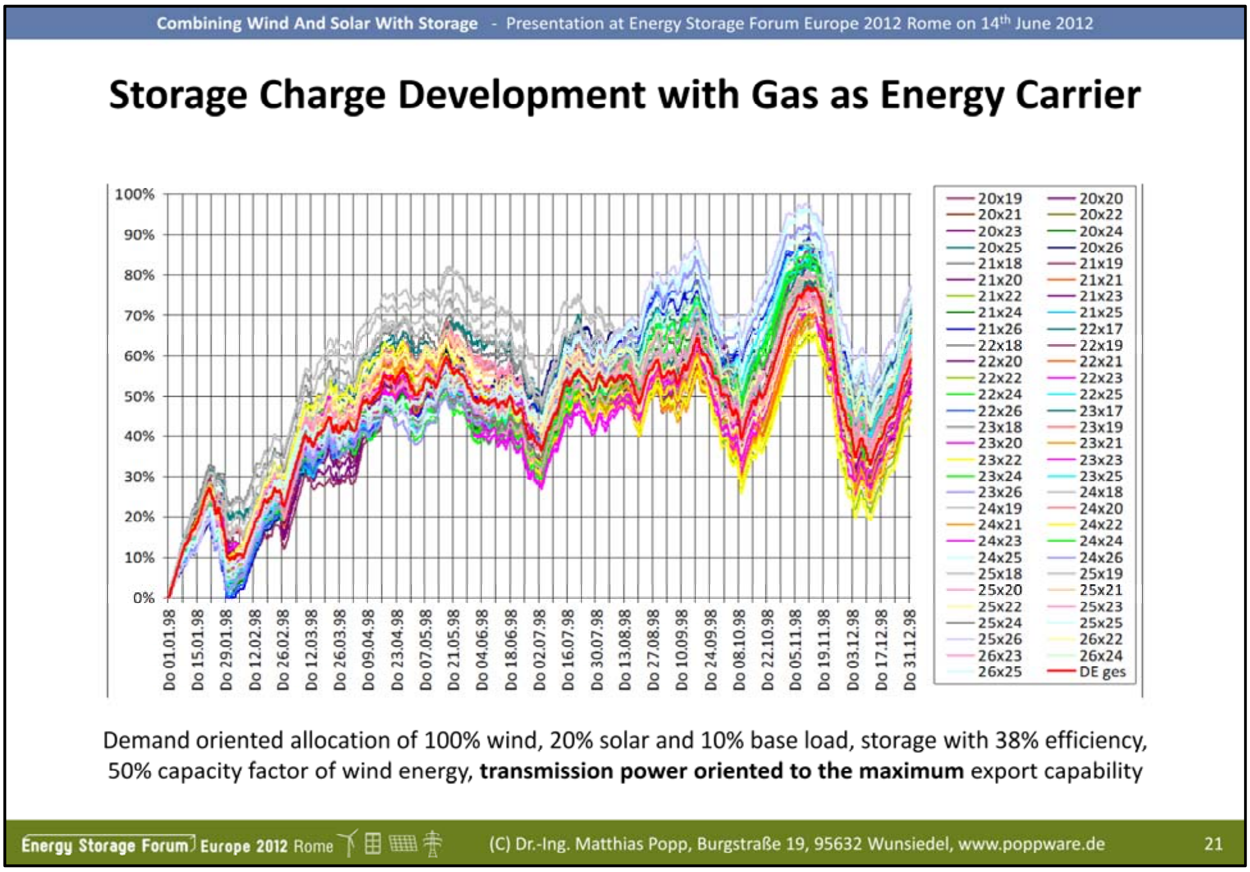
Longer weak wind phases will define the future challenge for storage systems and no longer the balancing between day and night.

During long lasting and country wide affecting meteorological conditions, neither a powerful electricity grid, nor a smart grid solution can fulfil the task.

If not a powerful conventional, on demand available production park shall be established and kept in standby state,
storage systems, designed with the necessary capacity reserves, will be required to meet this challenge.

As soon as these systems will be available, neither network expansion, nor smart grid solutions, nor short time storage systems are needed.

Short time storage and demand site management can than be fulfilled by the long time storage systems.



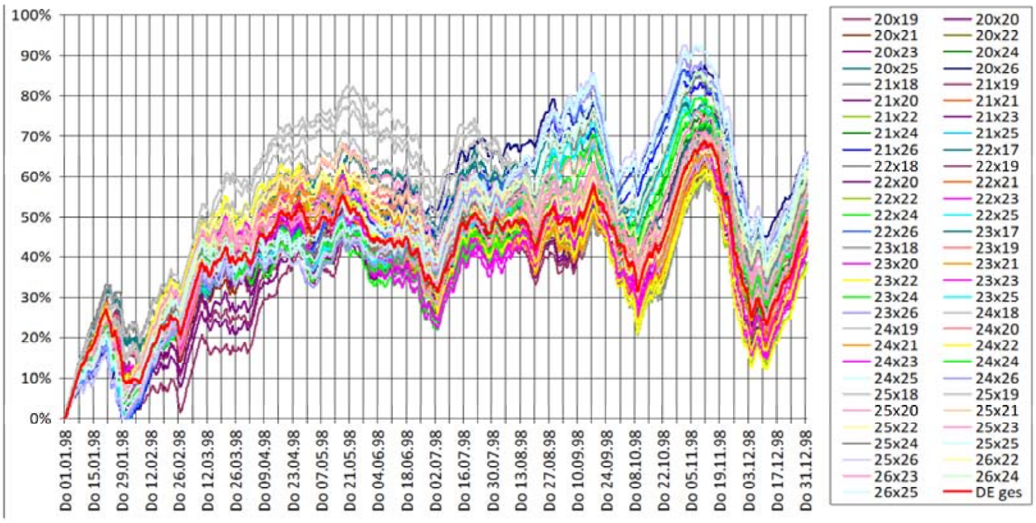
This results follows from the analysis of an optimized renewable electricity production system with an ideal allocation over the German country, based on raster areas with 90 times 90 kilometres as shown before on slide 10.

This chart shows charging and discharging of the assumed storage systems in every region of Germany for one exemplary year.

It belongs to storage systems, based on methane as energy carrier, in combination with a maximum power transmission grid.

An important result of this analysis, with real weather data, is, that the volatility of power availability in all regions of Germany is quite similar.

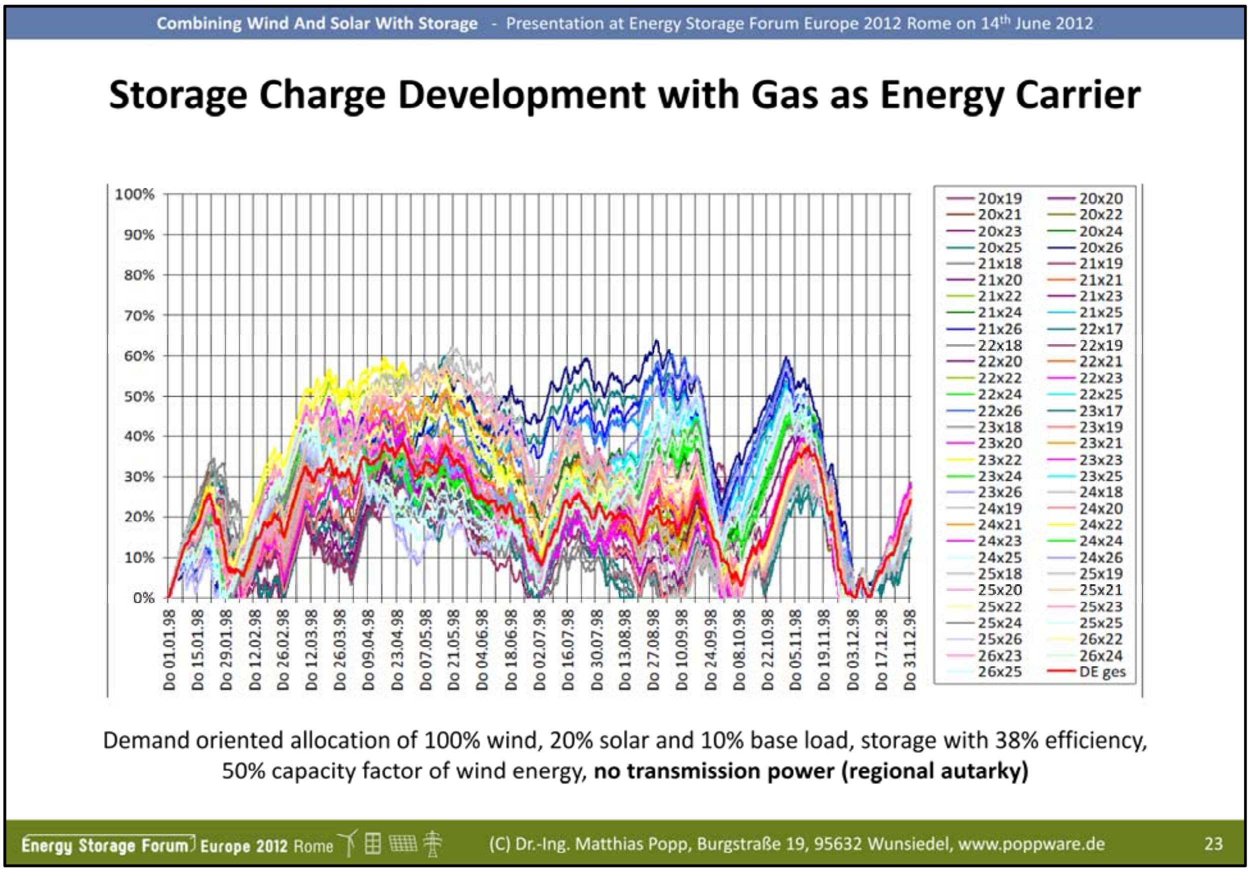
Storage Charge Development with Gas as Energy Carrier



Demand oriented allocation of 100% wind, 20% solar and 10% base load, storage with 38% efficiency, 50% capacity factor of wind energy, **transmission power limited to 50%** of the export capability

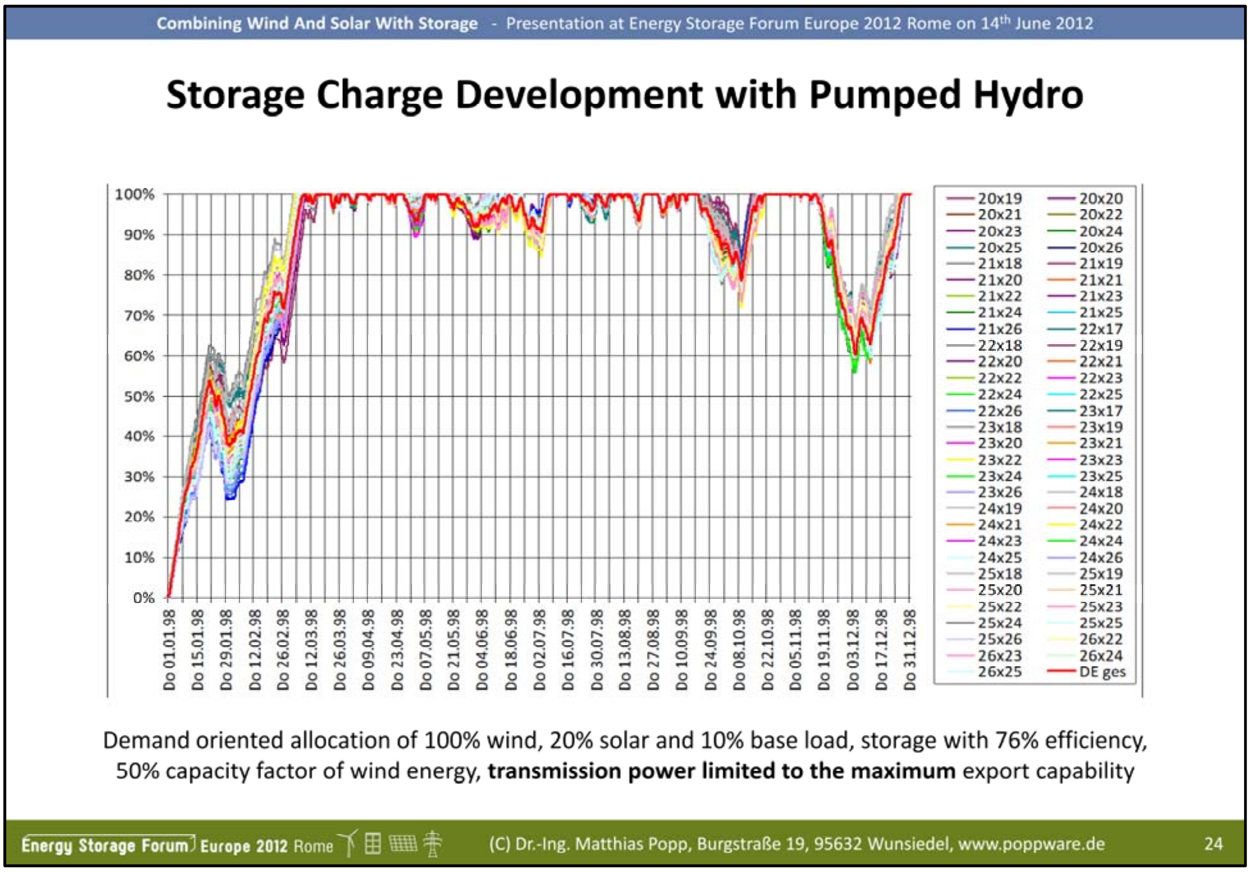
If the same production structure would be operated with a transmission grid, that could maximal transmit 50% of the regional power demand, the storage charge would rarely change.

At the end of the exemplary shown year, the storage load is about 10% lower.

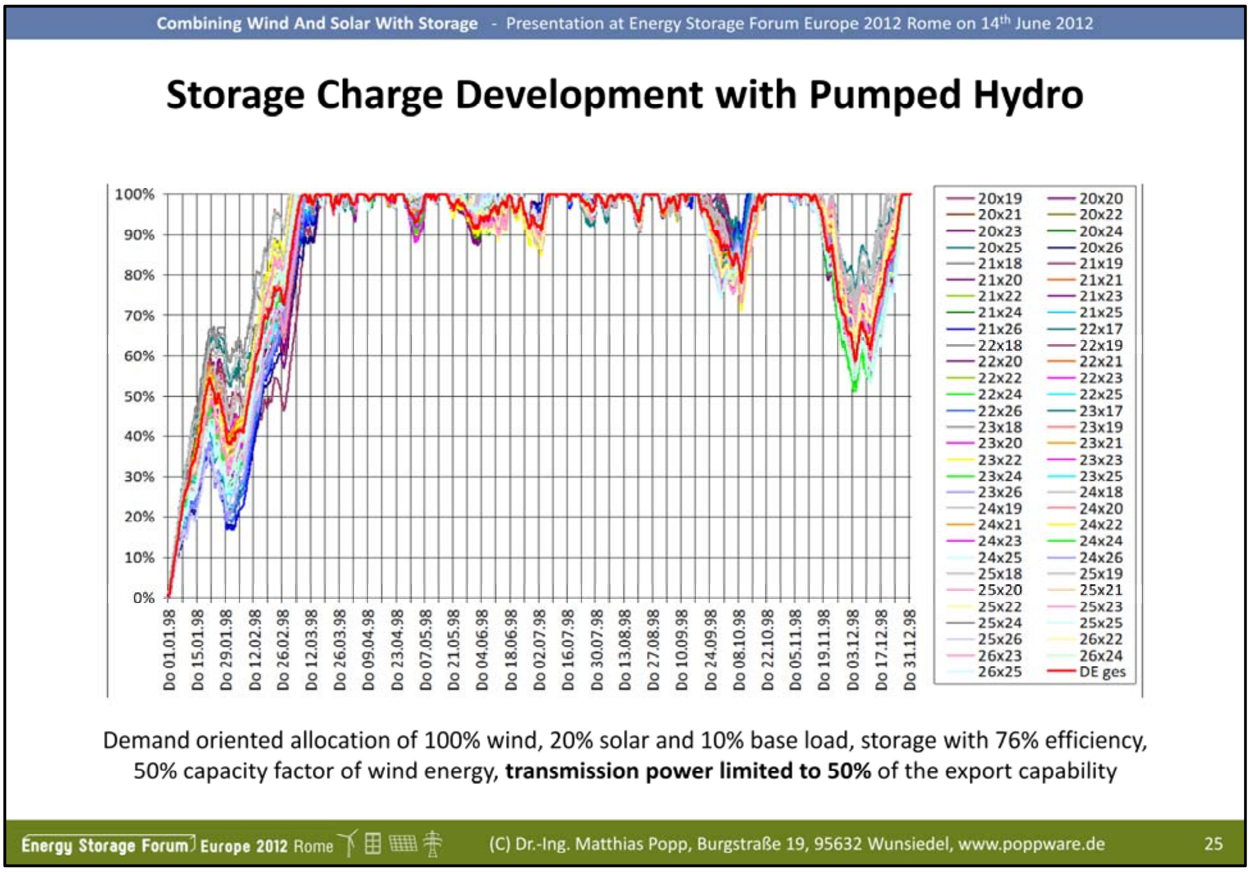


Even if theoretical, no long distance transmission power at all would be available, the storage systems would nearly have been able, to provide a secure power supply all over the year.

With a slightly larger production reserve, even this design of energy system would lead to a functioning power supply.

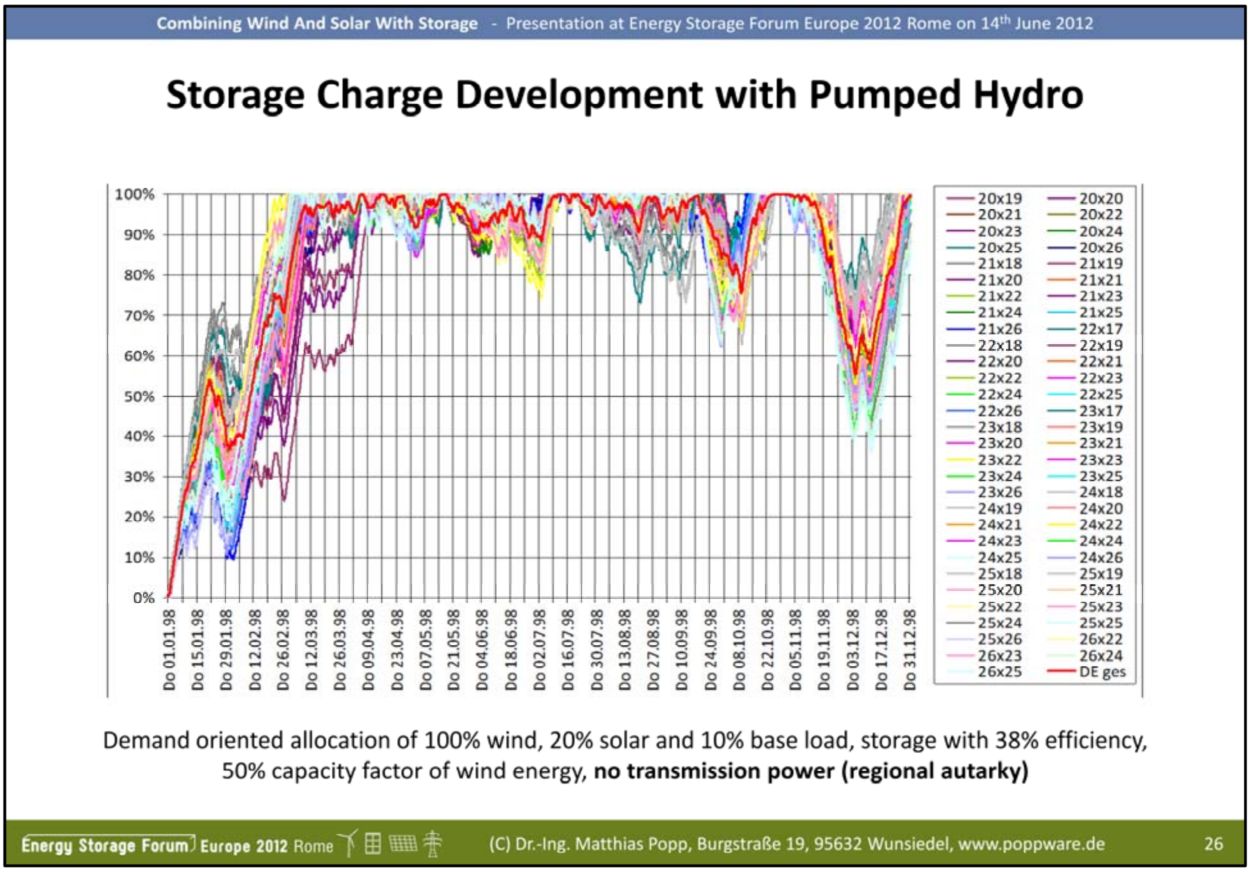


If the same production structure as before would not be balanced with low efficient gas storage systems, but with high efficient pumped hydro storage systems, the storage devices would charge much faster because of clearly lower efficiency losses.



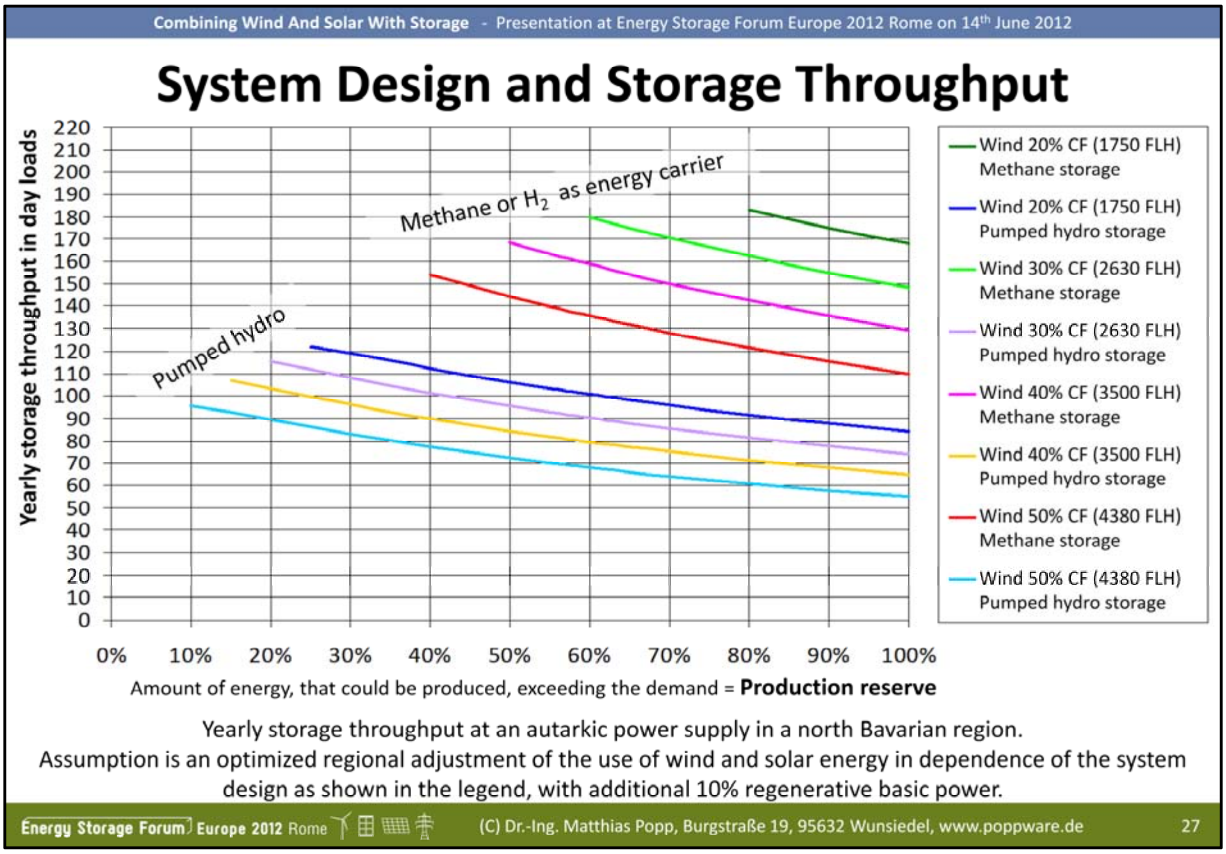
A power grid, that could transmit only 50% of the regional demand, would hardly change the quality of supply.

Storage demand, to bridge the longest calm wind phases would increase only marginally.



Even if no long distance transmission power at all would be available, the storage demand to bridge calm wind phases would overtop the storage demand with best transmission conditions with only about 20%.

A secure power supply without a supra-regional power grid could be realized.

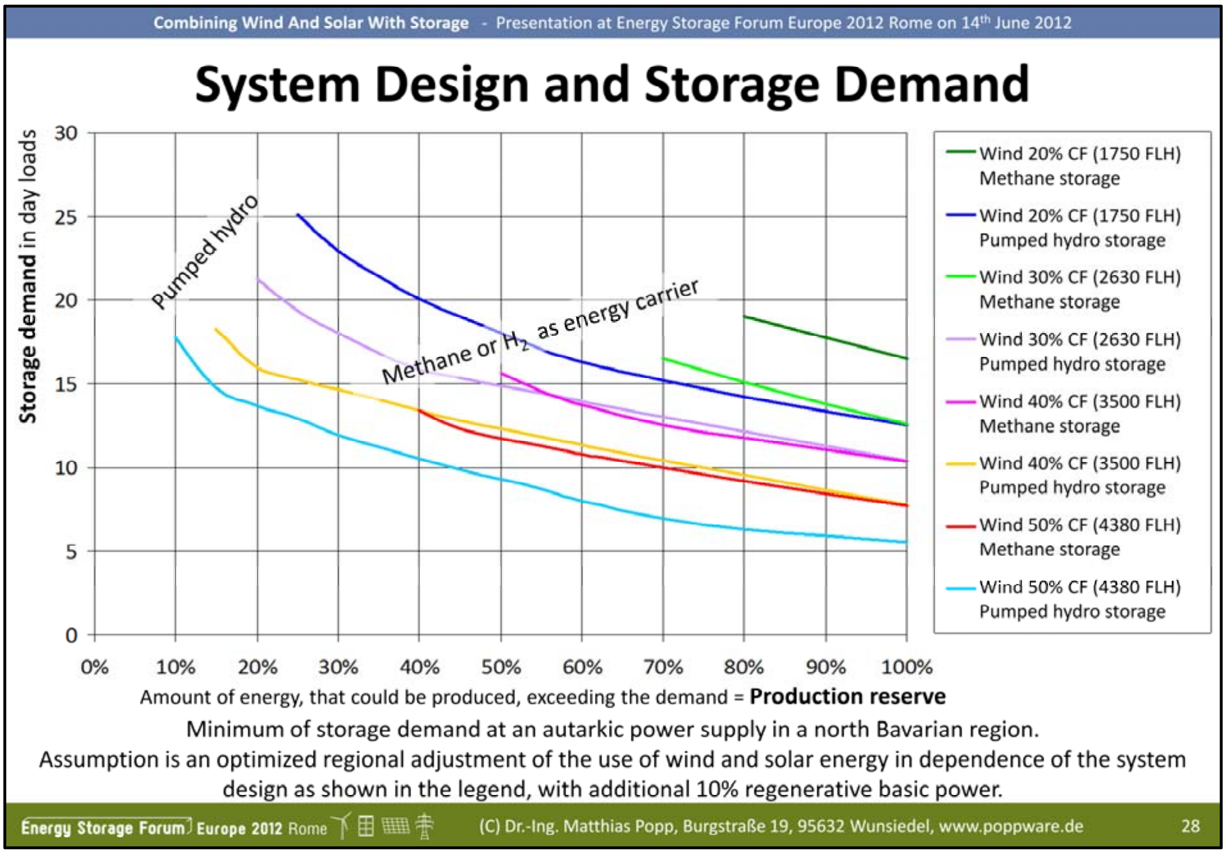


A reason for the good applicability of pumped hydro systems, is the storage throughput.
That is the total amount of the yearly energy to charge the storage devices.
The amount of dischargeable energy is reduced with the energy losses.

Large energy losses, taking place during a storage process, don't accrue with high efficient storage systems.

They require less storage throughput and less production reserve, to achieve a stable power supply.

It will be an economical question, which storage solution, in an holistic approach, will open the more attractive development corridors.



The design of the production system, as well as the storage efficiency, has significant influence on the necessary storage capacity.

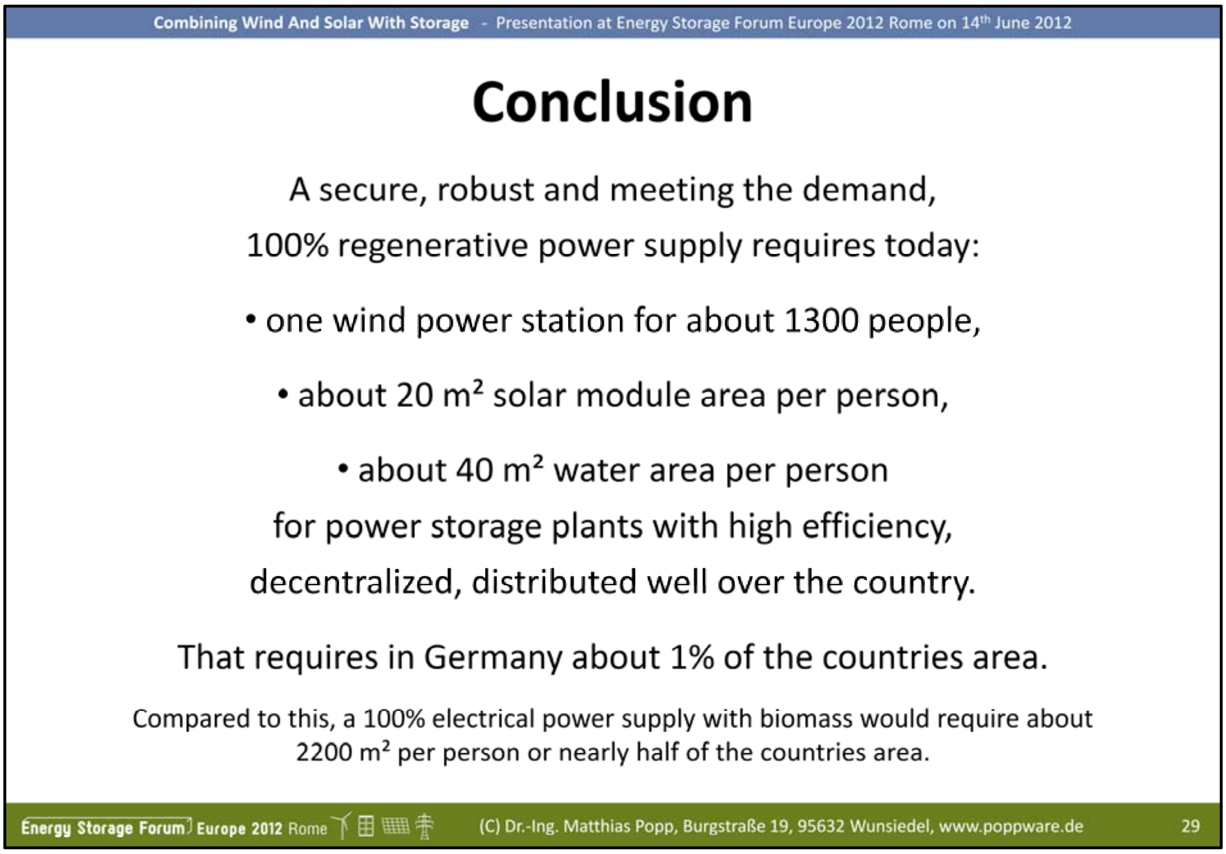
The required capacity is determined from the singular maximum of expected storage discharge in a long time consideration.

The characteristic lines show the minimum of necessary production power and the largest amount of expected storage discharge.

The obvious advantage of high efficient storage systems is, that less wind and solar power systems are needed, to achieve a secure power supply.

The higher the production reserve and the better the tuning of the production systems to the regional requirements, the lower the storage capacity will be.

If the combination of wind and sun isn't designed to minimize storage demand, the required storage capacity, the required production reserve and the macroeconomic costs of the renewable energy system would become clearly larger.

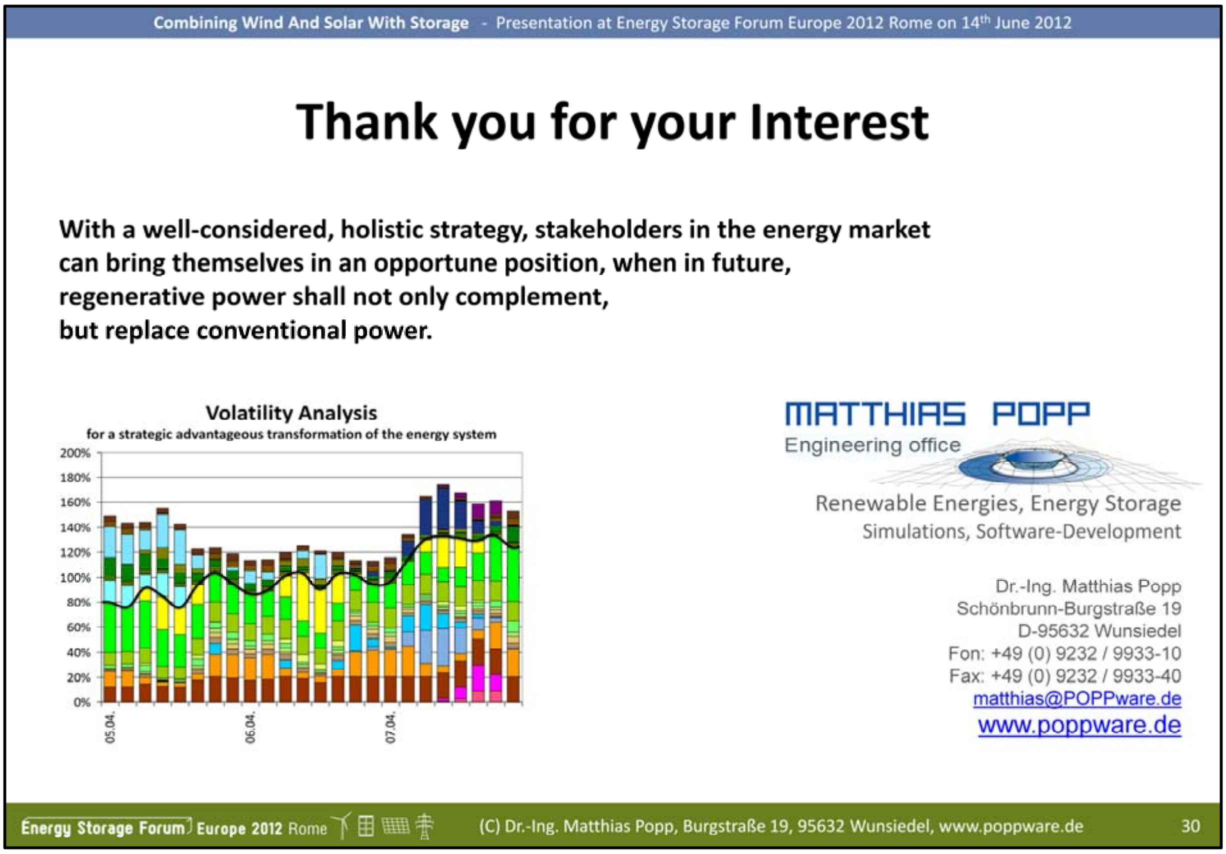


Today, a secure and 100% regenerative power supply, which meets the demand, is a real option for the future.

There are a lot of different possibilities, to realize it.
But for every region, a suitable combination of wind and solar with energy storage can be determined, to achieve the greatest economic value.

Volatility analysis is called the calculation method, to find out optimized corridors for macroeconomic favourable renewable energy systems in a holistic approach.

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



In the near future, important changes in energy economics will take place.

I hope, my presentation will motivate you and contribute to a holistic strategy, for a economic advantageous transformation of the energy system.