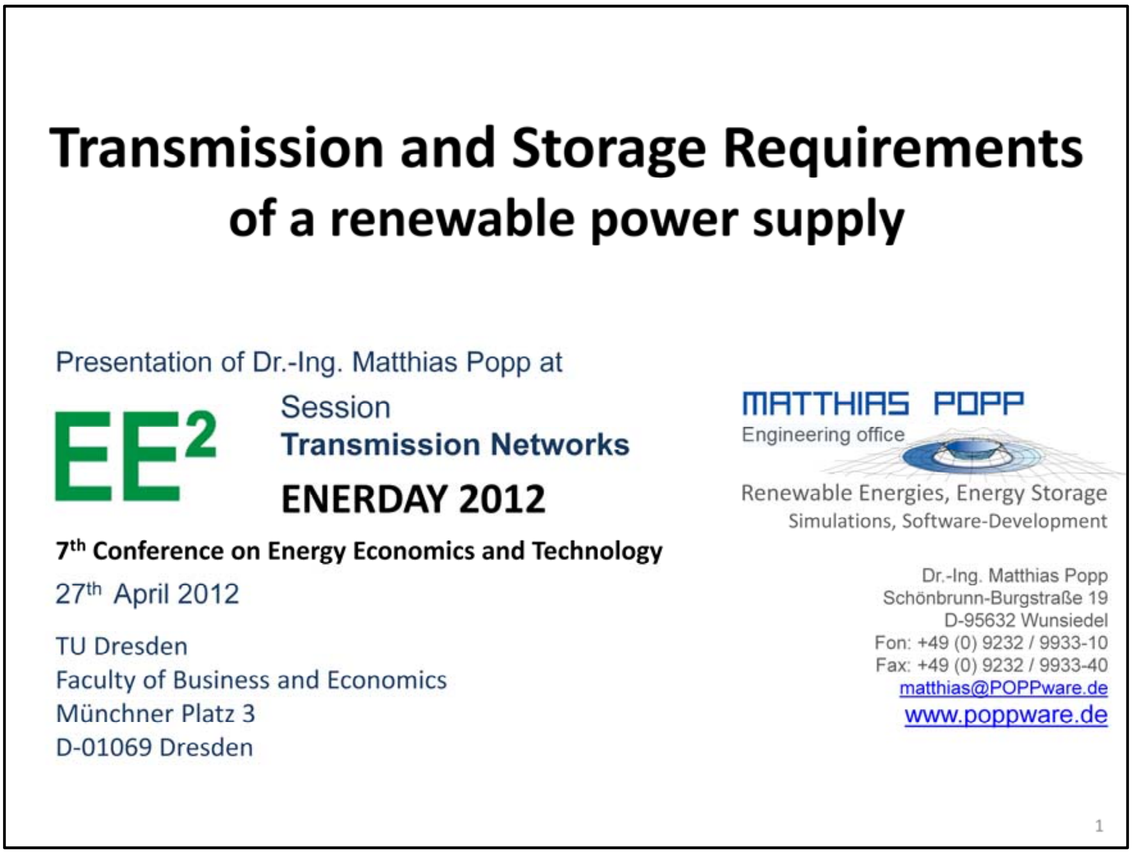


Ladies and Gentlemen,

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:

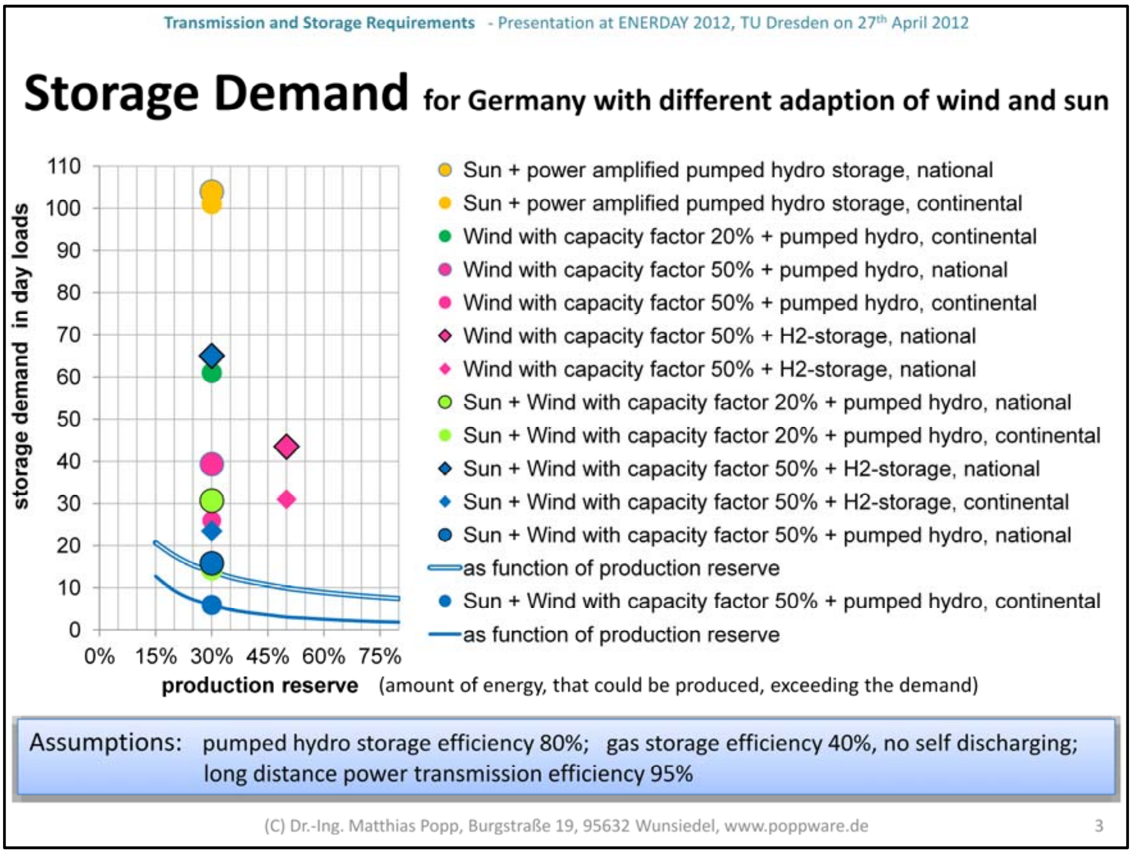
  How can energy storage plants deliver a contribution to a sustainable regenerative power supply?

- 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

In 2010, I made a doctorate with the title:

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

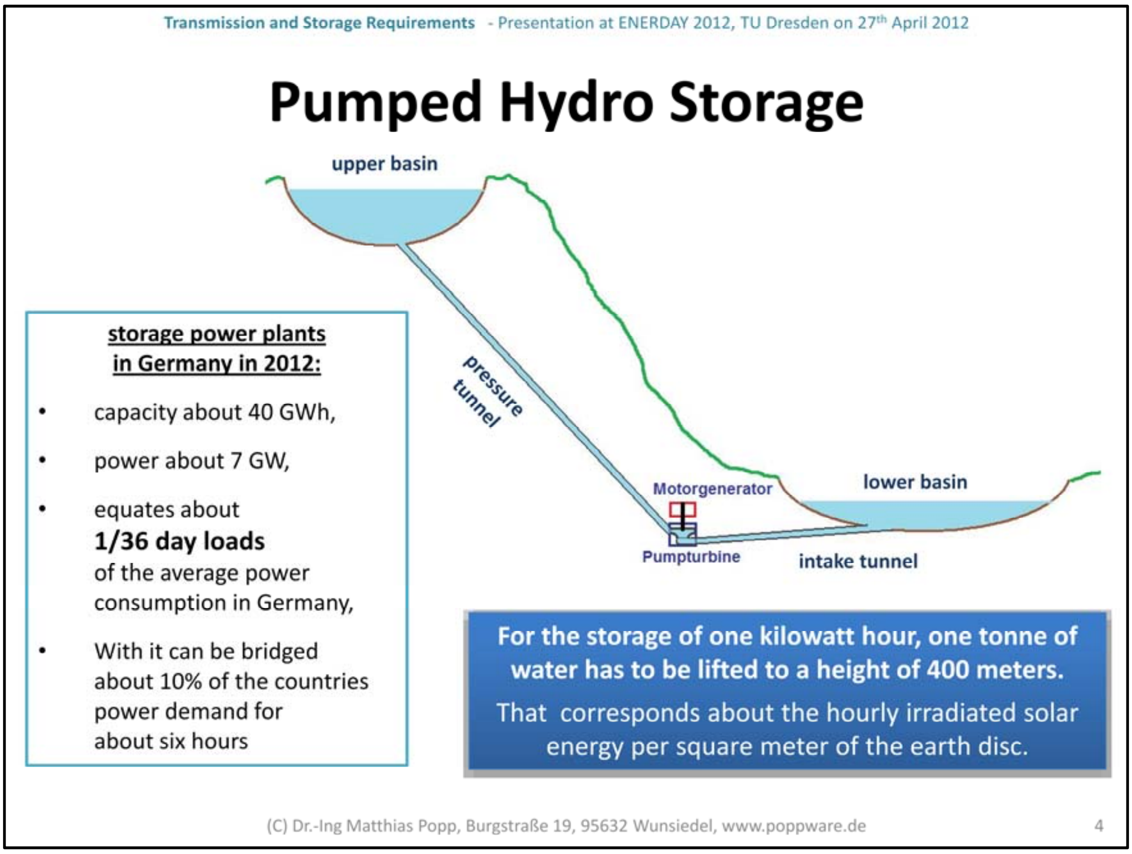
This doctoral thesis is published as book by Springer in German language.



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

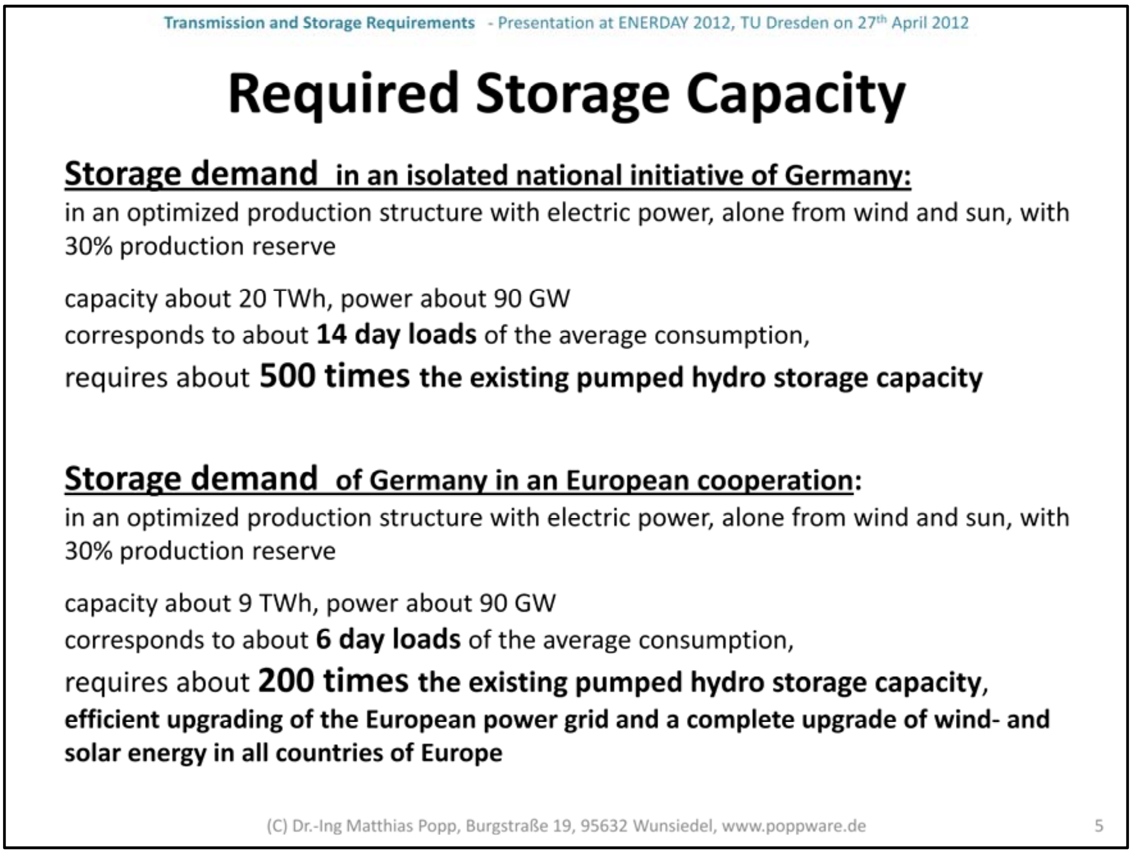
A day load is the, in average, daily consumed, amount of energy in the supplied area.

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.



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, ...



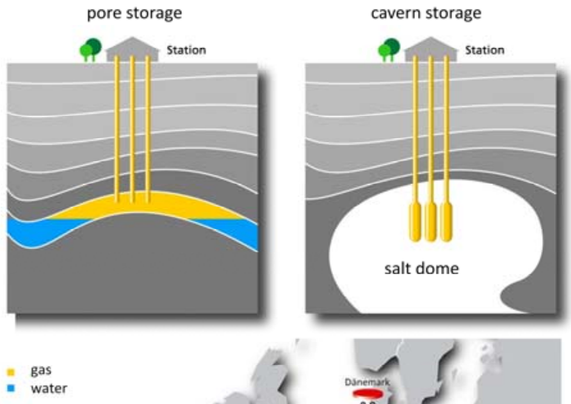
... , that in a national solo run, the actually available storage capacity would be required about 500 times as large.

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.

Gas Reservoir

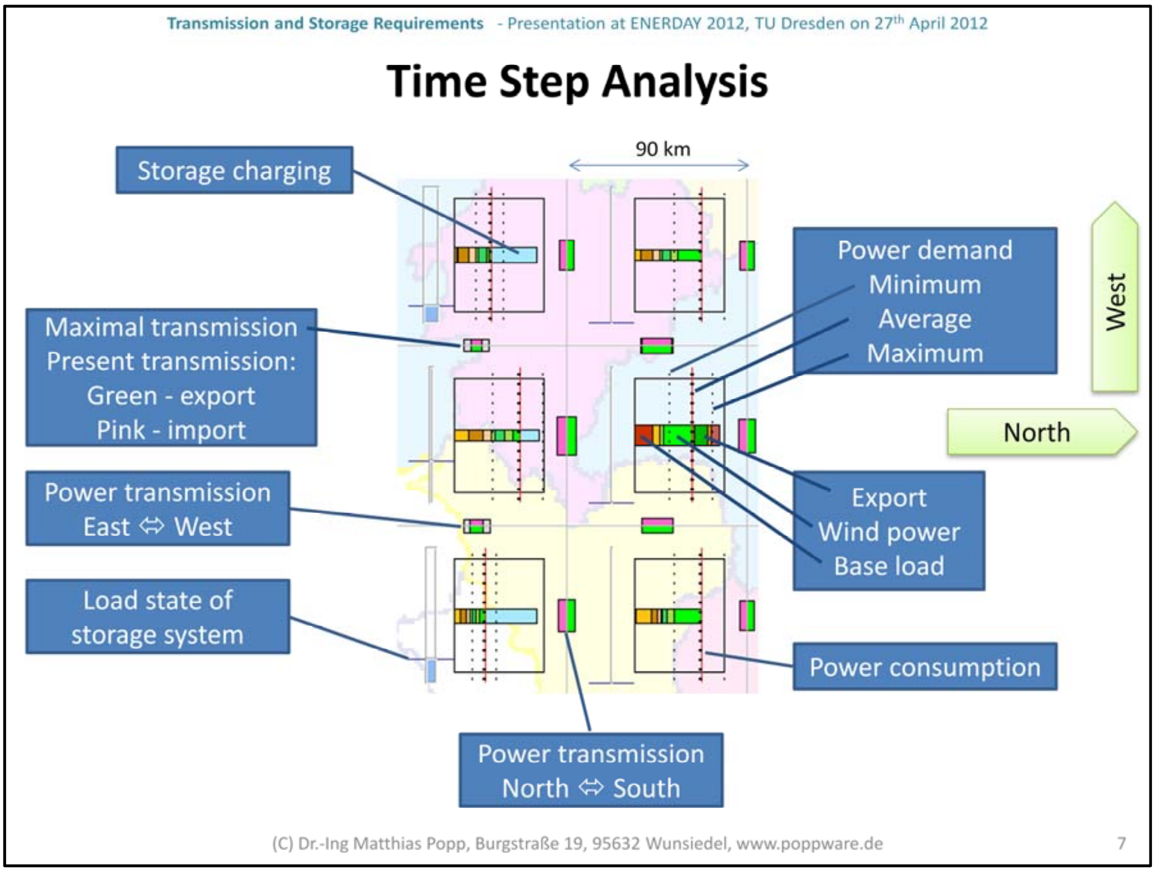
Gas Reservoirs in Germany:

- Total storage volume
  ca. 35.000 Mio. m³ V_n
- Maximum working gas volume
  ca. 20.800 Mio. m³ V_n
- Energy content of natural gas
  ca. 10 kWh/ m³ V_n = 10 GWh/Mio. m³ V_n,
- Energy storage capacity ca. 208 TWh
- Efficiency of electricity generation
  (combined-cycle plant, GuD) ca. 60%
- **Electricity storage capacity**
  ca. **125 TWh**, that corresponds to about
  87 day loads
  of the average electric power demand
  of Germany



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.

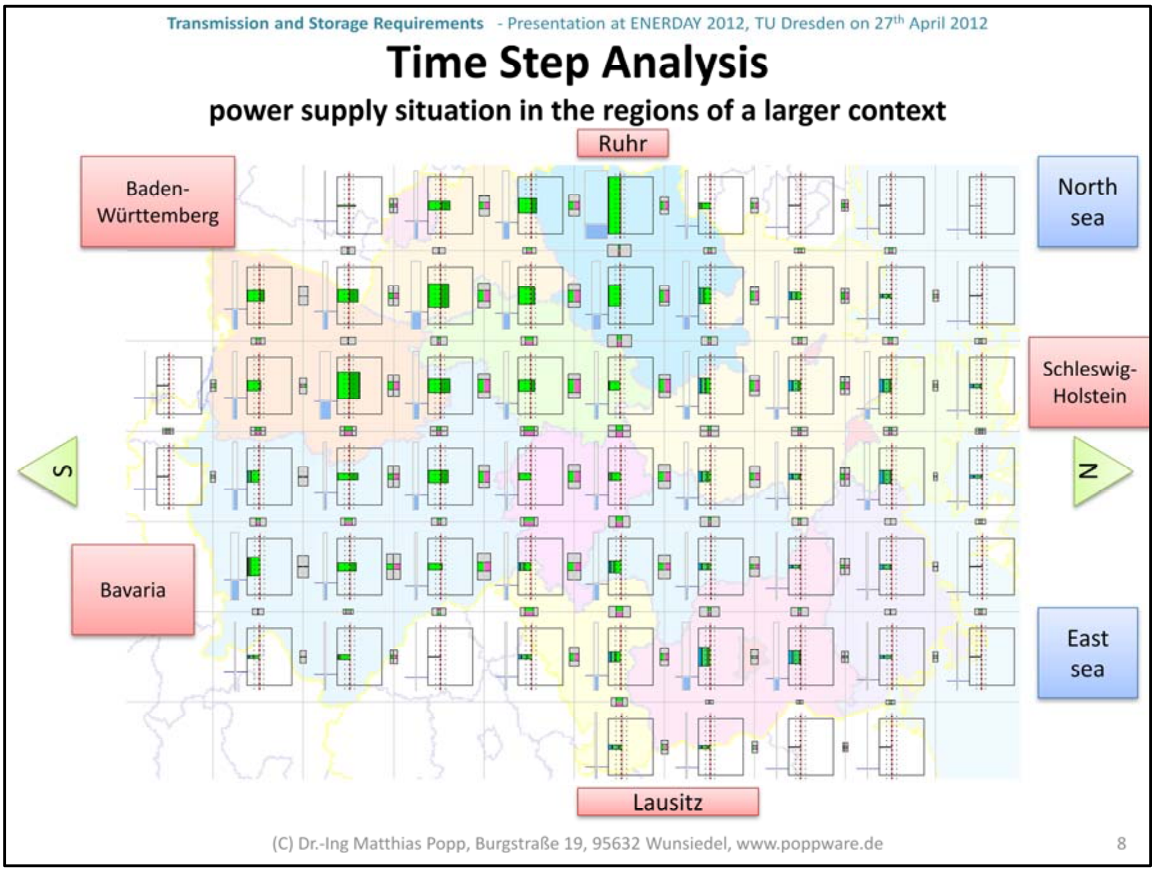
In contrast to the approved pumped hydro technology, much larger power losses would arise.



Time step analysis helps to get an overview of the electricity grid requirements of a renewable power supply.

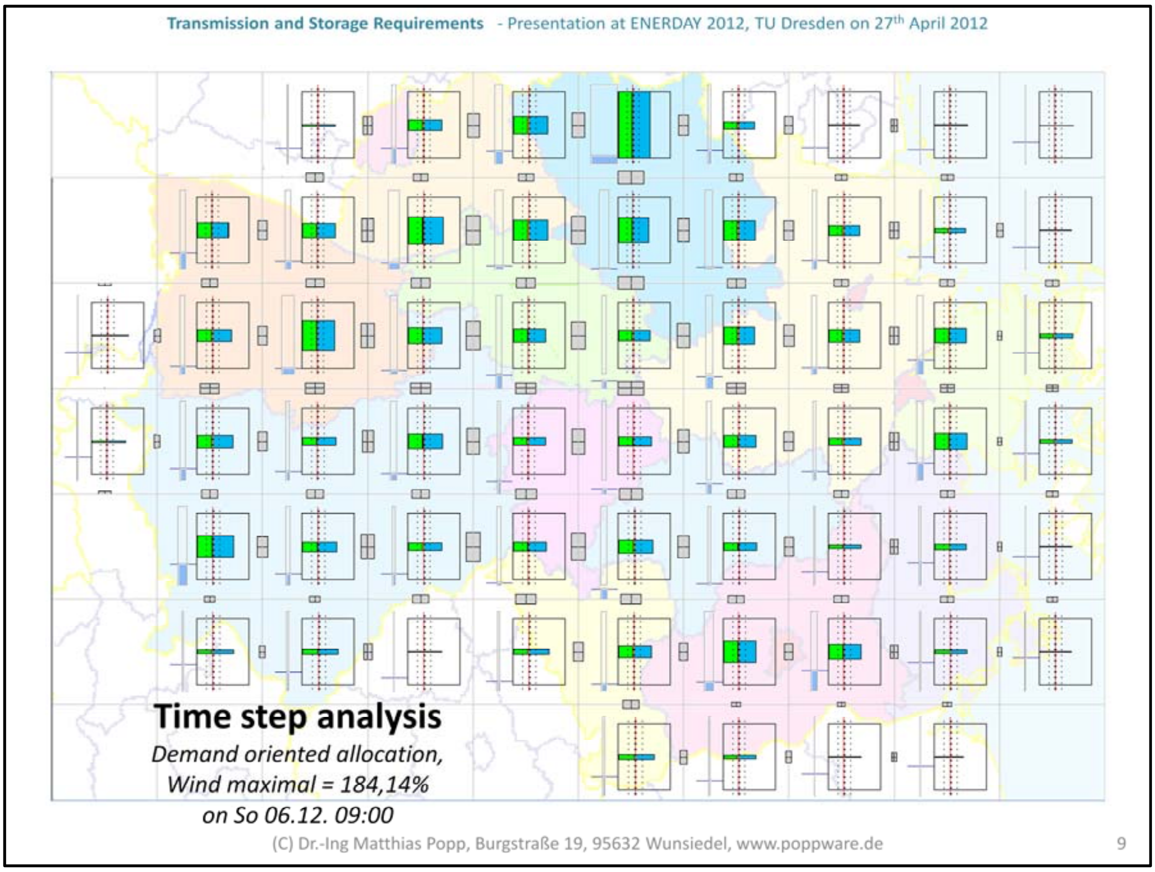
It shows the contribution of energy carriers in the regions of a larger investigation area,
the load state of the storage systems, the regional power consumption and the supra-regional current flow .

The time step analysis gives an overview of the conditions for a long distance electricity grid, arising with a high share of volatile power.



The following slides will present a choice of situations arising under usual weather conditions in the German electricity grid, with a high share of volatile power.

The following assumptions belong to the shown scenario:
Optimized design of wind and sun power stations, to minimize the storage demand,
with the ability to produce 120% of the, in average consumed energy.
Additional 10% renewable base power.
Demand oriented allocation over the country, combined with storage capacity to bridge 20 days, based on methane with 38% degree of efficiency.
Best transmission conditions, to balance all overruns and deficits between the included regions.


Transmission and Storage Requirements - Presentation at ENERDAY 2012, TU Dresden on 27th April 2012
Time step analysis
Demand oriented allocation,
Wind maximal = 184,14%
on So 06.12. 09:00
(C) Dr.-Ing Matthias Popp, Burgstraße 19, 95632 Wunsiedel, www.poppware.de
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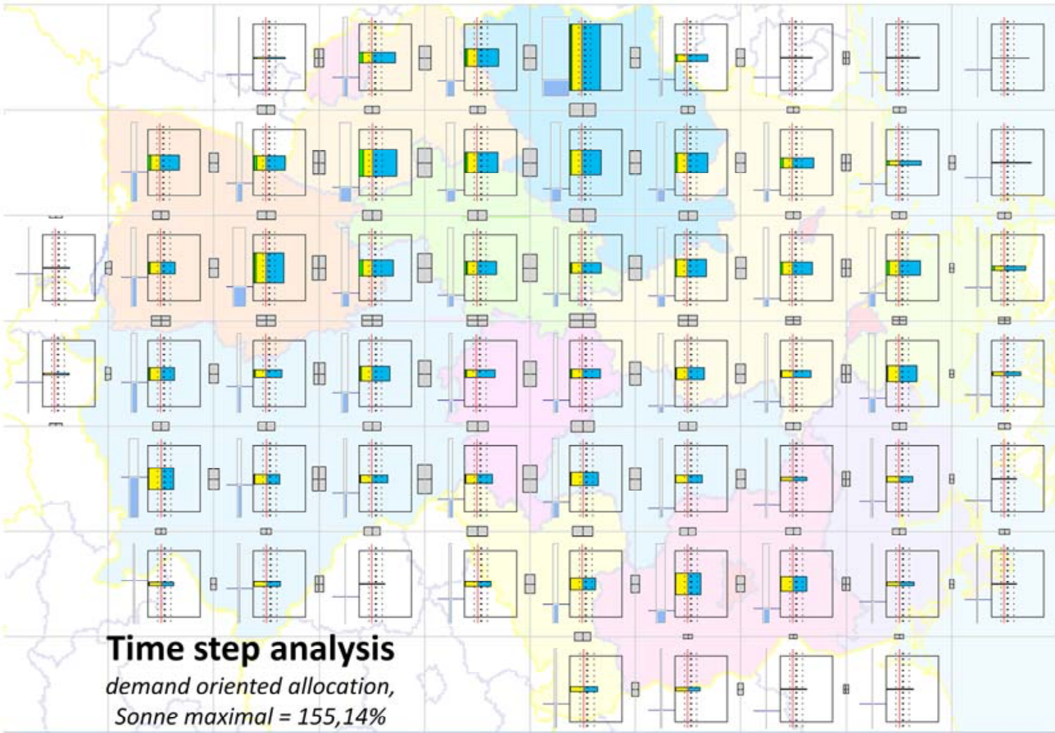
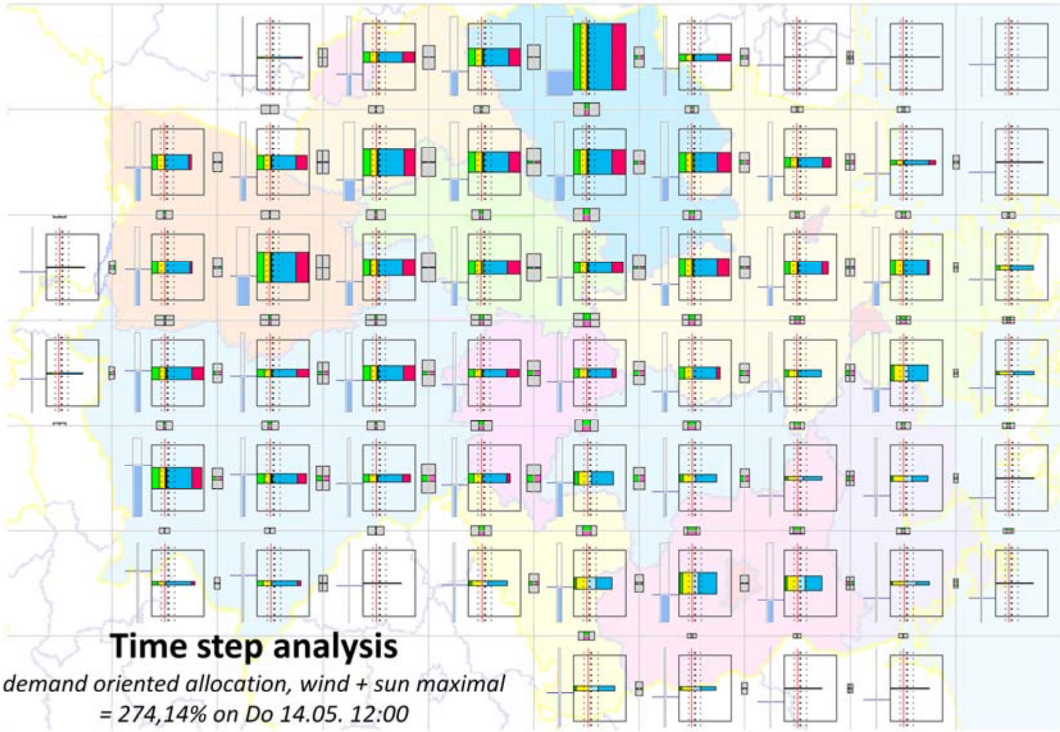


Time step analysis

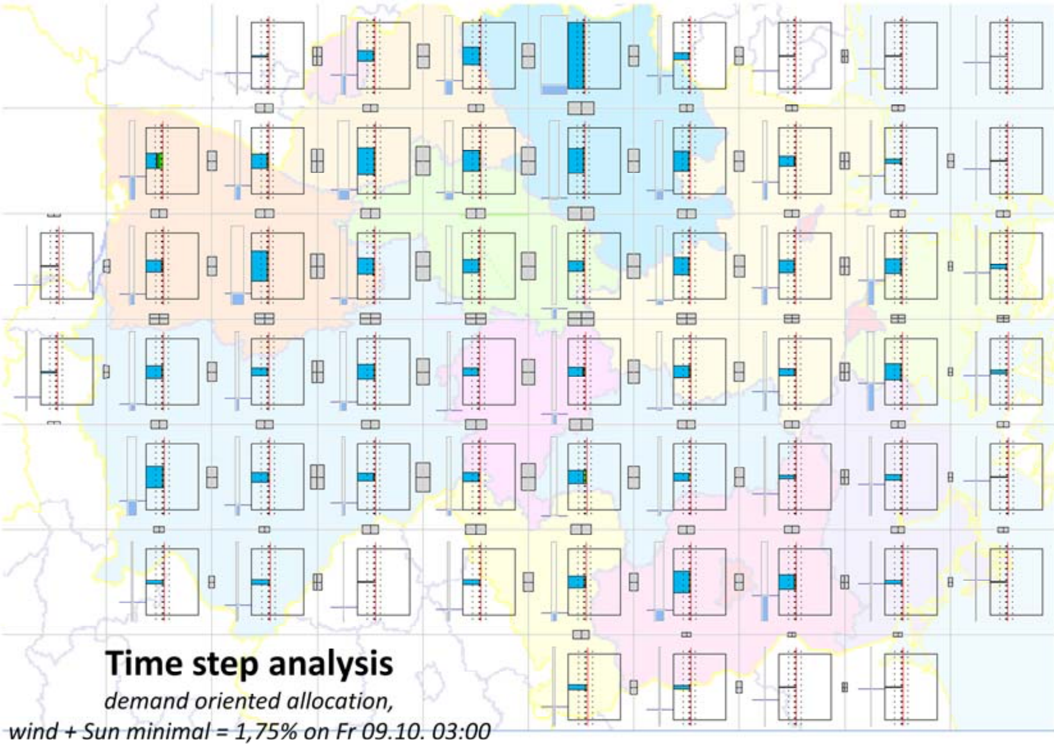
demand oriented allocation,
Sonne maximal = 155,14%
on So 21.06.98 12:00



Time step analysis

demand oriented allocation, wind + sun maximal = 274,14% on Do 14.05. 12:00

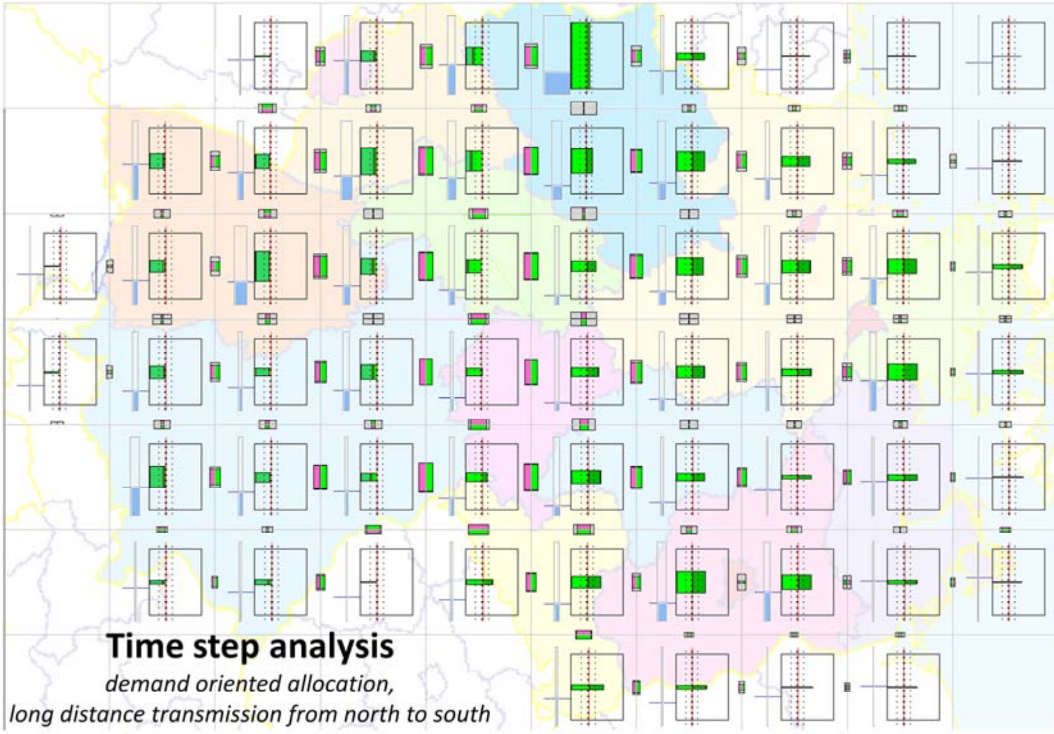
not usable overproduction maximal = 50,97%



Time step analysis

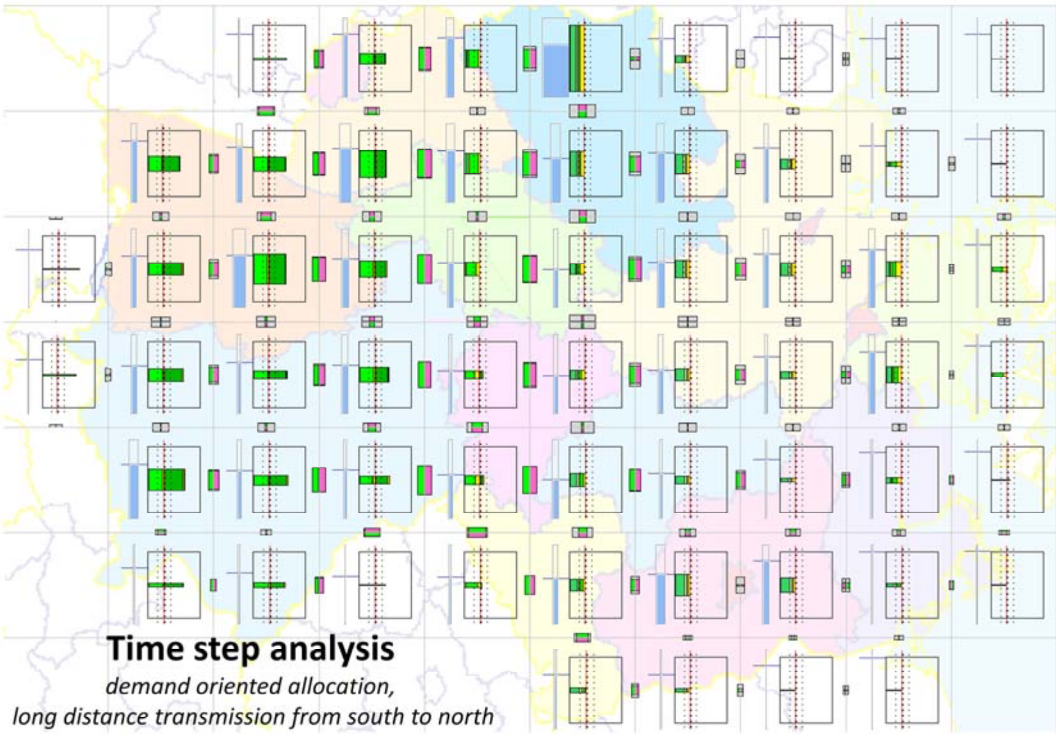
demand oriented allocation,

wind + Sun minimal = 1,75% on Fr 09.10. 03:00



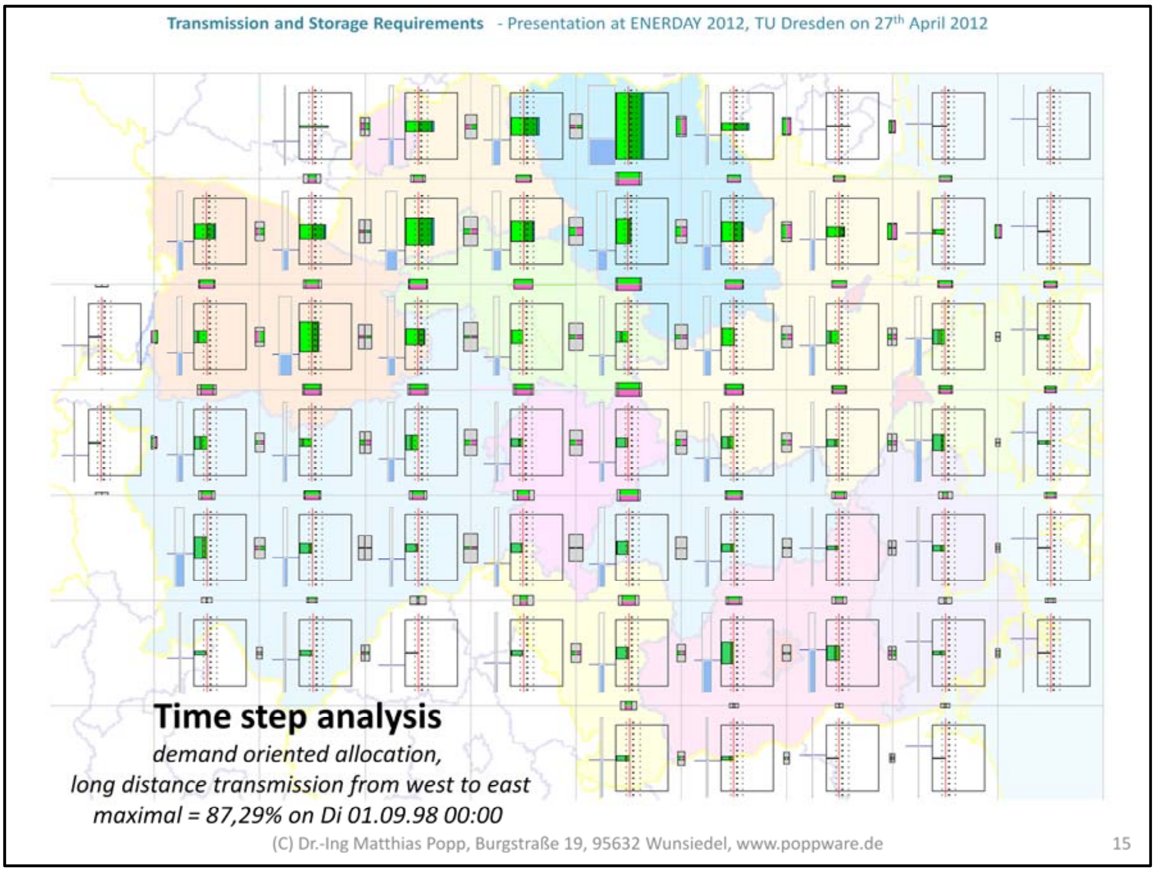
Time step analysis

demand oriented allocation,
long distance transmission from north to south
maximal = 136,33%, on Fr 02.10.98 03:00



Time step analysis

demand oriented allocation,
long distance transmission from south to north
maximal = 129,85% on So 15.11.98 09:00


Transmission and Storage Requirements - Presentation at ENERDAY 2012, TU Dresden on 27th April 2012
Time step analysis
demand oriented allocation,
long distance transmission from west to east
maximal = 87,29% on Di 01.09.98 00:00
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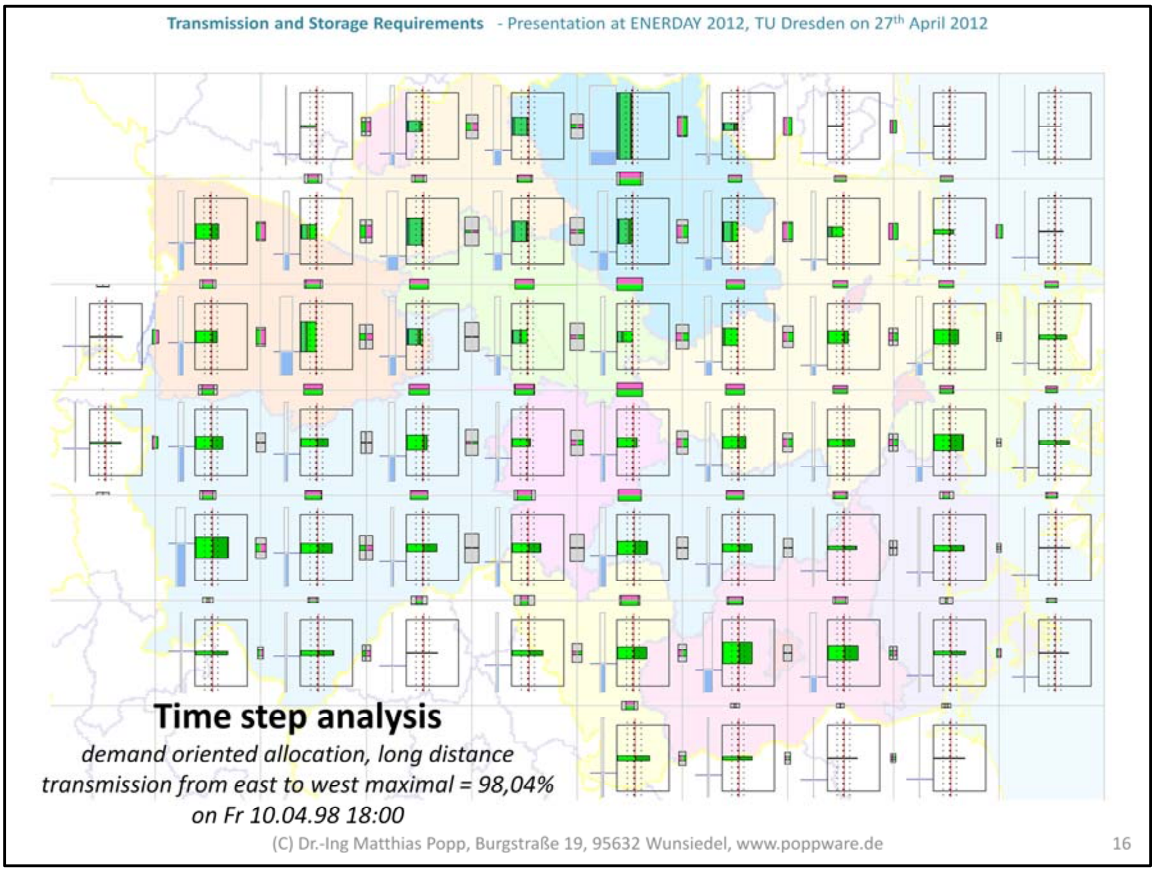
15


Transmission and Storage Requirements - Presentation at ENERDAY 2012, TU Dresden on 27th April 2012
Time step analysis
demand oriented allocation, long distance
transmission from east to west maximal = 98,04%
on Fr 10.04.98 18:00
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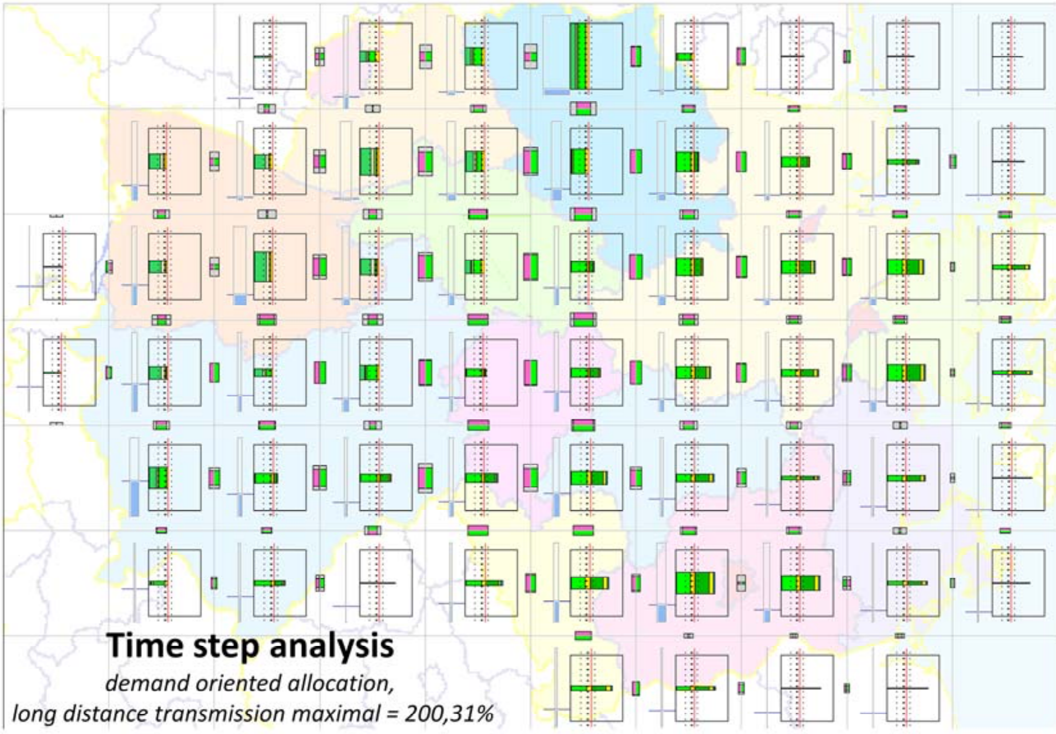
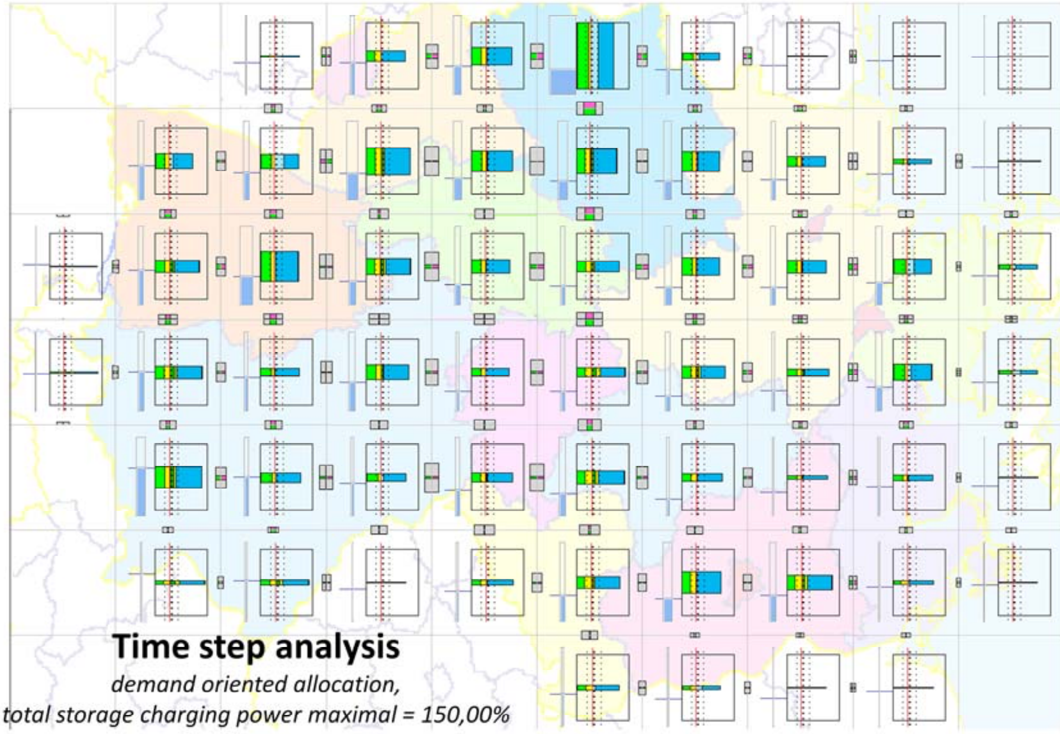


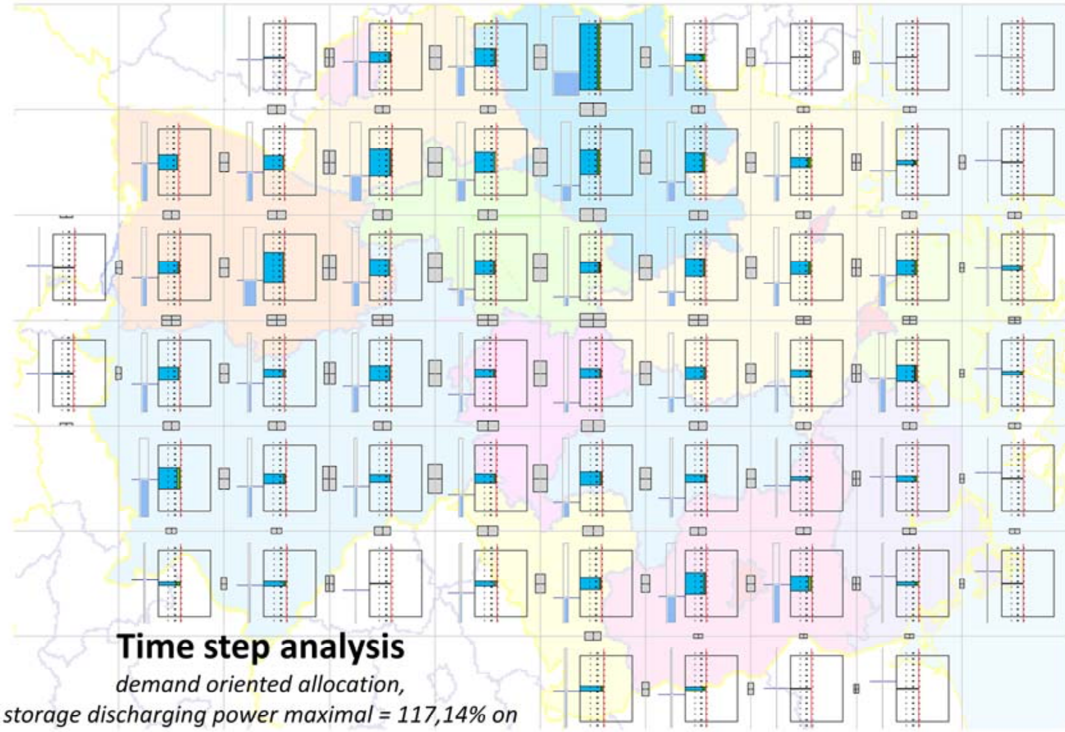
Time step analysis

demand oriented allocation,
long distance transmission maximal = 200,31%
on Mo 23.03.98 06:00



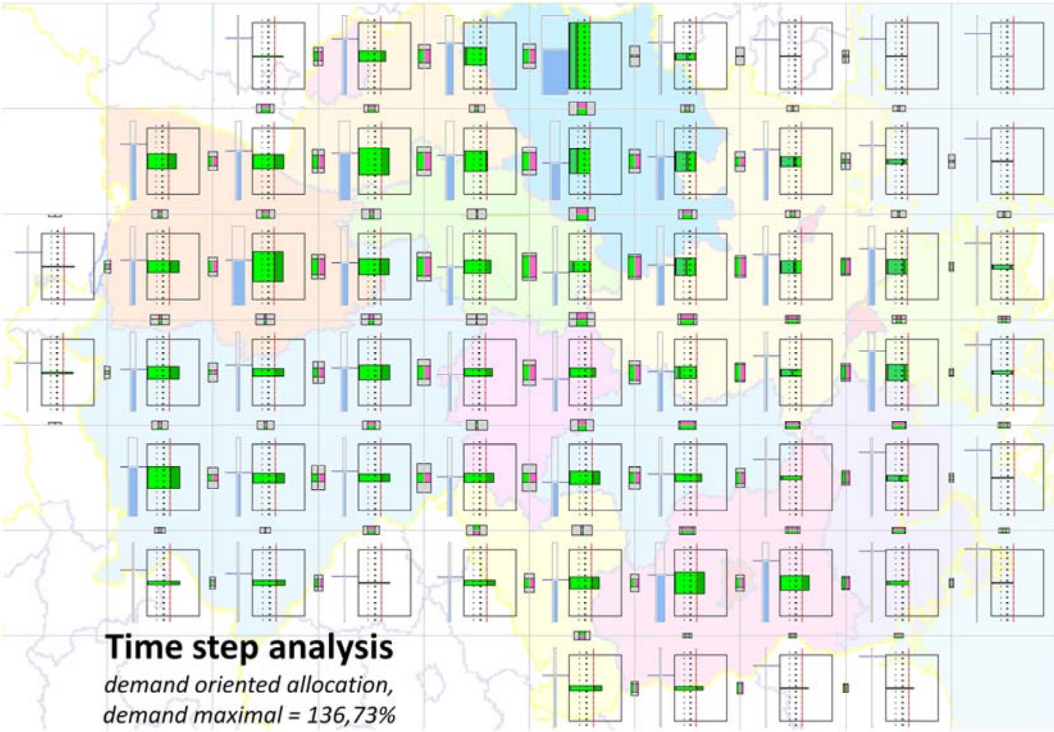
Time step analysis

demand oriented allocation,
total storage charging power maximal = 150,00%
on Sa 18.07.98 12:00



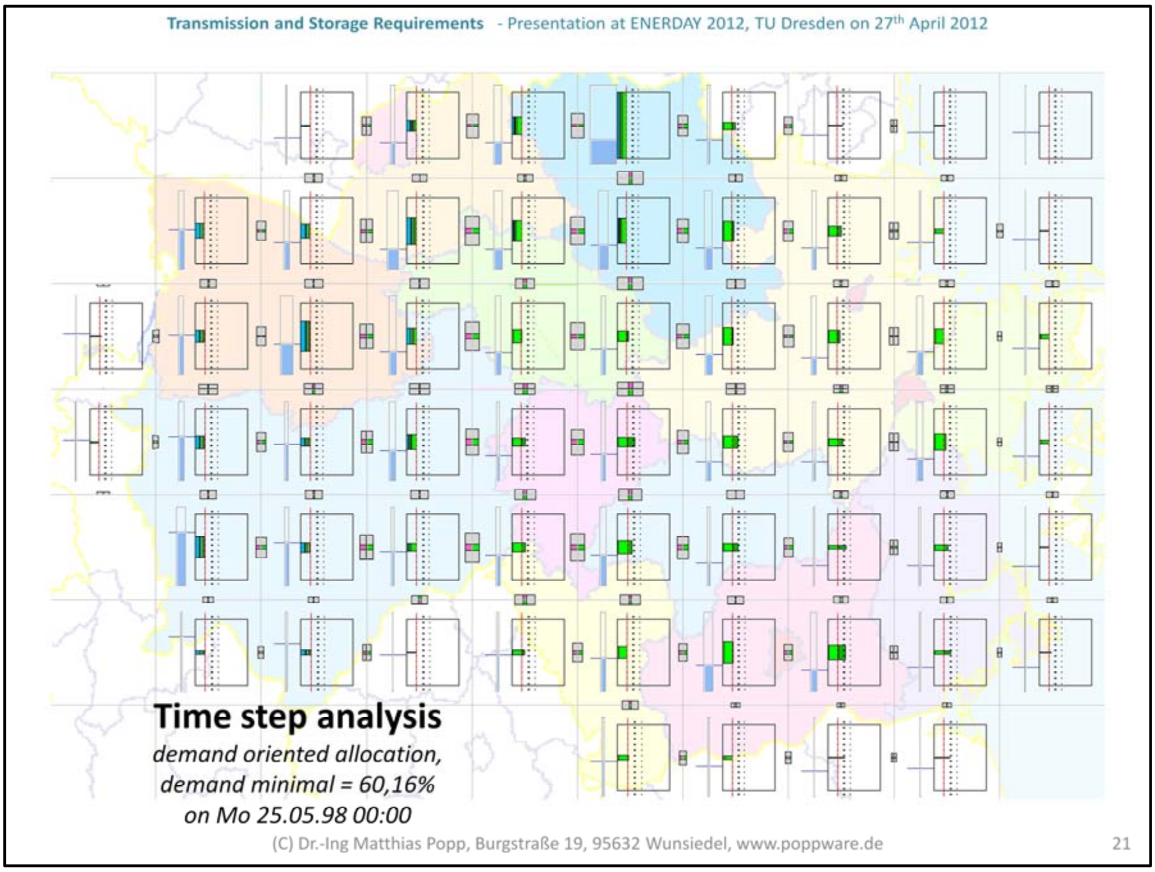
Time step analysis

demand oriented allocation,
storage discharging power maximal = 117,14% on
Mi 25.11.98 15:00



Time step analysis

demand oriented allocation,
demand maximal = 136,73%
on Mi 04.11.98 15:00


Transmission and Storage Requirements - Presentation at ENERDAY 2012, TU Dresden on 27th April 2012
Time step analysis
demand oriented allocation,
demand minimal = 60,16%
on Mo 25.05.98 00:00
(C) Dr.-Ing Matthias Popp, Burgstraße 19, 95632 Wunsiedel, www.poppware.de
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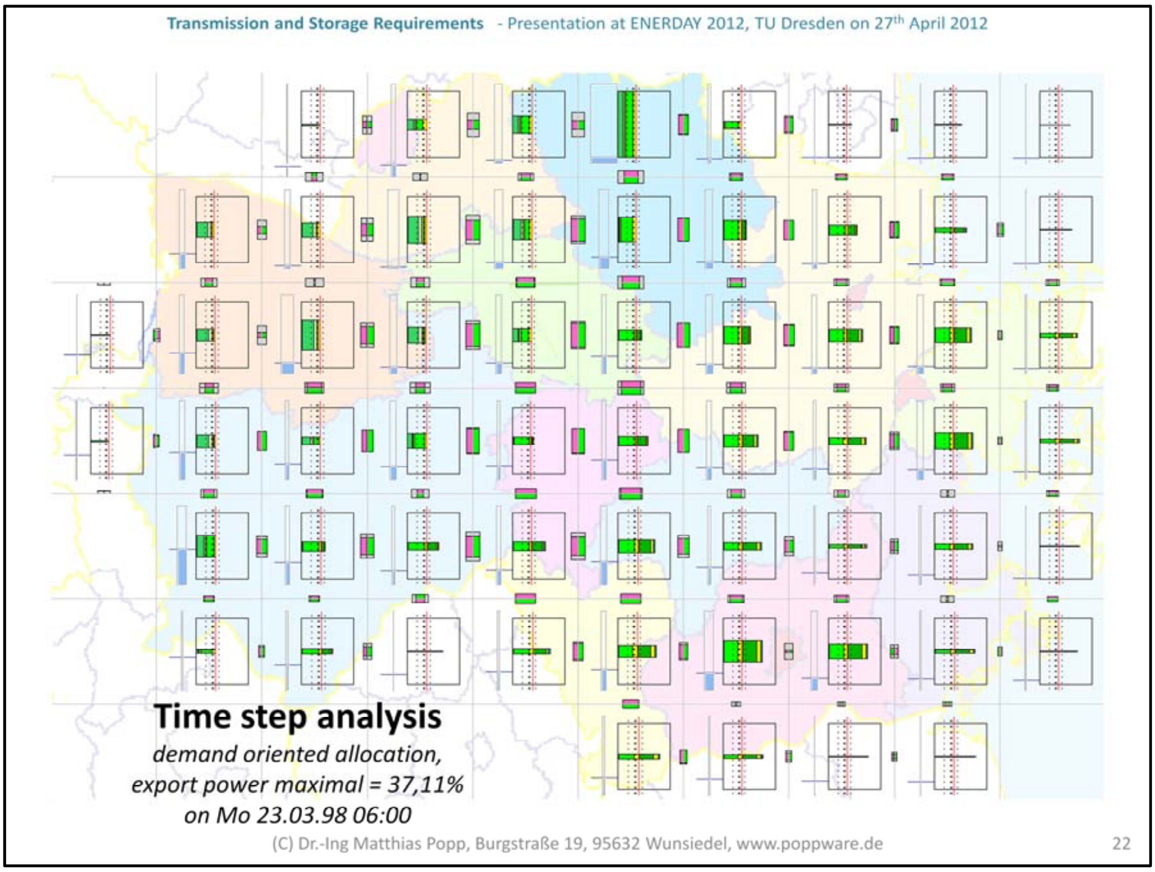
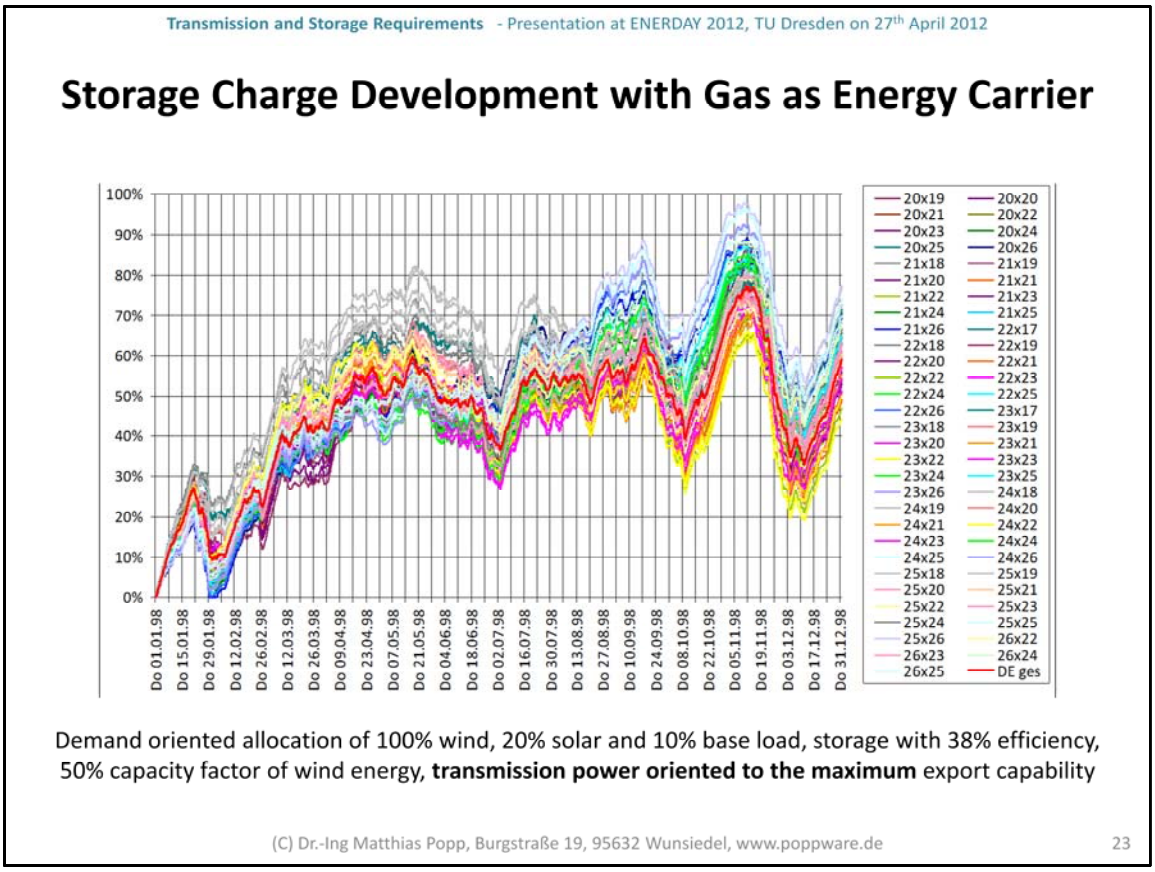


The time step analysis shows a lot of situations, where a powerful electricity grid can contribute to balance local volatile power variations.

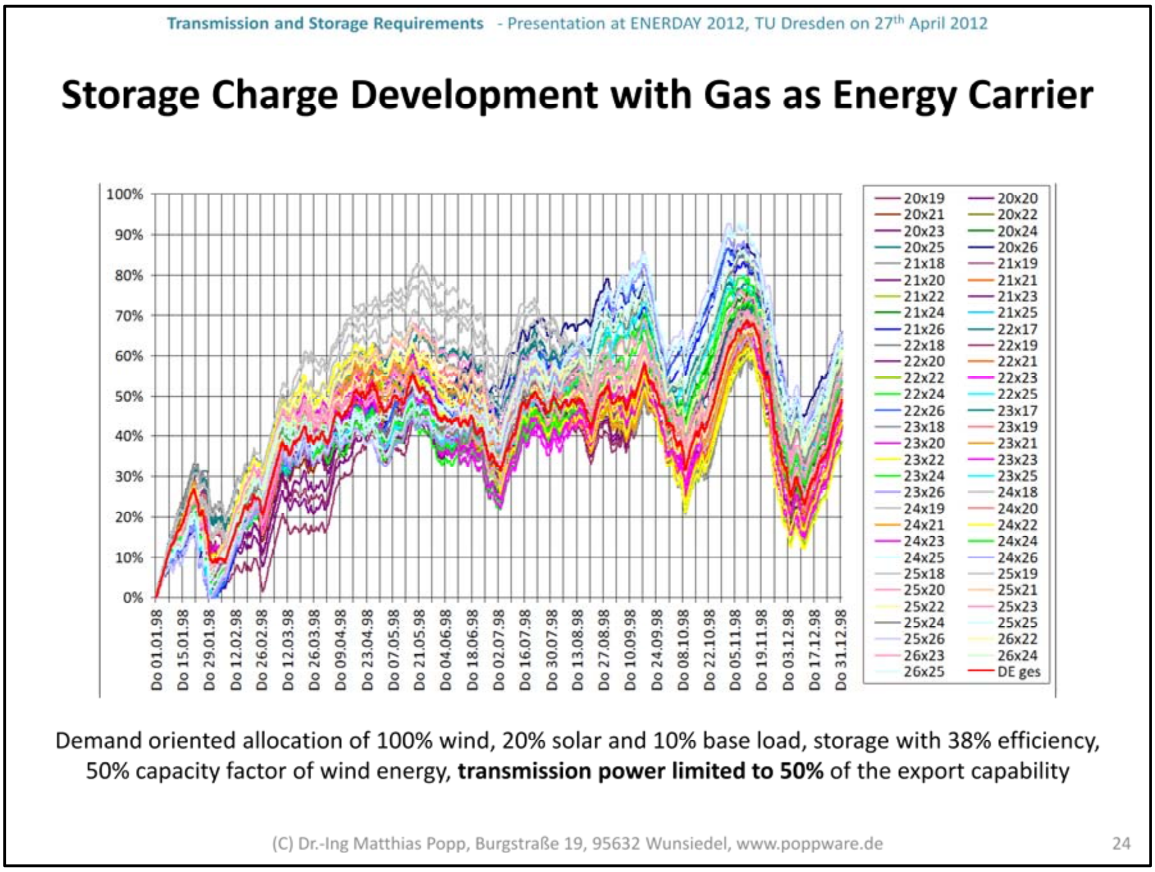
To get a feeling for the possibilities of the electricity grid to balance power divergence, the storage charge development delivers valuable information.



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

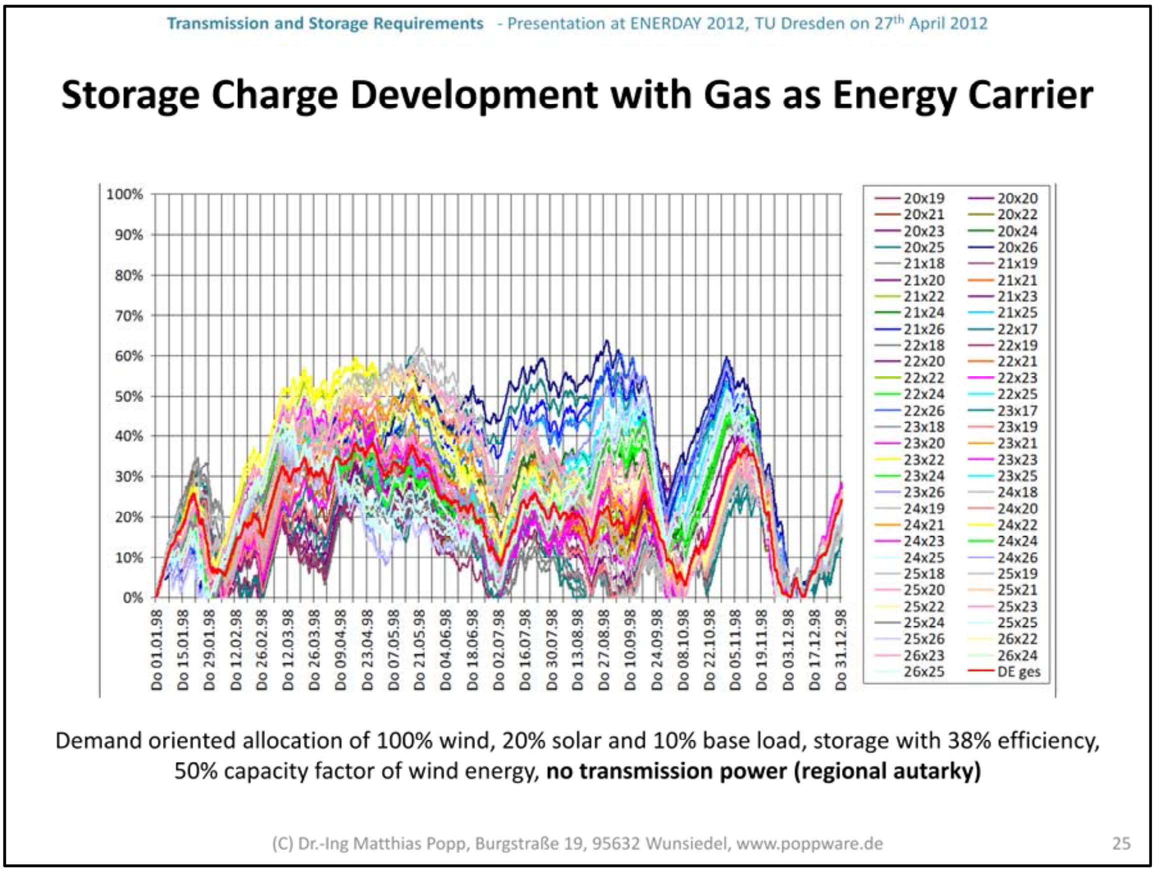
It belongs to the previous shown time step analysis with a maximum power transmission grid.

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.



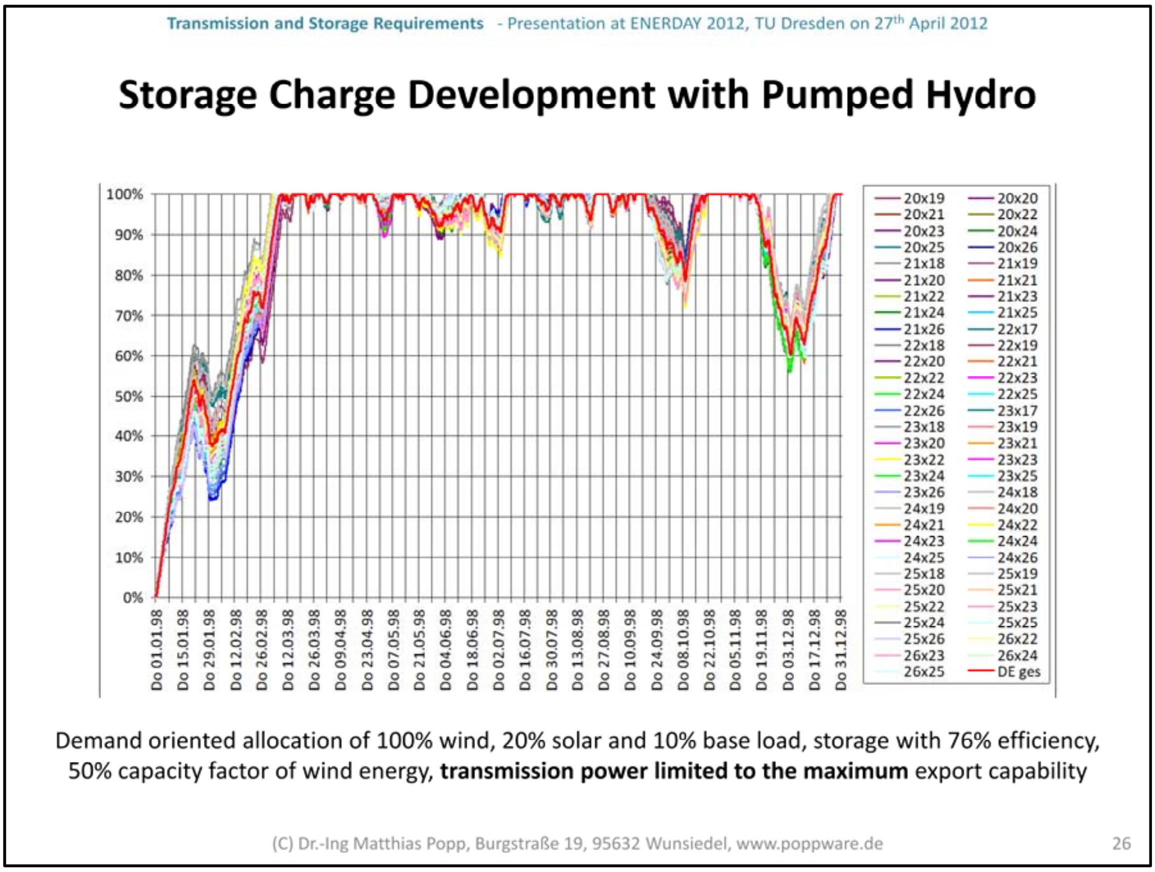
If the same production structure would be operated with a transmission grid, that could maximal transmit 50% of the regional power demand, the storage charge would rarely change.

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



Even if no 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.

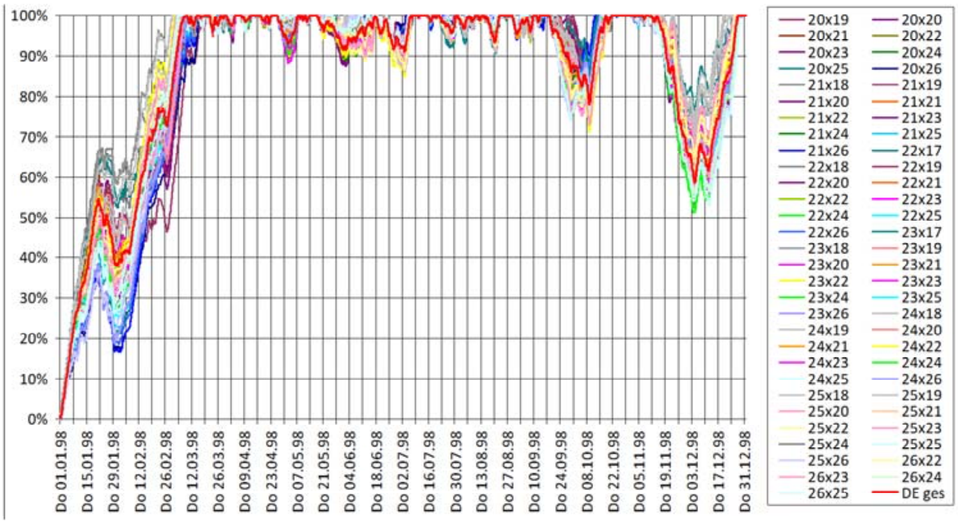
With a slightly larger production reserve, even this design of energy system would lead to a functioning power supply.



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.

Transmission and Storage Requirements - Presentation at ENERDAY 2012, TU Dresden on 27th April 2012

Storage Charge Development with Pumped Hydro

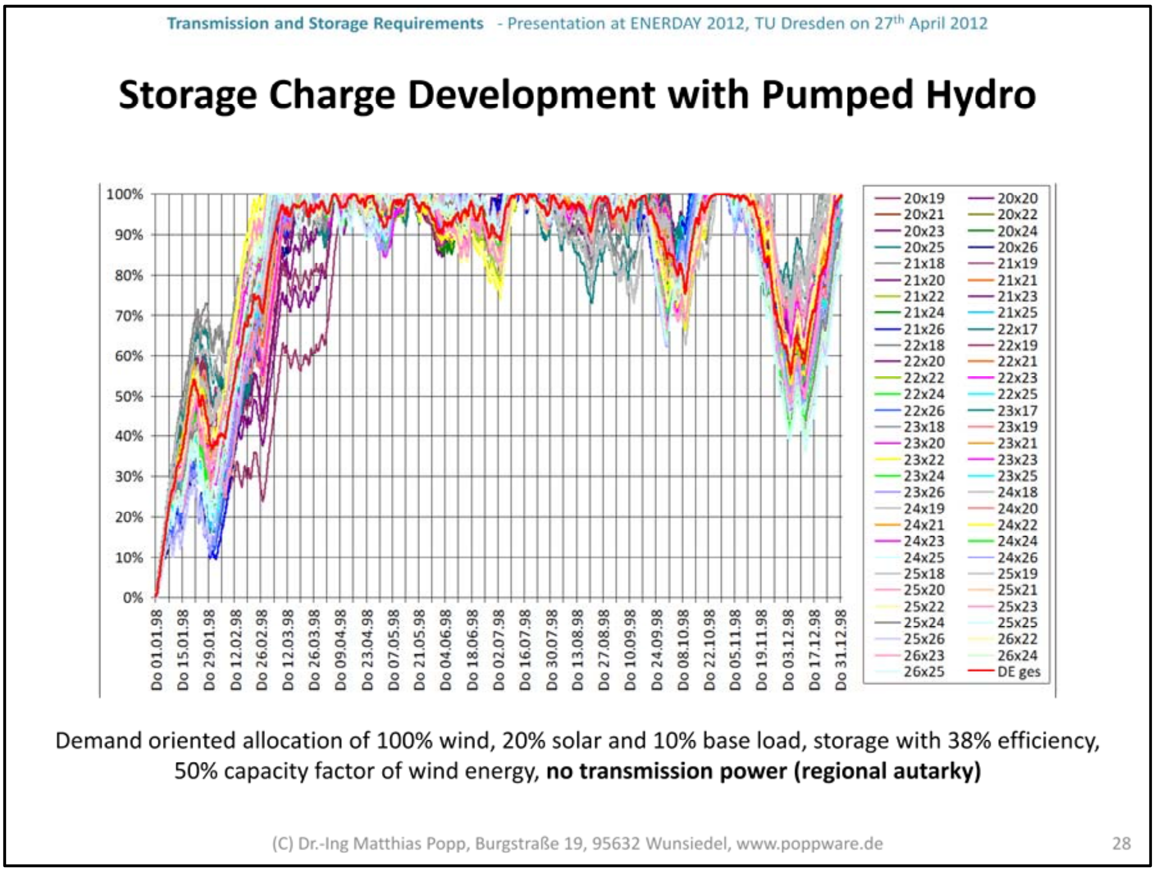


Demand oriented allocation of 100% wind, 20% solar and 10% base load, storage with 76% efficiency, 50% capacity factor of wind energy, **transmission power limited to 50%** of the export capability

 27

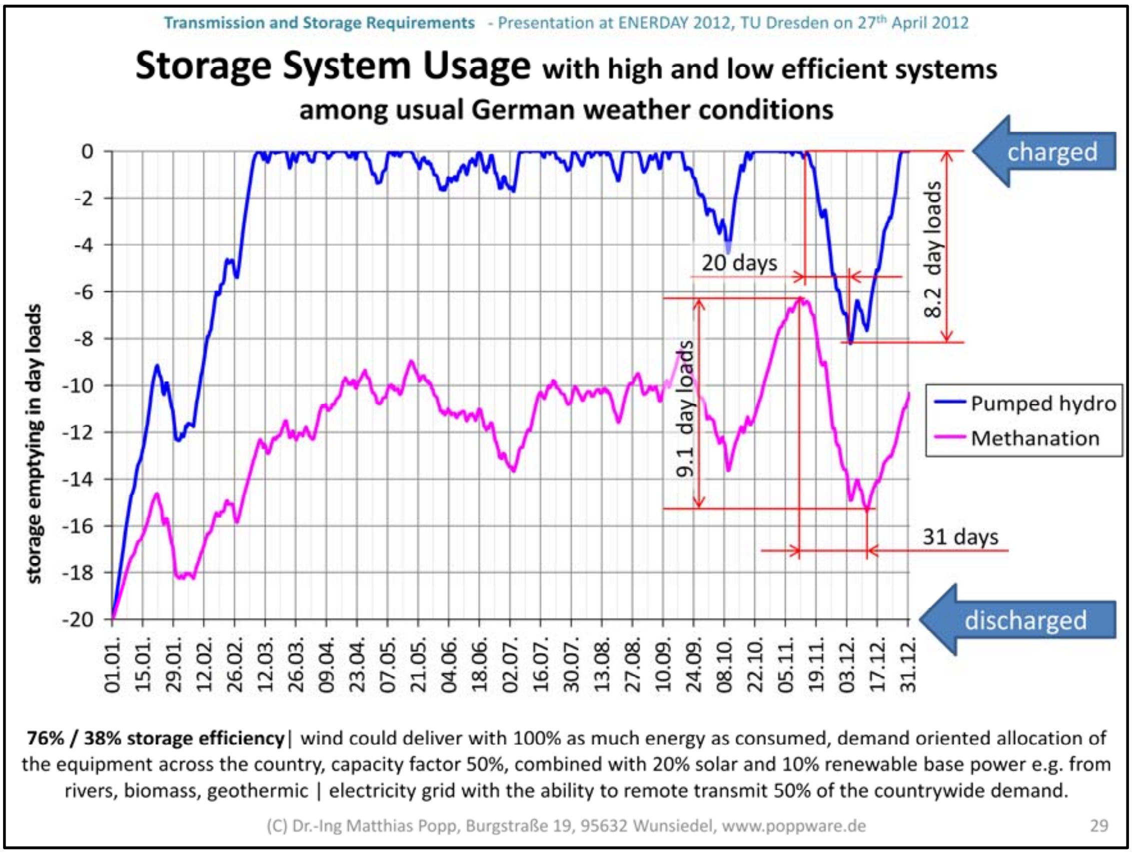
A power grid, that could transmit only 50% of the regional demand, would hardly change the quality of supply.

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



Even if no 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.



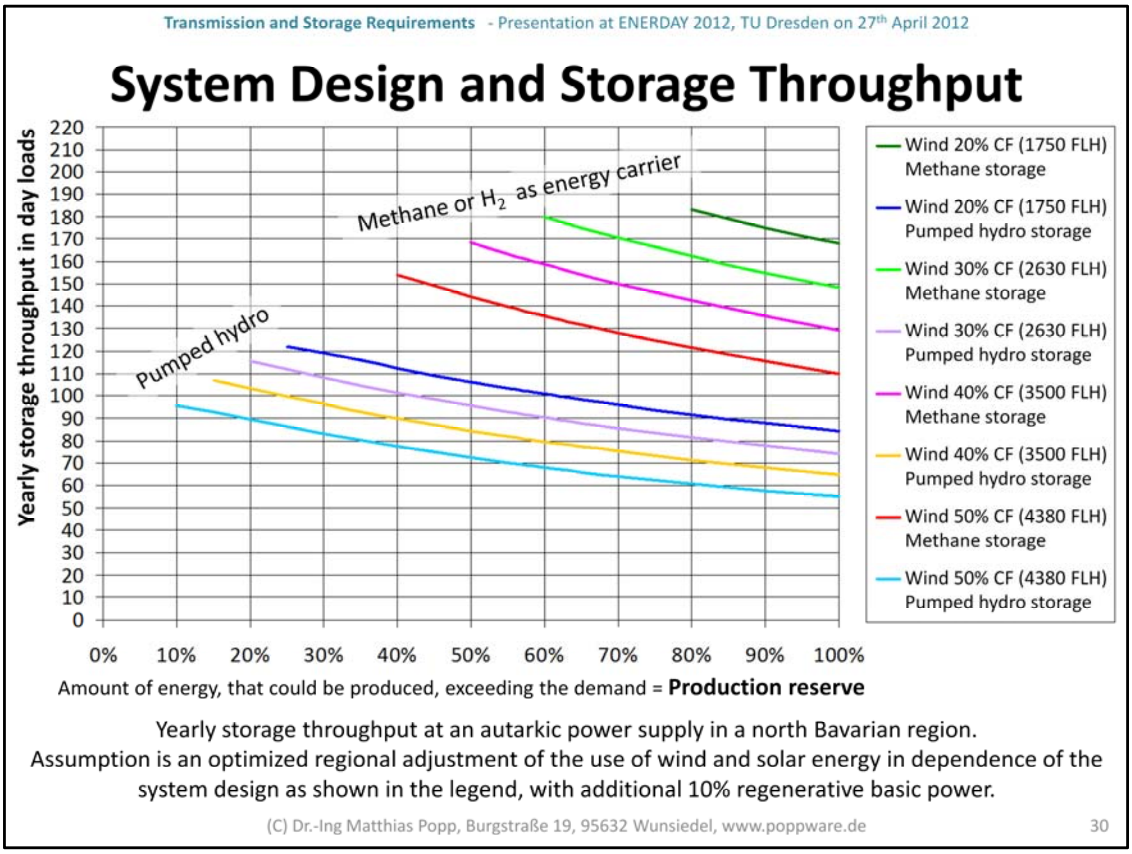
Longer weak wind phases will define the future challenge for storage systems and no longer the balancing between day and night.

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 the task of smart grids can than be fulfilled by the long time storage systems.

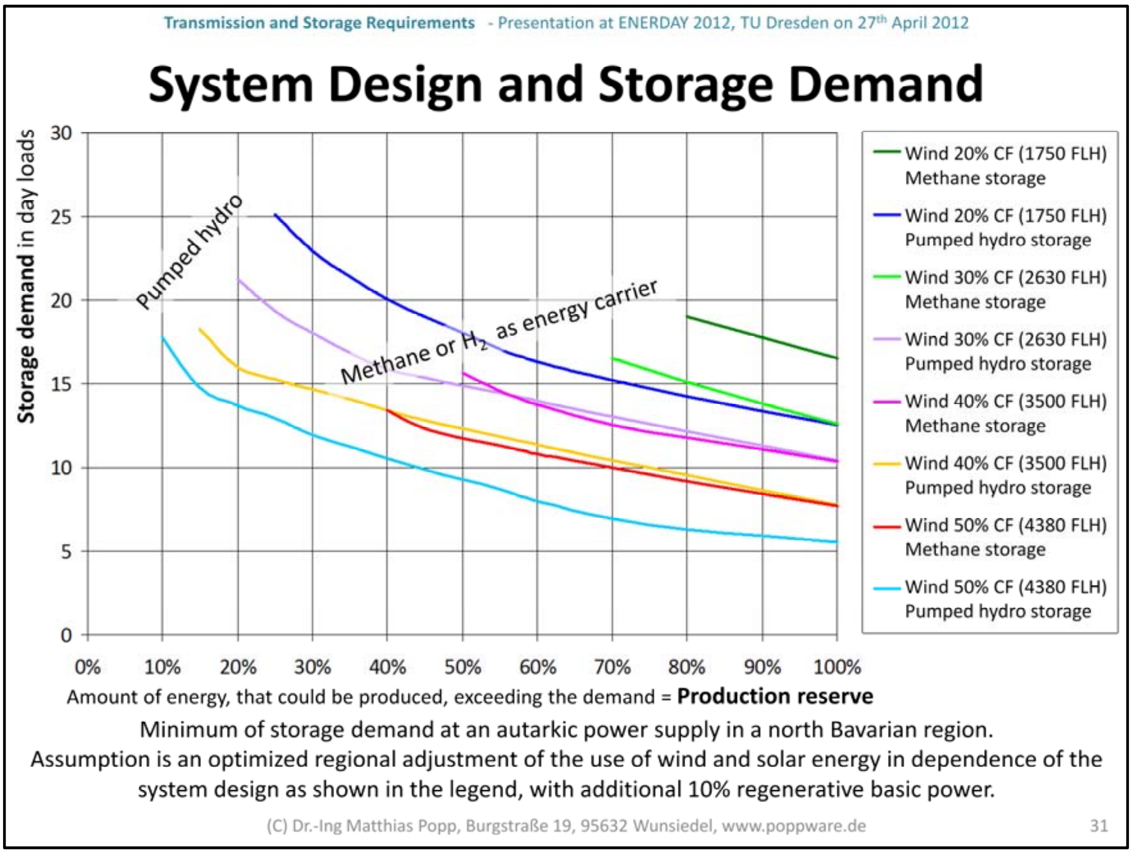


A reason for the good applicability of pumped hydro systems, is the storage throughput.

Large energy losses, taking place during a storage process, doesn’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.

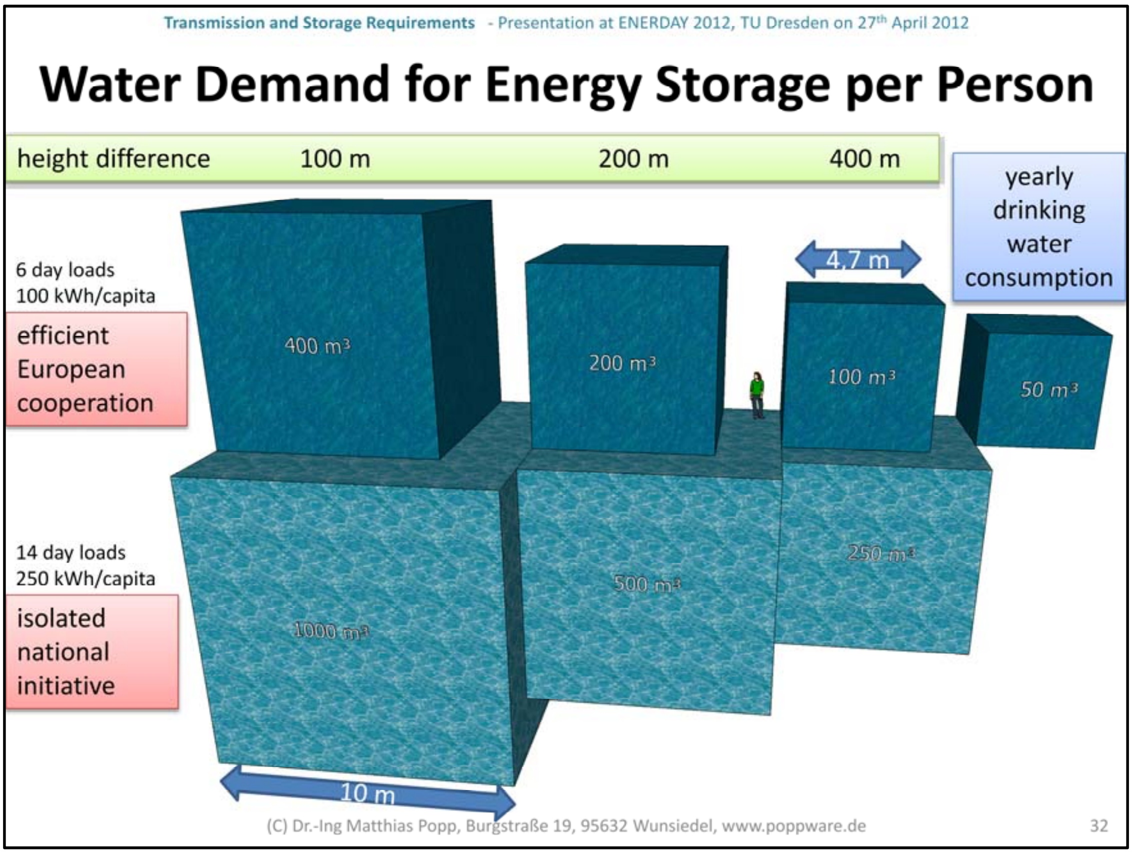


The design of the production system, as well as the storage efficiency, has significant influence on the necessary storage capacity.

The 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.

Thereby, I expect significant potentials in the domain of geotechnics.



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

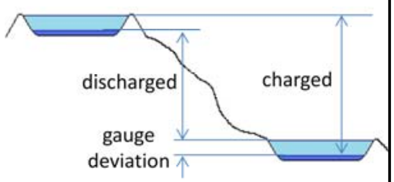
The uniquely required water volumes, to fill up pumped hydro systems, per capita of Germany, are compared here, in a true scale, with the yearly drinking water consumption.

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

Transmission and Storage Requirements - Presentation at ENERDAY 2012, TU Dresden on 27th April 2012

Demand of Land Area for Energy Storage

- The exchange volume of a pumped hydro station must be stored in the upper basin when charged and in the lower basin when discharged. **Therefore, the storage space has to be provided twice.**
- At a given area, the larger the gauge deviation between charged and discharged is realized, the more volume can be stored.



Demand of water surface per capita to create the storage volume							
	Water volume						Unit
Storage demand	100 kWh/capita (Europe-wide)			250 kWh/capita (national)			
Height of fall	400	200	100	400	200	100	m
Gauge deviation	100	200	400	250	500	1000	m³
1 m	200	400	800	500	1000	2000	m²
5 m	40	80	160	100	200	400	m²
20 m	10	20	40	25	50	100	m²
50 m	4	8	16	10	20	40	m²

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If pumped hydro systems, with a given capacity, shall be established in a land saving way,
than it depends, besides a maximum height difference, on a maximum gauge deviation in the storage basins.

Practicable implementations would require between 20 and 50 m² per capita.

Demand of Land Area for Energy Storage

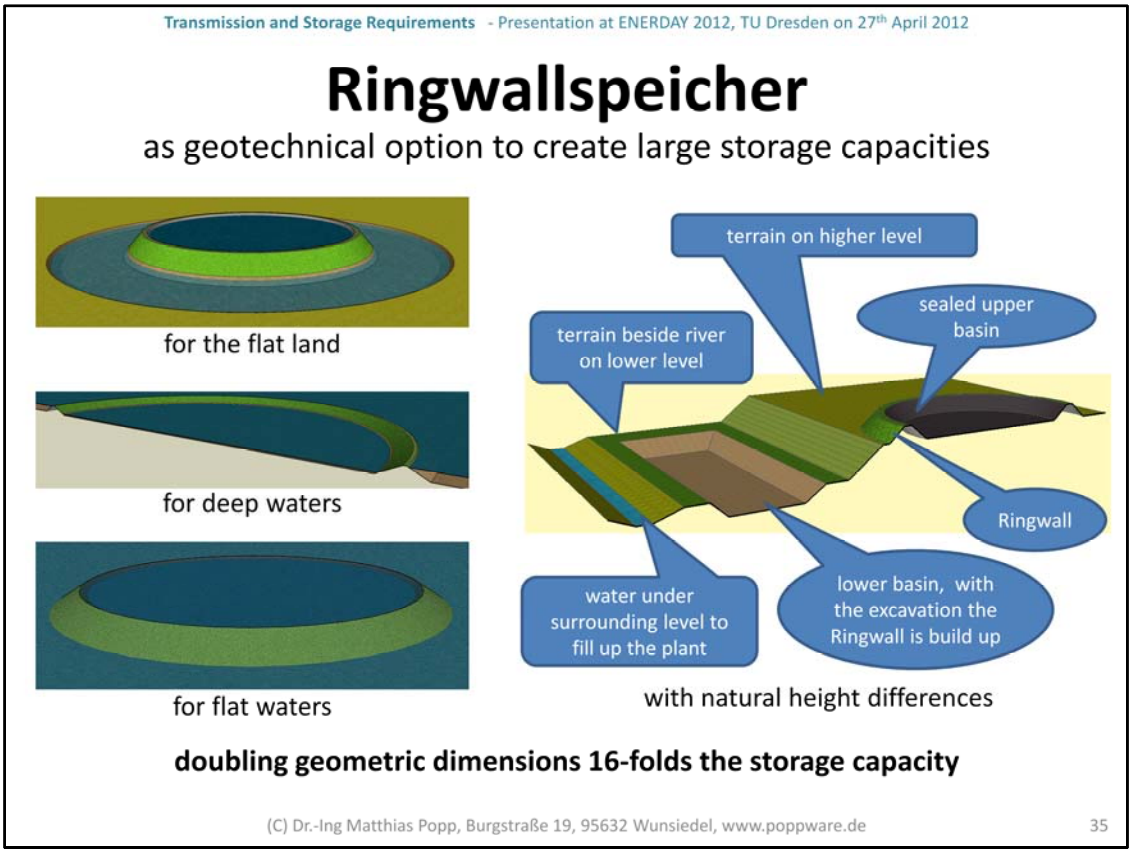
Water surface demand in Germany to create the storage volume (80 Mio. inhabitants)							
Gauge deviation	**Water volume**						Unit
	8	**16**	**32**	**20**	**40**	**80**	**km³**
1 m	16000	32000	64000	40000	80000	160000	km²
5 m	3200	6400	12800	8000	16000	32000	km²
20 m	800	1600	3200	2000	4000	8000	km²
50 m	320	640	1280	800	1600	3200	km²

Water surface demand in comparison to the land area of Germany (country's territory 357.126 km²)							
Storage capacity	Mean vertical height of the water surfaces						Unit
per capita	(Europe-wide) 100			(national) 250			kWh
Germany-wide	(Europe-wide) 8			(national) 20			TWh
Gauge deviation	**400**	**200**	**100**	**400**	**200**	**100**	**m**
1 m	4,48%	8,96%	17,92%	11,20%	22,40%	44,80%	
5 m	0,90%	1,79%	3,58%	2,24%	4,48%	8,96%	
20 m	0,22%	0,45%	0,90%	0,56%	1,12%	2,24%	
50 m	0,09%	0,18%	0,36%	0,22%	0,45%	0,90%	

The countrywide necessary land requirements of water for energy storage would be marginal in comparison to other forms of land use.

Depending on the system design, the land requirements could become even less, then the land requirements of photovoltaic.

Taking all these thoughts into account, leads to the proposal of the Ringwallspeicher .



Large storage capacities with a high degree of efficiency can be built also in areas, where classic pumped hydro systems wouldn‘t be considered.

Height differences can be created or increased and the water gauge deviations offer a wide scope in designing.

With the excavation of the lower basin the dam for the upper basin is raised and sealed on the inside after this.

Ringwallspeicher Hybrid Power Plant

Alternative to two nuclear power stations with 2 GW average and 3.2 GW maximum power

Assumptions
diameter:
outer ring 11,4 km
Ringwall 6 km

height difference:
200 m

gauge deviation:
lower basin 20 m
upper basin 50 m

Capacity:
14 day loads, 700 GWh

wind power:
about 2000 systems in largest design

solar module area:
about 25 km²

Illustration: Stefan Schiessl, first published: Bild der Wissenschaft 10/2010

„Ringwallspeicher as technical building and tourism paradise"
citation of Prof. Dr. Carsten Ahrens from the Jade Hochschule in Oldenburg,
he introduced the Ringwallspeicher at the 19th October 2010 on the Ingeniera 2010 in Buenos Aires.

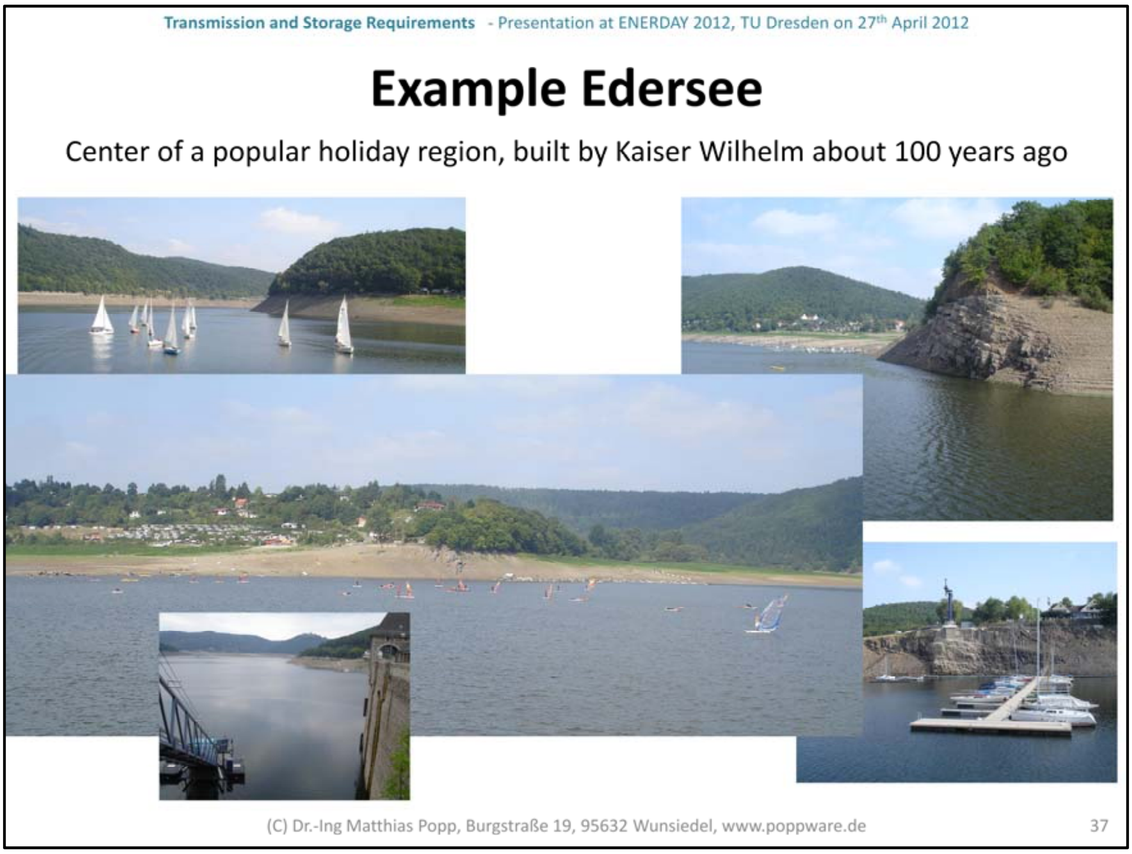
This very big and idealized model would probably not be built in this way.

It shows principles and possibilities of the concept.

The upper basin and the south ridge are covered by solar panels.

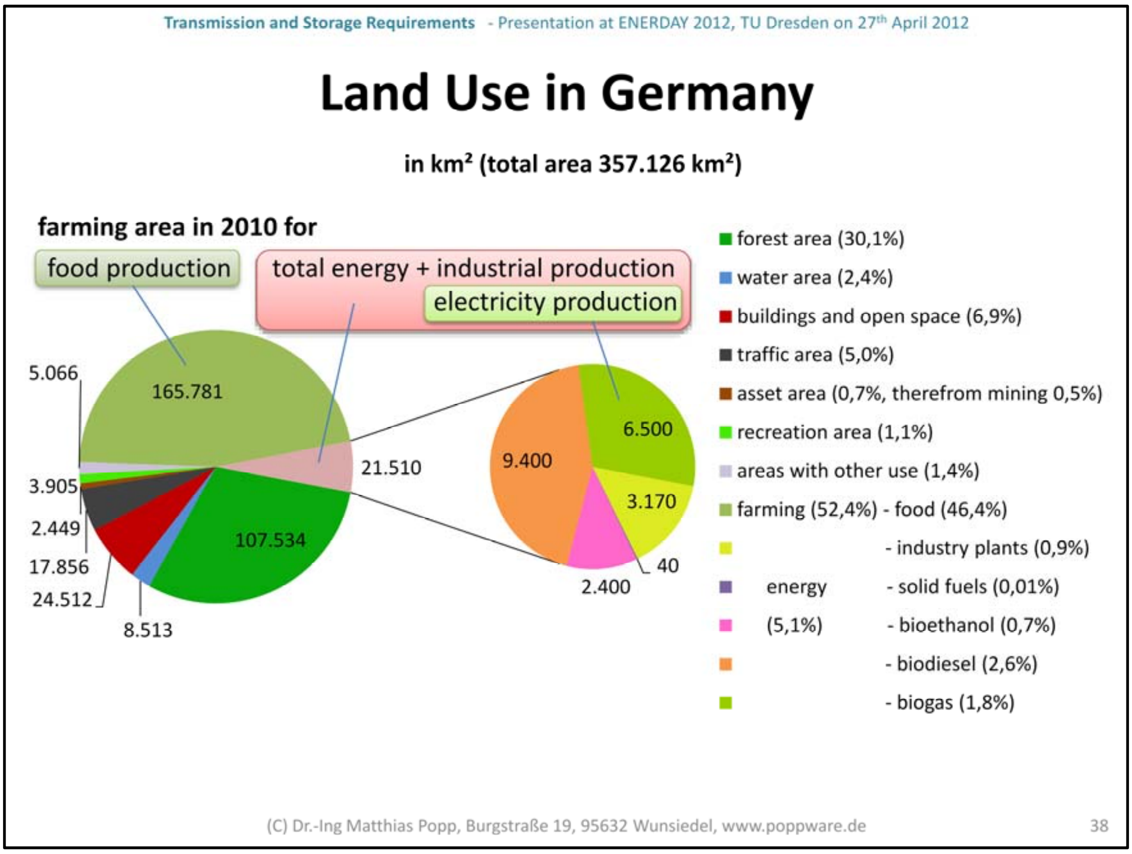
In combination with the required wind energy plants, this device could deliver secure electricity for about 2.7 million people.

Especially, the lower basin would be usable for water sport activities, because the whole capacity will only rarely be used.



Touristy used lakes with large gauge deviations exist.

With yearly up to 30 meters of gauge movement, a lot of leisure and water sport activity takes place.

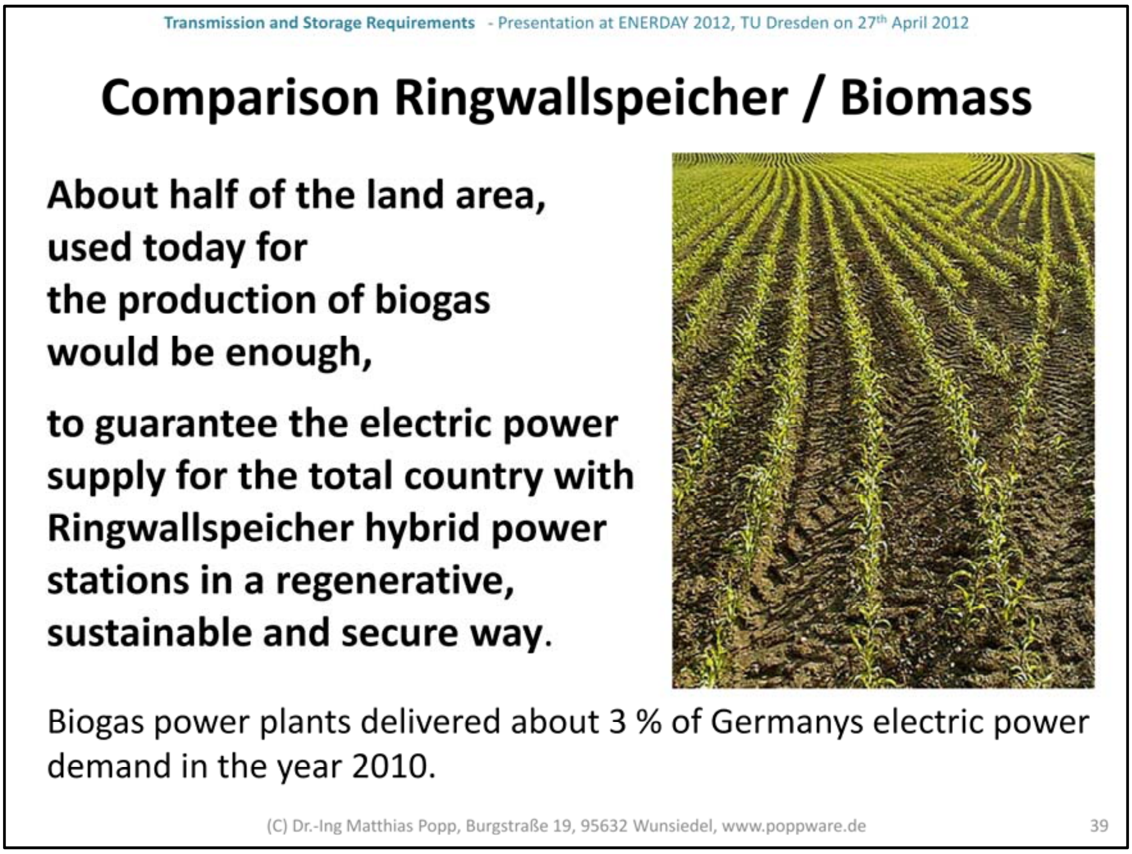


Together with all wind and sun power plants, the idealized shown Ringwallspeicher would cover about 100 km².

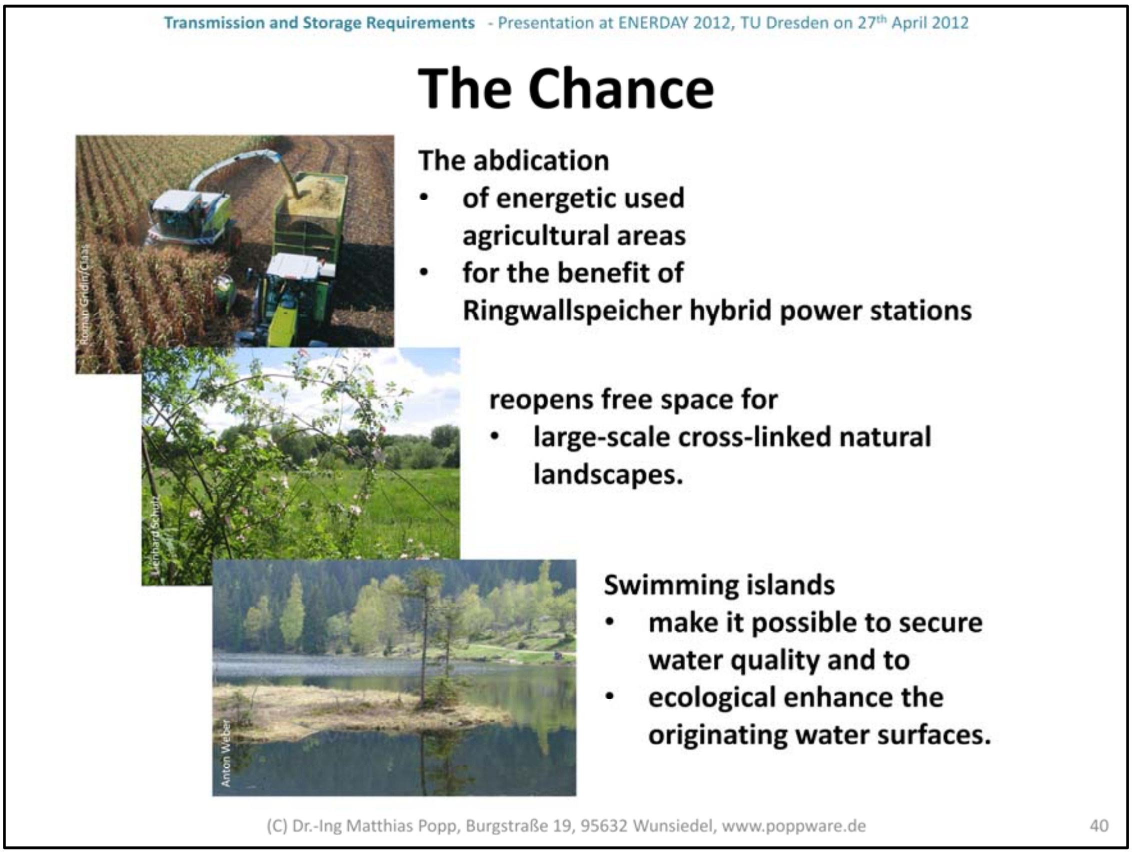
30 of these idealized hybrid power stations could supply the complete electric power of Germany, alone from wind and sun.

The required total land area would be about 3000 km².

That would be less than 1 % of the countries area and less than half of the area, cultivated with biomass for electric power production.



Ringwallspeicher hybrid power plants would deliver about 50 times more electricity on a given land area, as biomass production.



Rethinking this way of land use could create free spaces for areas close to nature,
and could contribute to concentrate the resources of the country to the real challenge.

Comparison Ringwallspeicher / Brown Coal

Landscape impacts of larger degree, than needed for Ringwallspeicher are reality in Germany.

Brown coal mining areas are the only structures, where much more earth is moved, than needed for the construction of large Ringwallspeicher systems.

The competence of the operators of daylight mining areas, could be of interest for a cost-effective construction of these storage devices.

Comparison Ringwallspeicher / Brown Coal

Brown coal daylight mine Hambach

- example link: http://de.wikipedia.org/wiki/Tagebau_Hambach
- dimension: about 85 km²
- depth: up to 400 m
- operating time: about 45 more years
- electrical power: about 4 GW
- the elevated dump "Sophienhöhe" overtops the landscape about 200 meters
- the baring volume will reach more than 10 km³

These moved earth masses alone relate to the required earth volume for seven Ringwallspeicher hybrid power stations with

- 215 m wall height,
- 14 GW average and
- 22.4 GW maximum power.

The largest German daylight mine, Hambach, will reach a dimension, comparable to the water surface of the illustrated Ringwallspeicher .

The ground water level is deepened down to about 500 meters on a large scale.

The created hybrid power systems could provide much more electrical power, than this daylight mine.

Comparison Ringwallspeicher / Daylight Mine

Circular **Ringwallspeicher systems**
are an ideal concept, which will hardly be realized in this way.

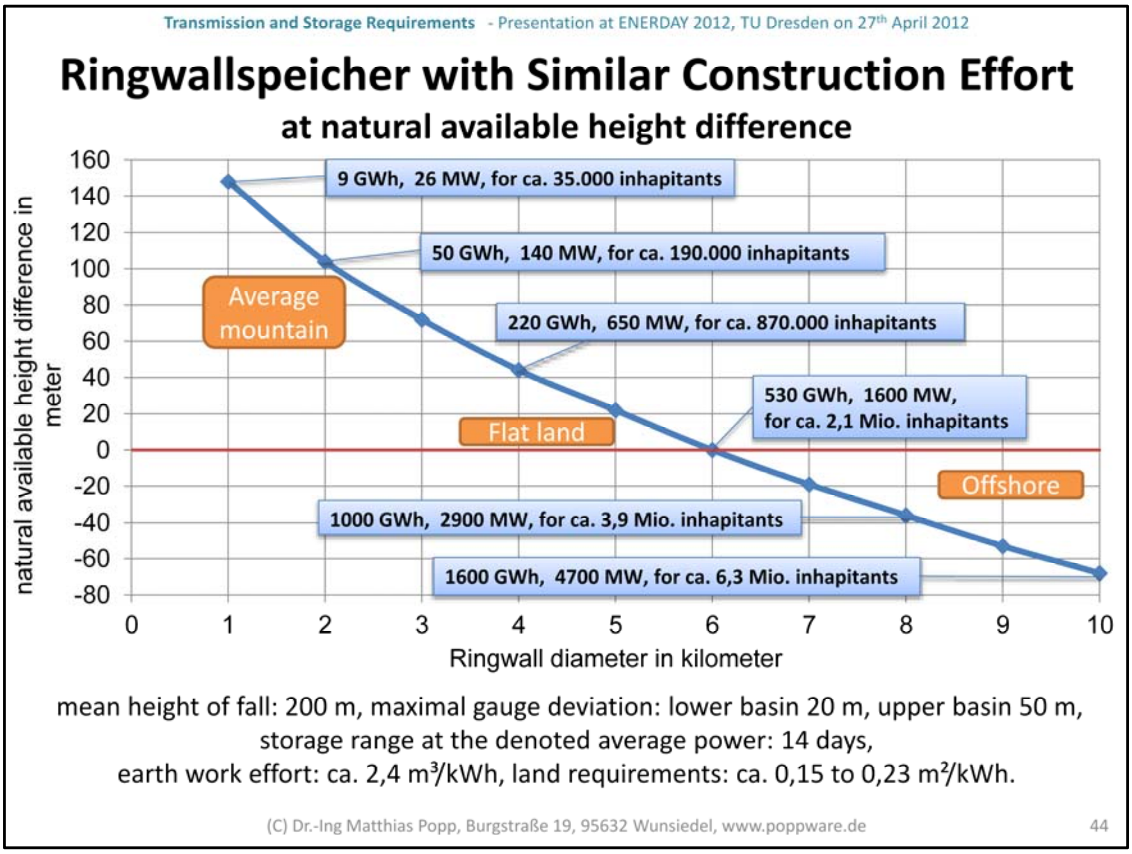
In praxis, the dimensions of the plant and the run of the waterline will orientate on the possibilities and conditions of the landscape.

In opposite to **daylight mining projects**, populated areas and sensible zones can be recessed and integrated in the sustainable renewable energy system.

Ringwallspeicher will most likely not adopt this idealized, circular form, as shown in the illustration.

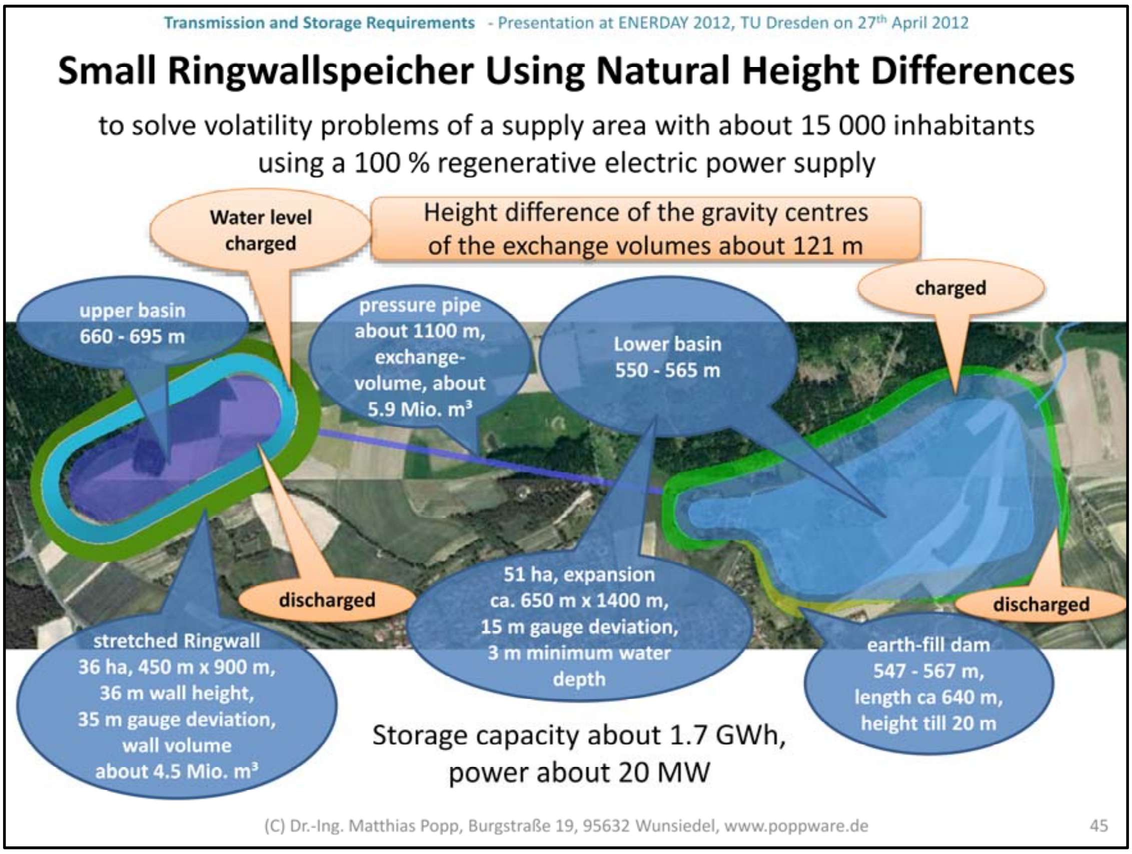
Sensible areas and urban areas can be recessed and integrated attractively in the created new landscape.

By using natural height differences, they can also be constructed in a smaller scale by a comparable economy.



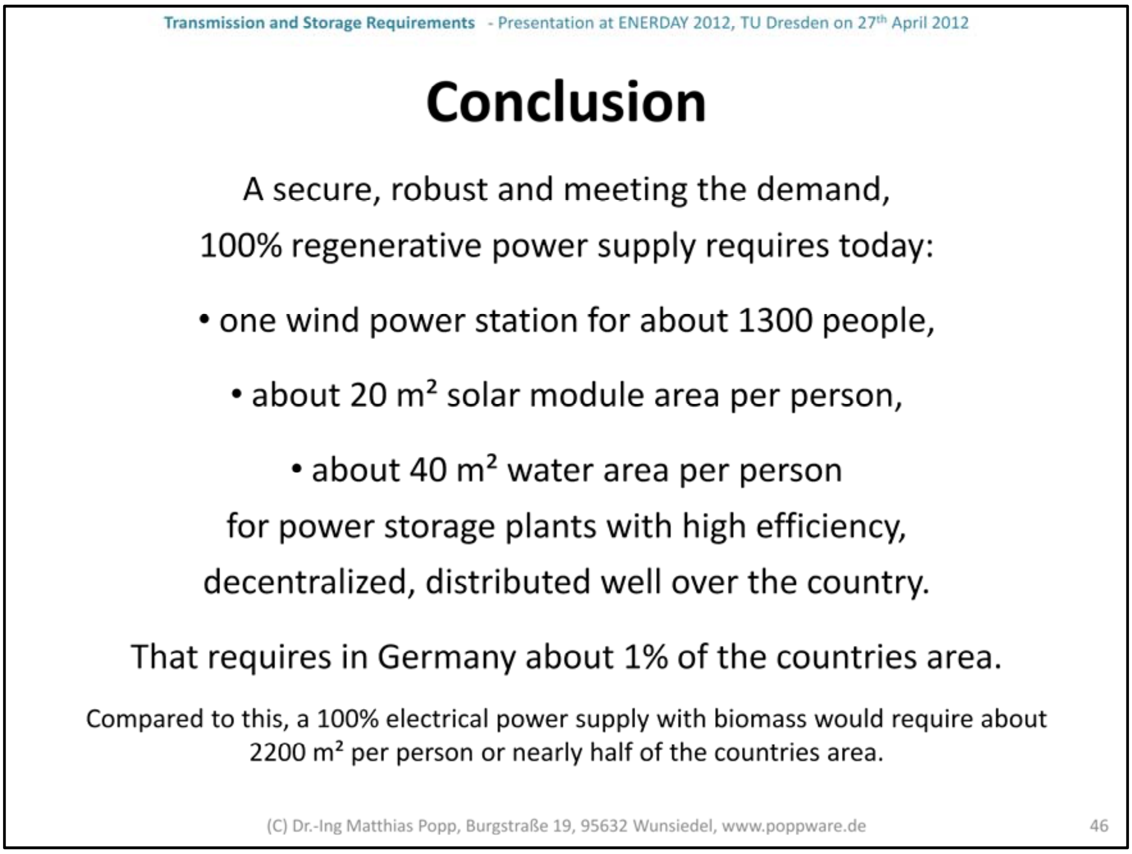
Dams require the most earth work volume in the base.

Small natural height differences, allow the construction of considerable smaller systems as on flat land, by keeping similar convenient economical conditions.



An example how such a storage system can be embedded in a hilly landscape for a small power supply area is shown here.

Flooding protection, recreational lake and sustainable supply with renewable energy could be combined.



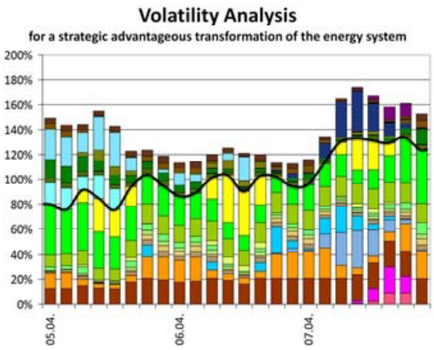
Today, a secure and 100% regenerative power supply, which meets the demand, is a real option for the future.

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 understanding and acceptance in the society.

Thank you for your Interest

With a well-considered, holistic strategy, stakeholders in the energy market can bring themselves in an opportune position, when in future, regenerative power shall not only complement, but replace conventional power.



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

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