„Energiewende“ in Germany
- issues and problems -

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Introduction

Two terms, not to be confused – **energy (TWh) and power (GW)**

A machine/system uses energy to do work e.g. steam engine
chemical energy → thermal energy → mechanical energy → electricity

Generally, heat is produced when energy is converted or transformed into work

primary energy (PE): energy content of fuels (chem. energy)

net energy: energy in the desired, useful form (electricity)

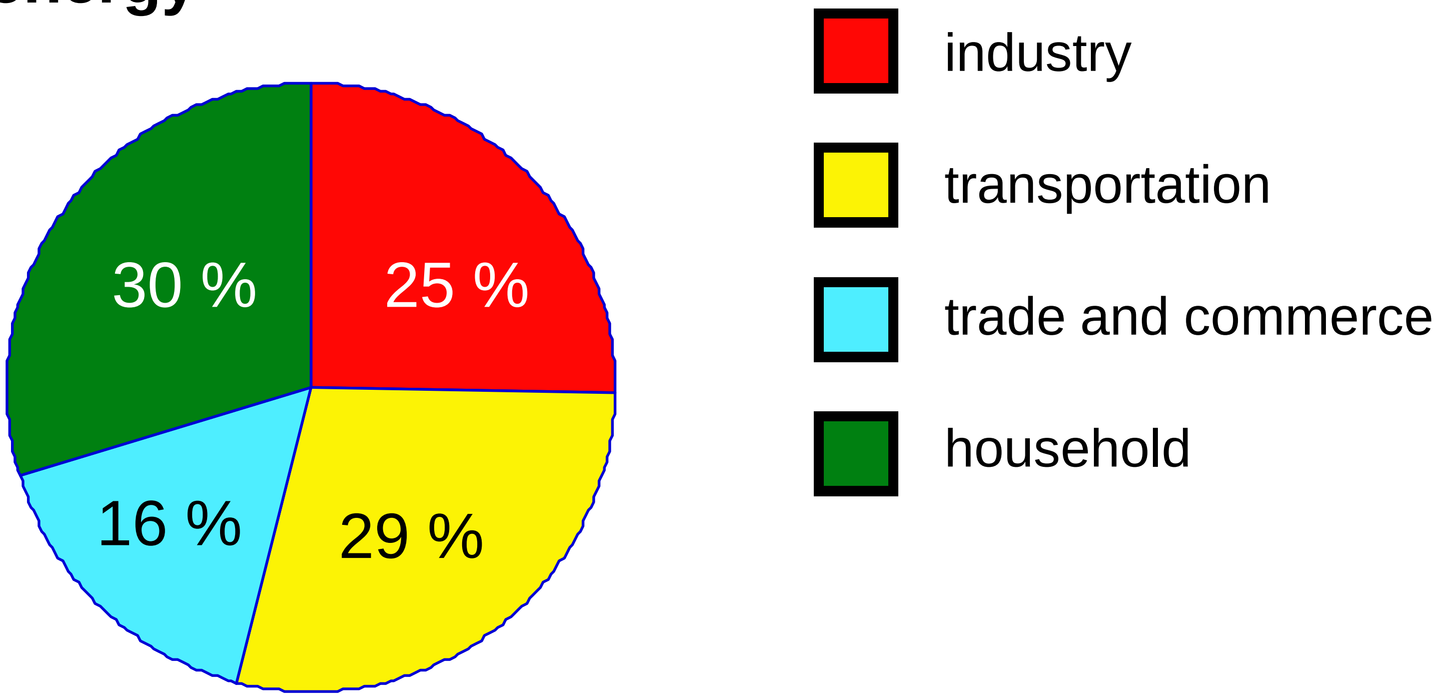
Germany, 2012: PE: **3820 TWh**; electricity produced: **630 TWh**

A human being needs 100 W for his/her metabolism
and is able to provide 120 W for steady-state work

Average power needs: 3820000000000000 Wh/82000000 people/8760h →
5320W/120W = **45 (slaves, working for us)**

Use of energy in Germany

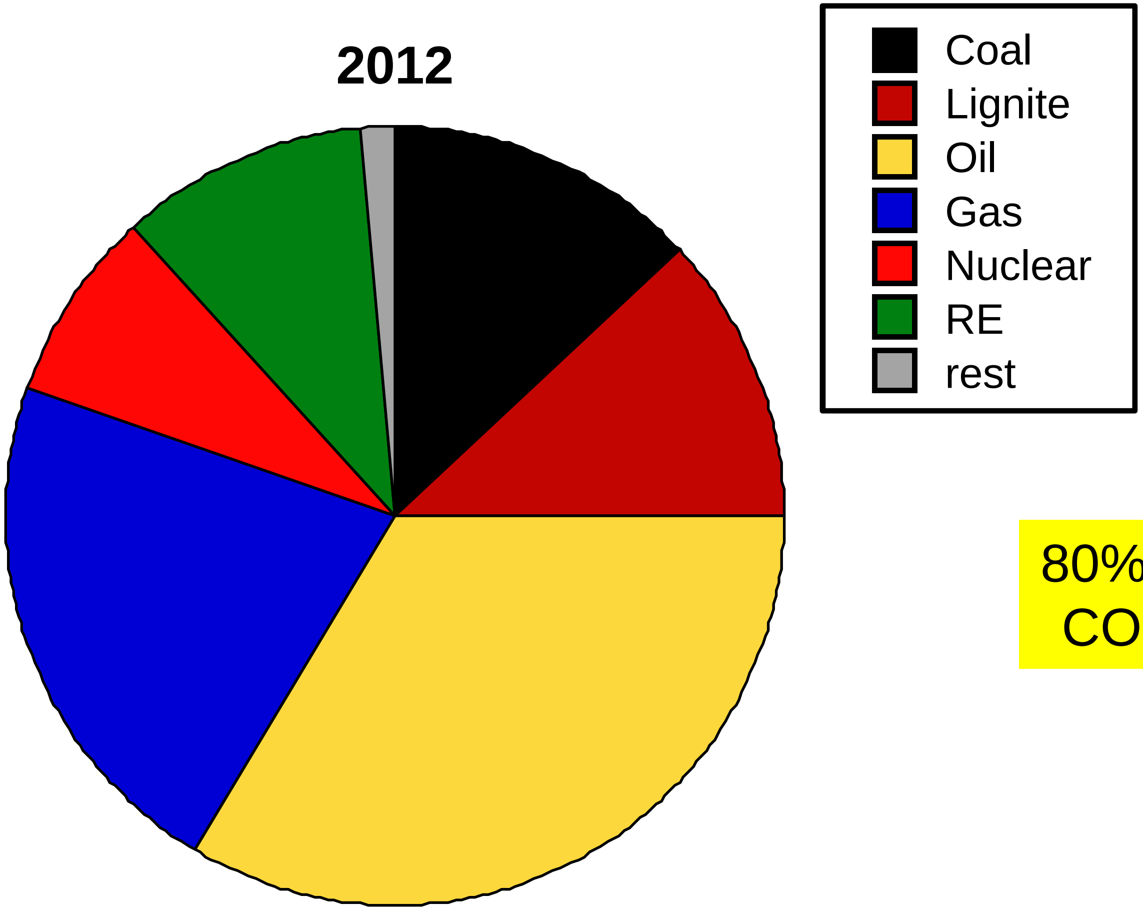
Net energy



only ~ 1/3 for households

rest: into the sectors of our economic acitivities

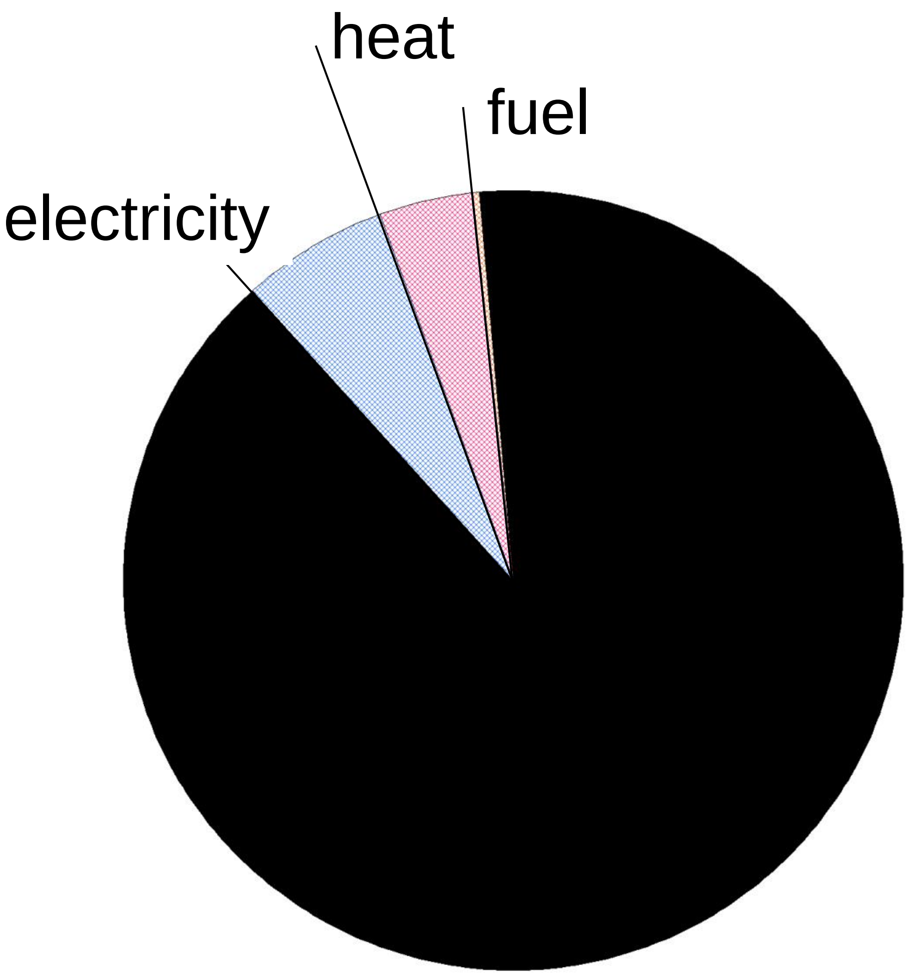
Energy carriers of primary energy



80% fossil with CO_2 emission

Quelle: AGEB und bdew

Use of Renewable Energies (RE)

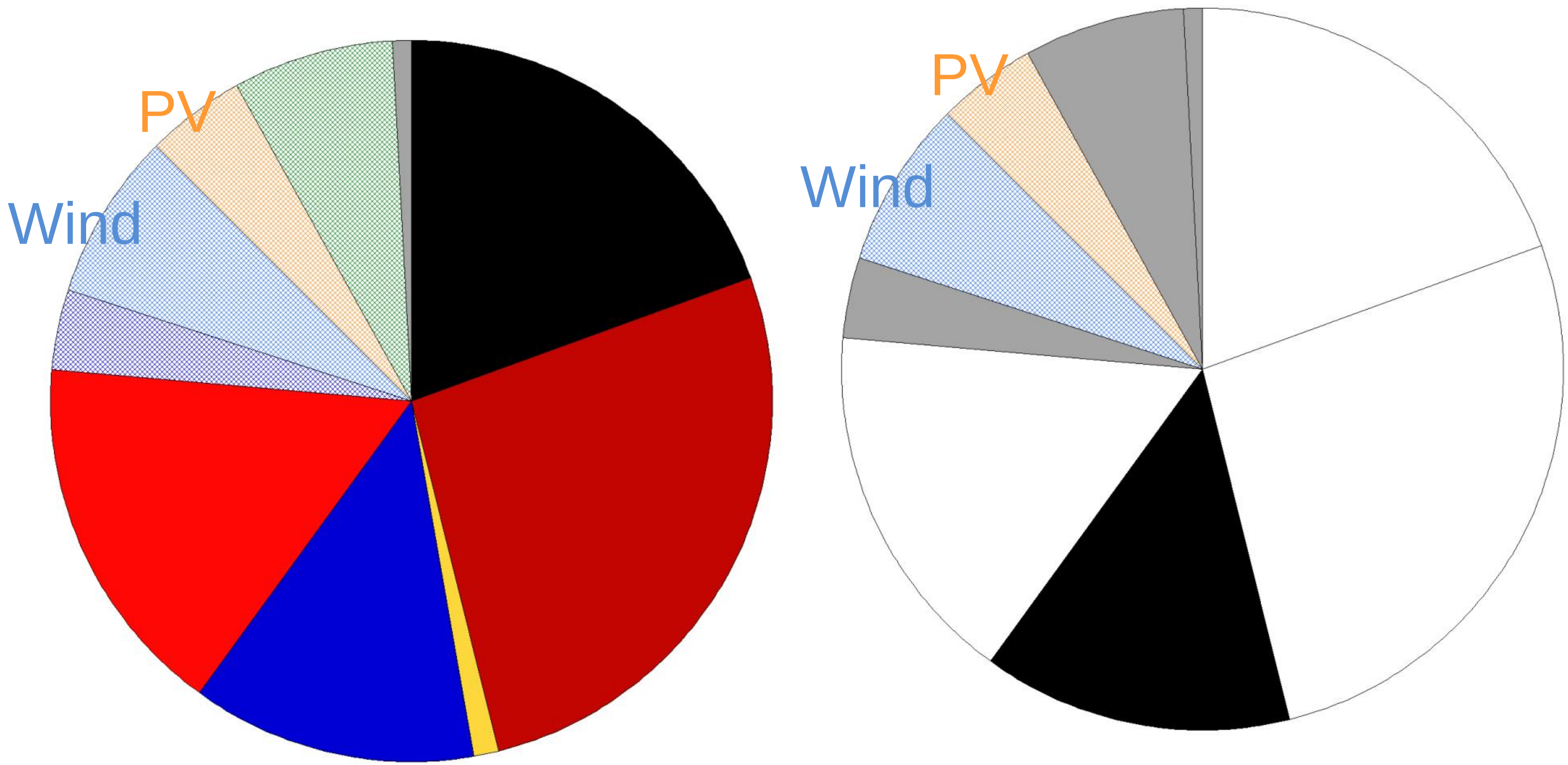


11.6 % RE

The task of the future…

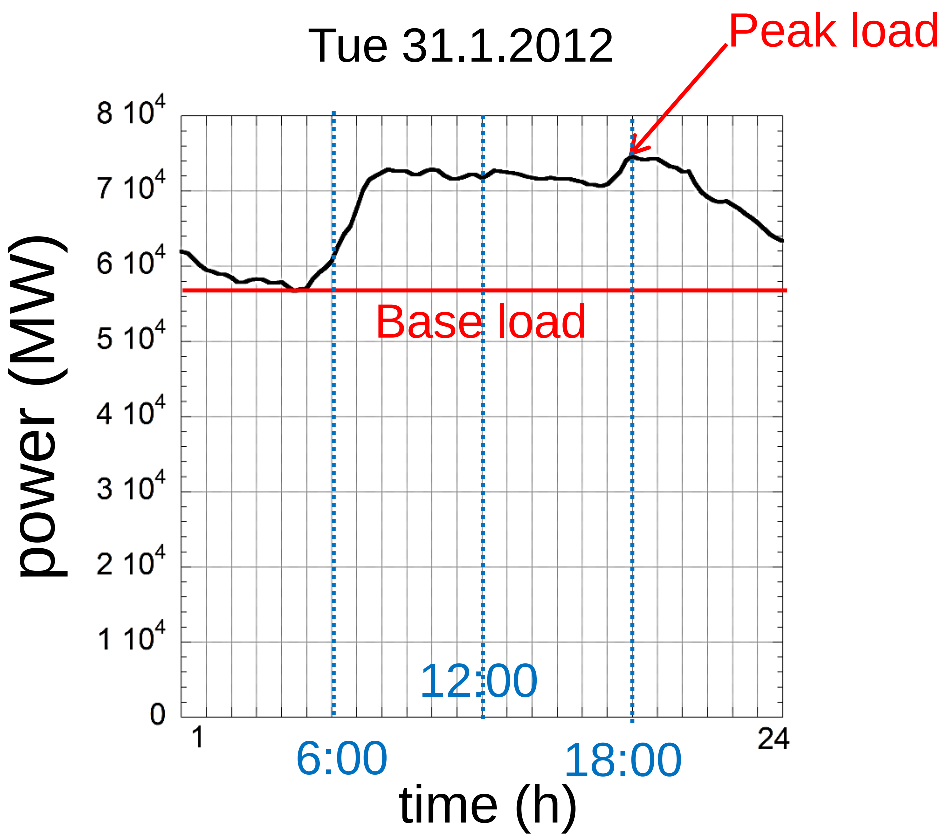
…replacing coal and nuclear

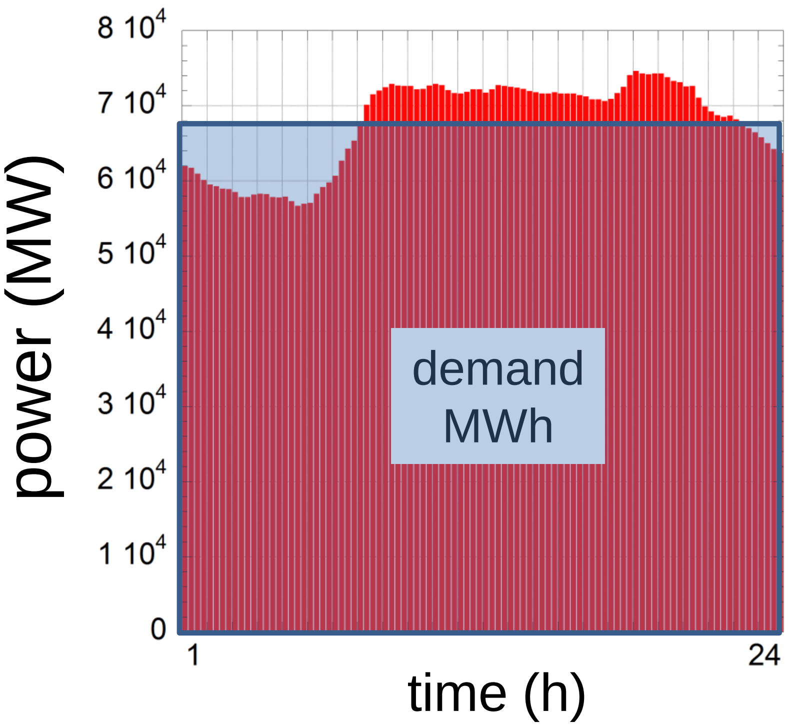
Without nuclear and coal



Electricity demand during the day

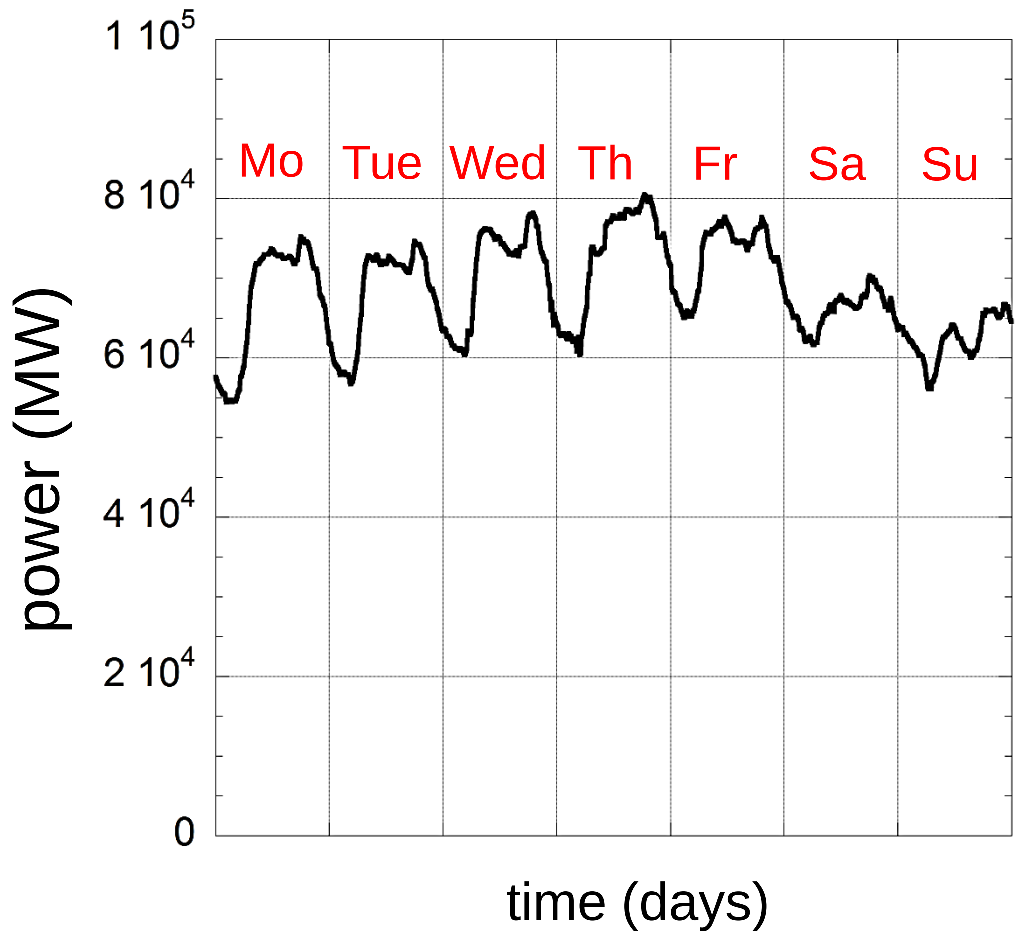
Definition: load = demand



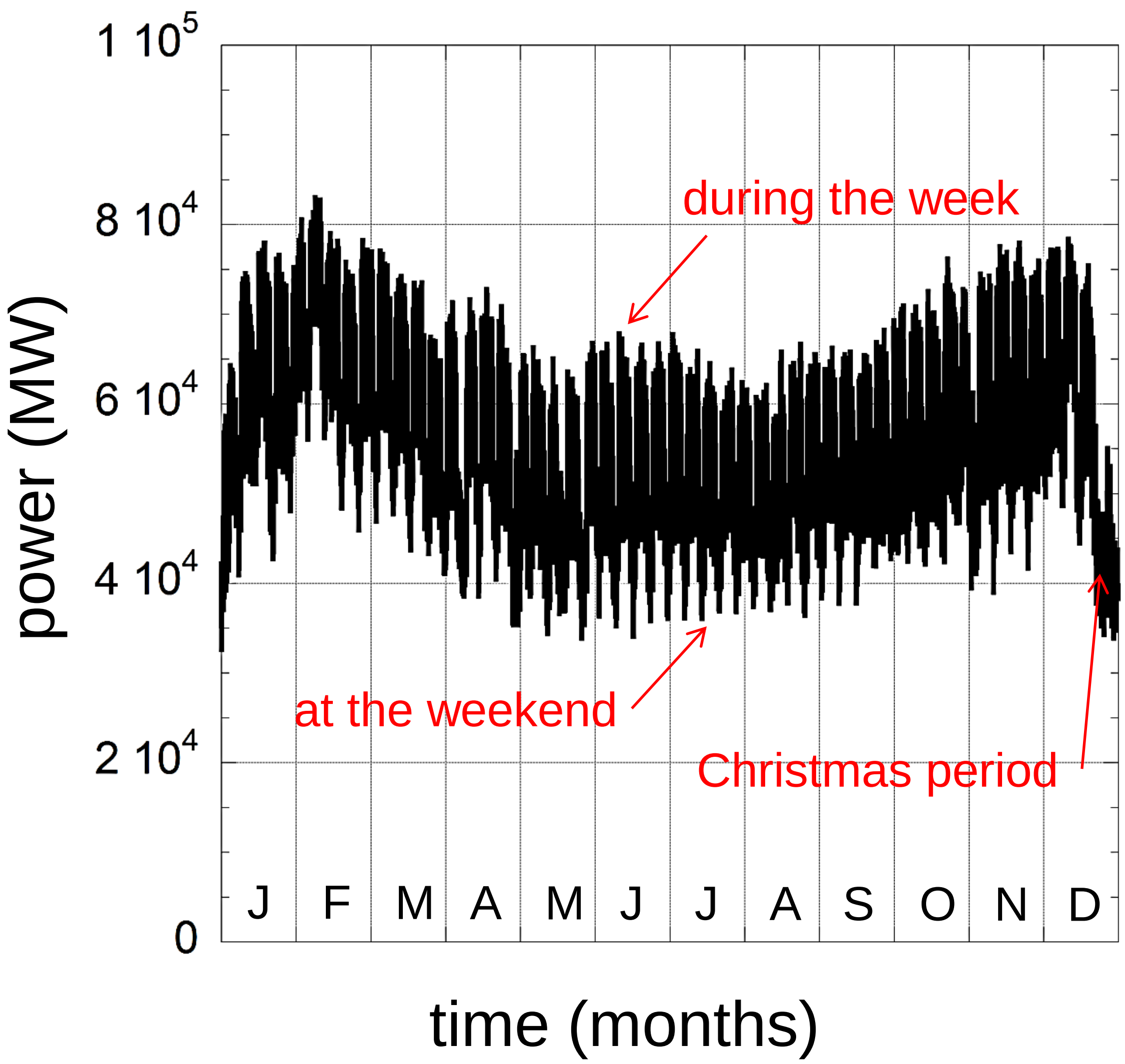


68 GW x 24 h x 365 days =
600 TWh

Electricity demand during the week



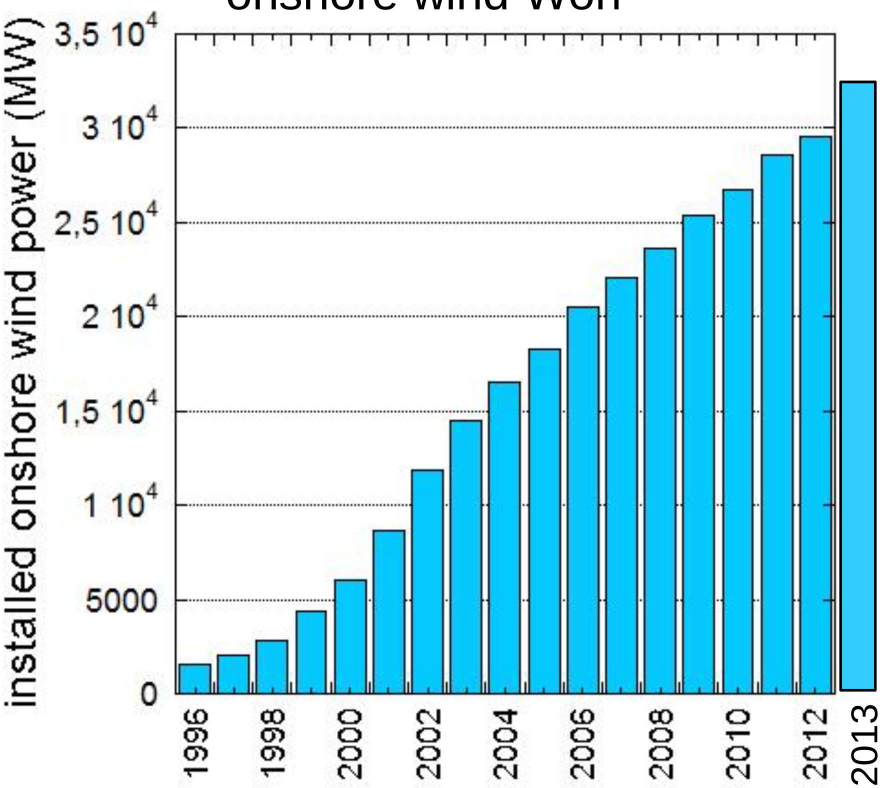
Electricity demand during the year 2012



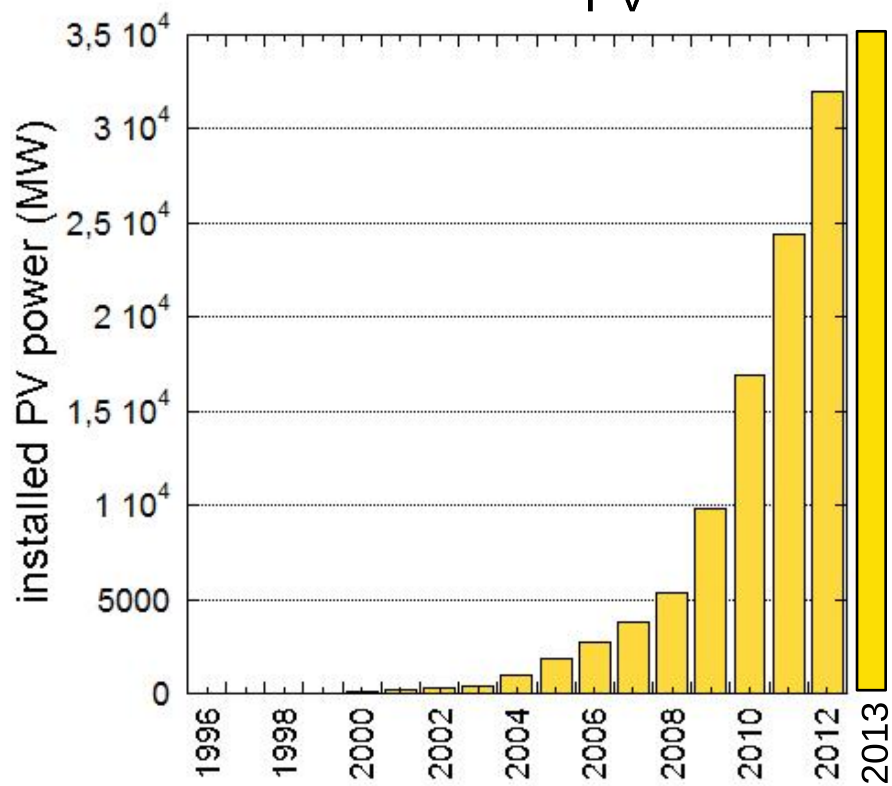
Growth of wind and PV in Germany

Growth of installed wind and PV power in Germany

onshore wind Won

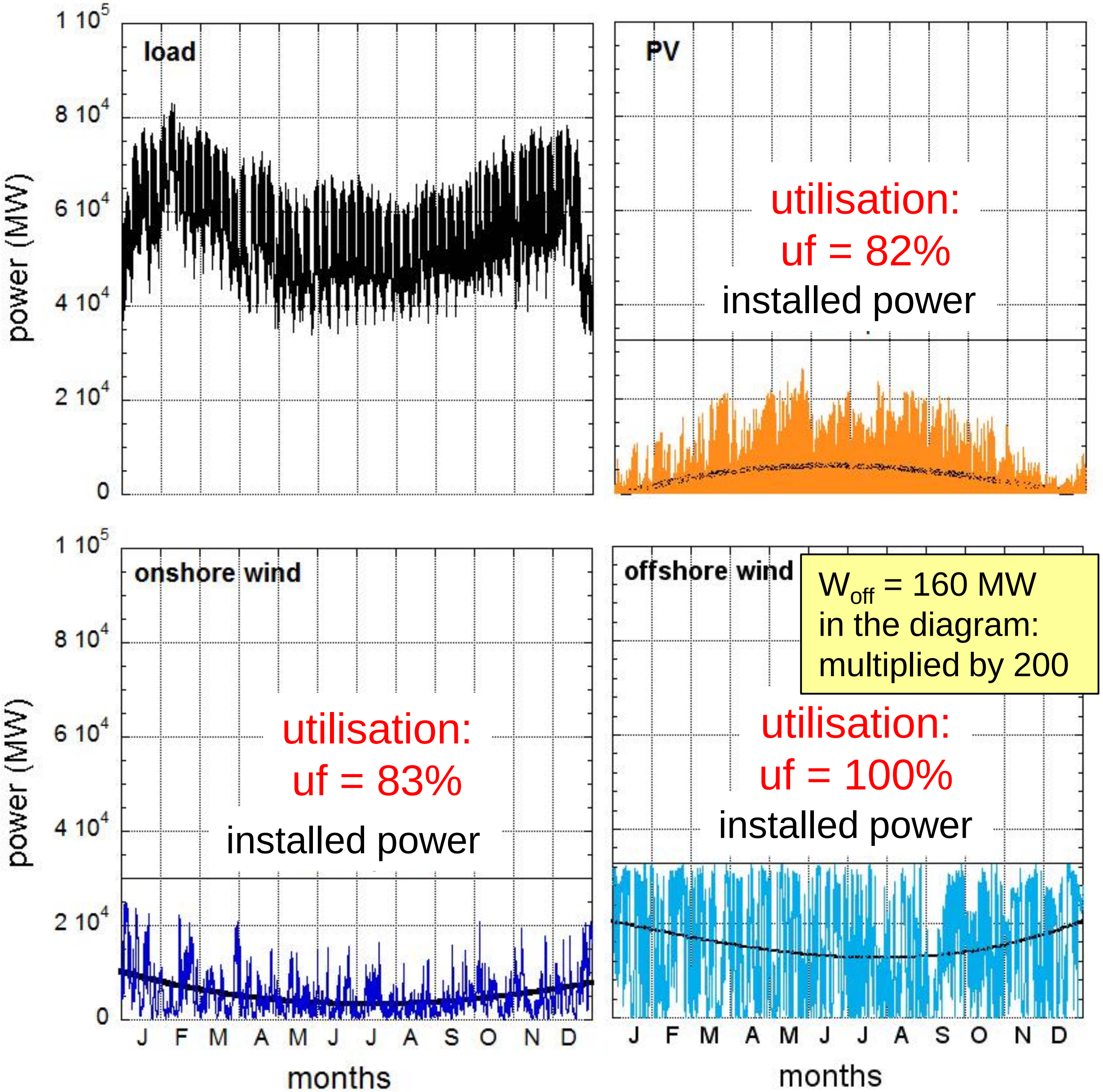


PV



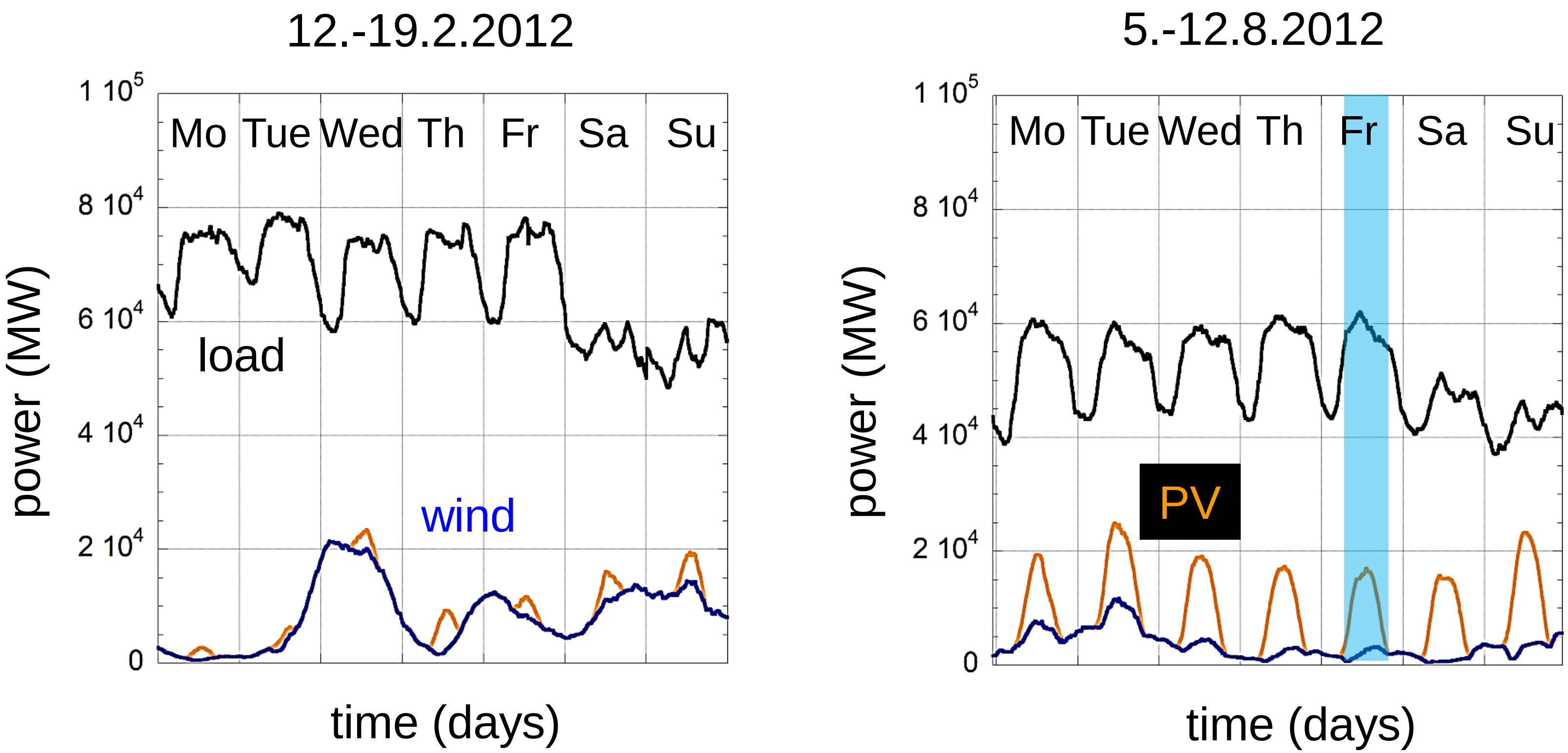
2013: Wind: 32.5 GW; PV: 36 GW

Situation 2012



Wind fits well to the annual variation of the demand

Wind und PV power in winter and summer

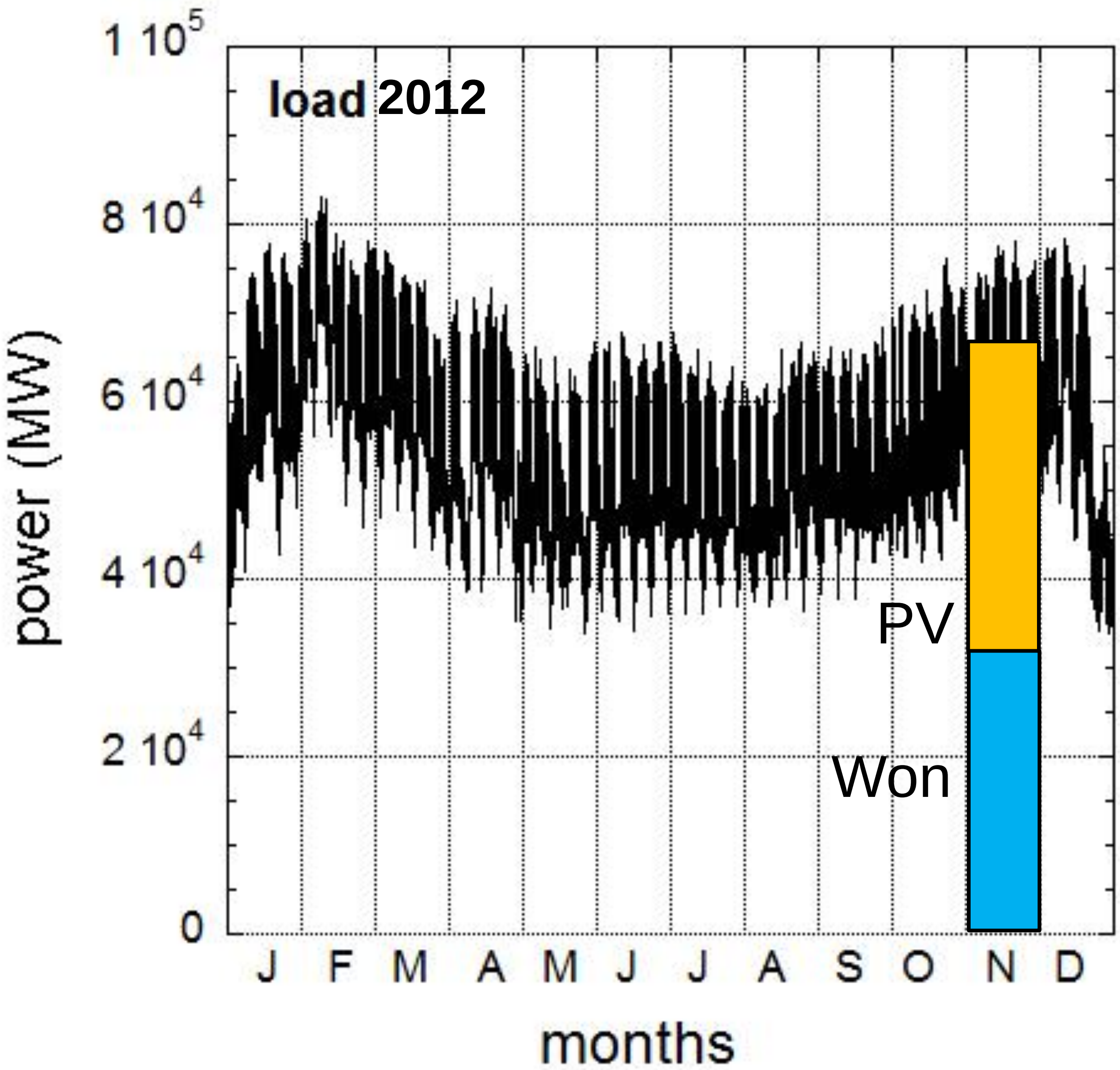


Wind is erratic and strong in winter
PV is periodic, strong in summer and aligned to the maximal demand

→ **there is an optimal mix between wind and PV: ~ 20 %**

Optimum: residual power is minimum

Comparison: load – installed RE power



RE have feed-in priority

periods with strongly reduced thermal power

periods with surplus

Peak (installed) power and energy production

Power:

Maximal demand: 83 GW

Wind: 32.5 GW; 39 %
PV: 36 GW; 43 %

Energy:

Annually produced electricity: 630 TWh

Wind: 50.7 TWh; 8.1 %
PV: 26.4 TWh; 4.2 %

High capacities are necessary to produce energy by RE

All components have to be ready to work at high power levels

What next ?

Scale 2012 data to higher installed powers and analyse

Assumptions:
electricity demand will not change
(electric cars, saving measures, air conditioning)

Hydroelectricty and electricity from waste will not change

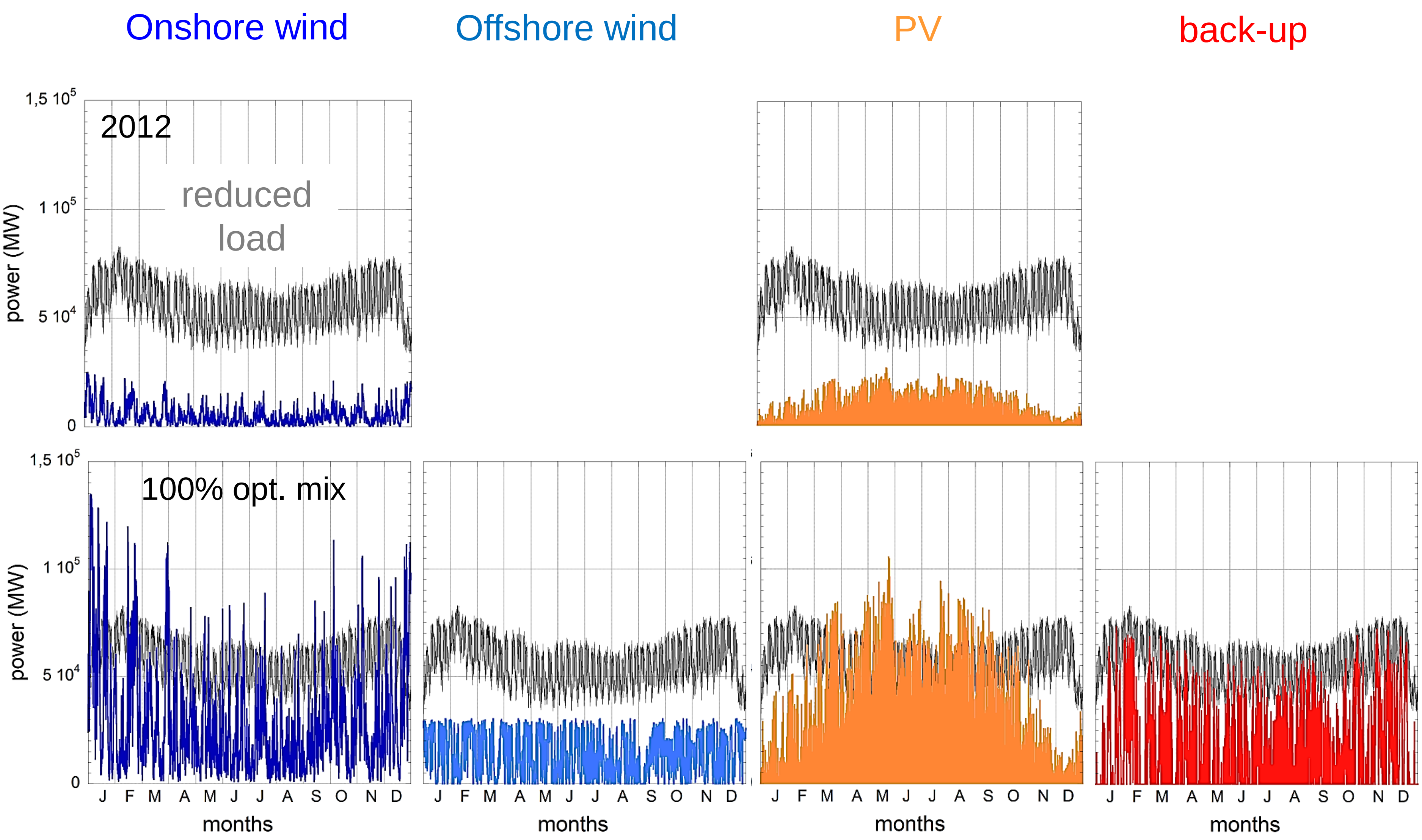
Biomass will be used for transportation not for electricity production

Target: 630 TWh produced – 595 used – 537 net – hydro: 21, waste: 5 TWh

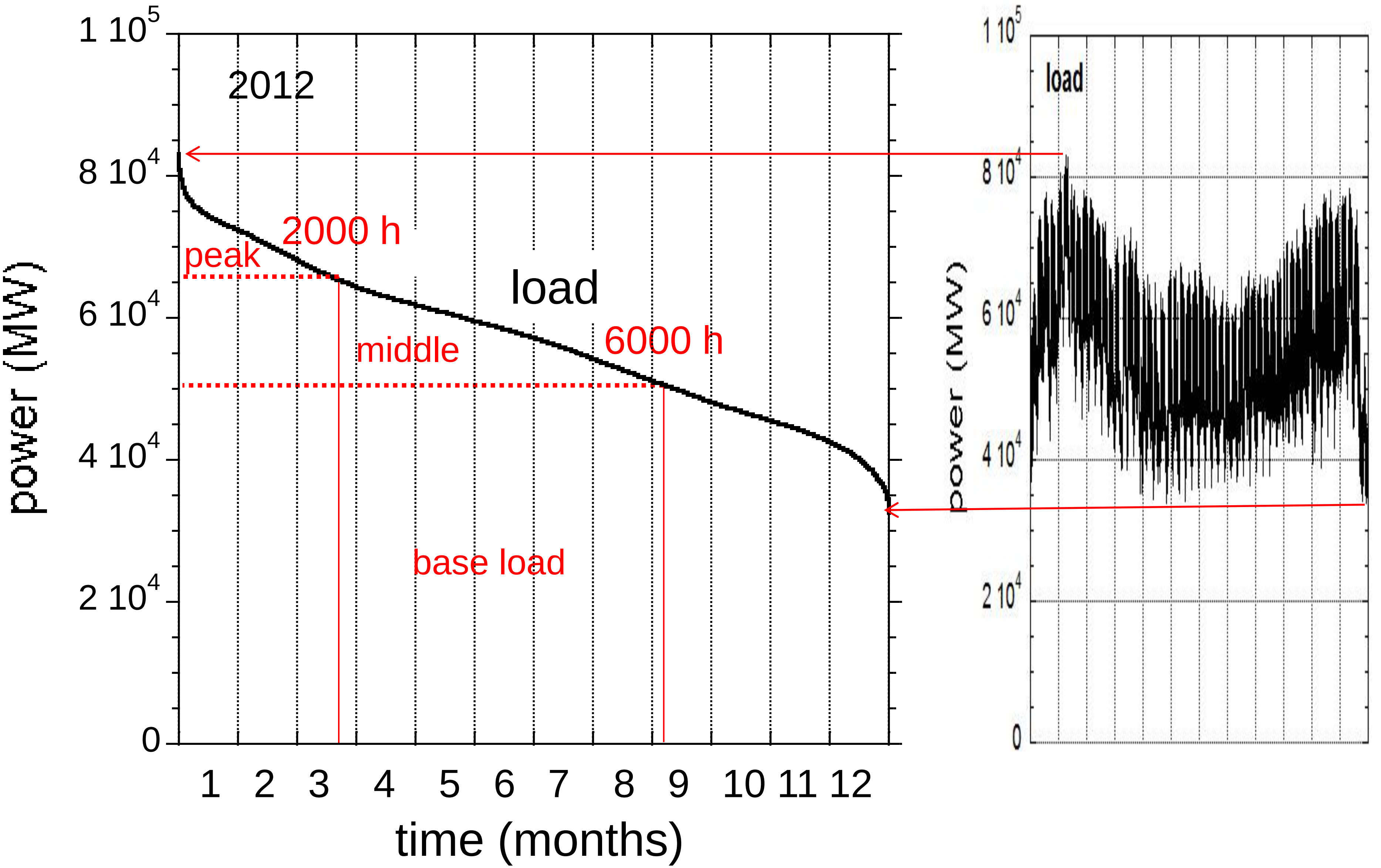
Target: reduced load: 500 TWh

Term: 100%, optimal mix case:
Wind + PV: 500 TWh; W_{on} = 2/3 wind; W_{off} = 1/3 wind; PV = 20%

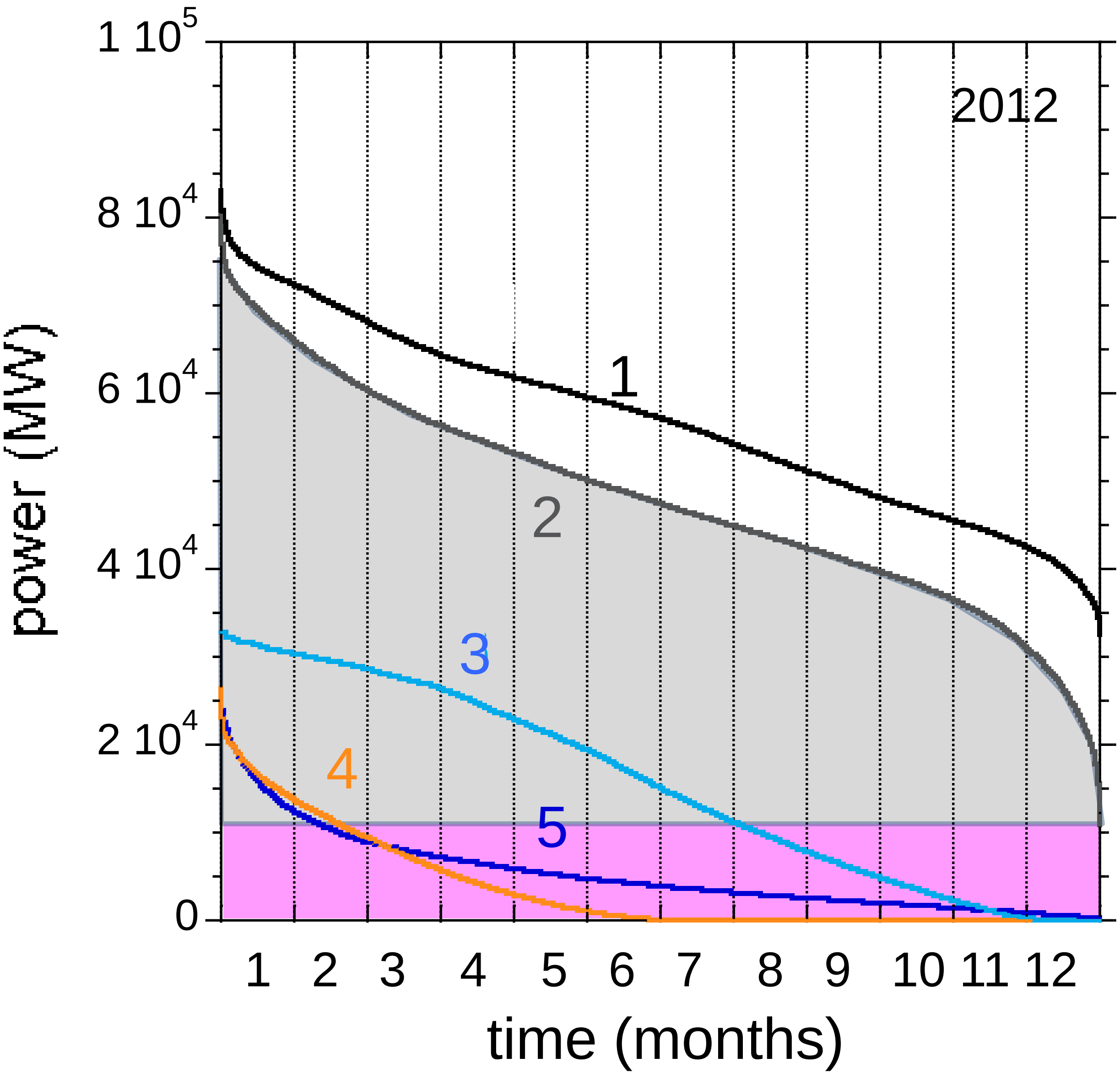
Scaling to 100% supply by RE



Duration curve: load



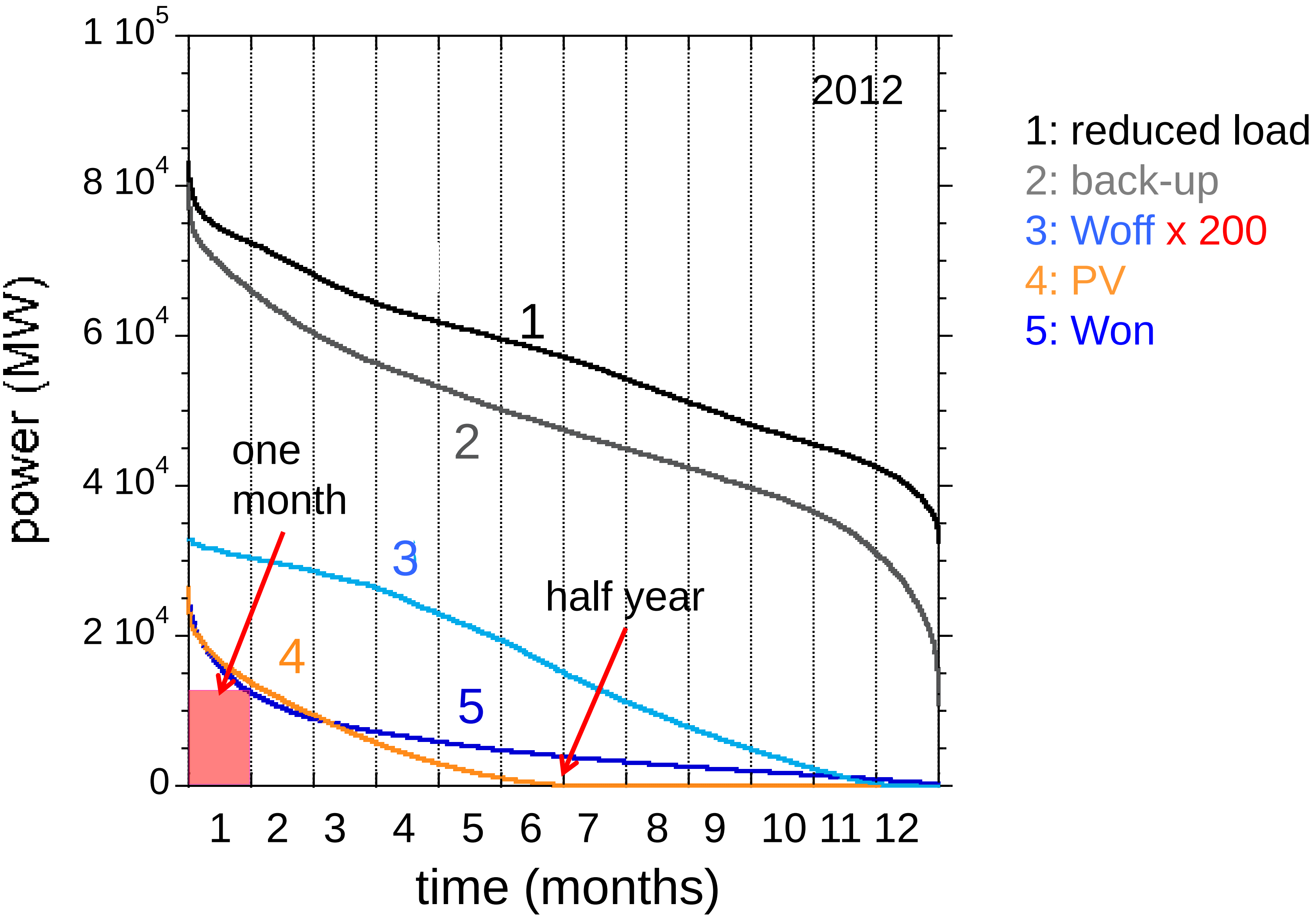
Duration curve



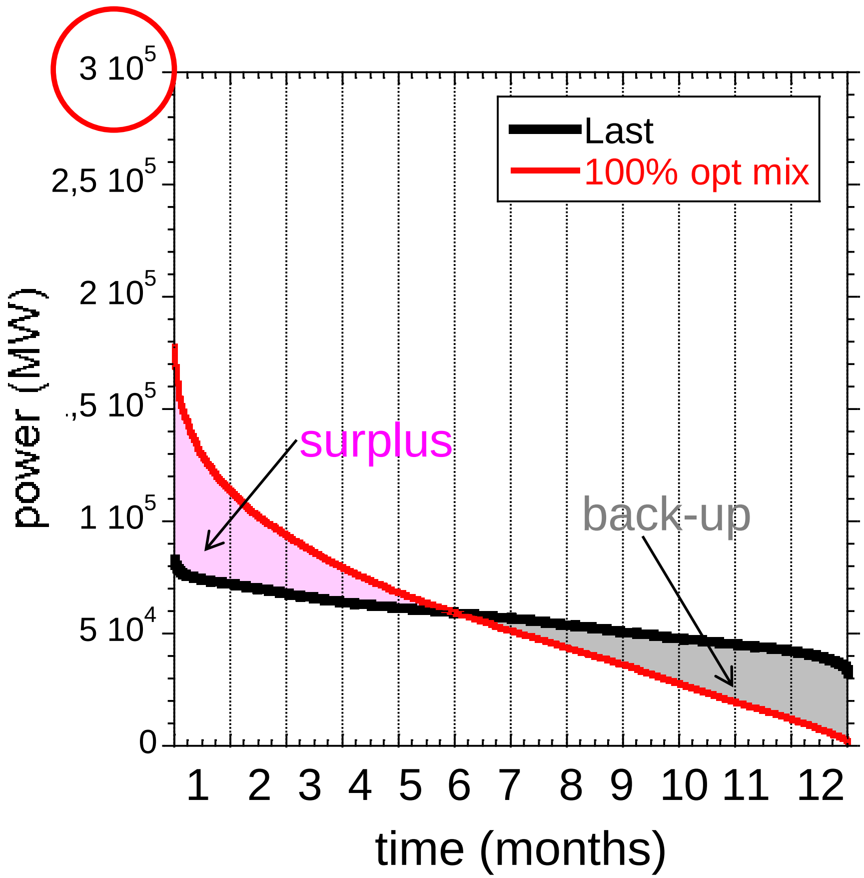
1: reduced load
2: back-up
3: Woff x 200
4: PV
5: Won

grey: fossil power
red: nuclear power

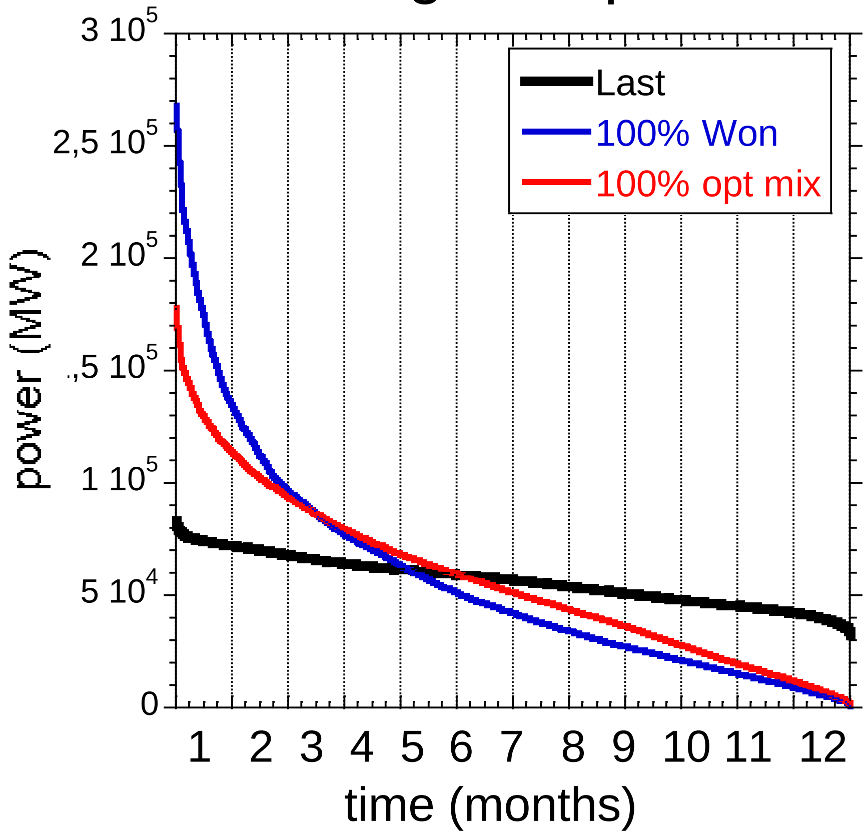
Duration curve



Scaling to 100% supply by RE



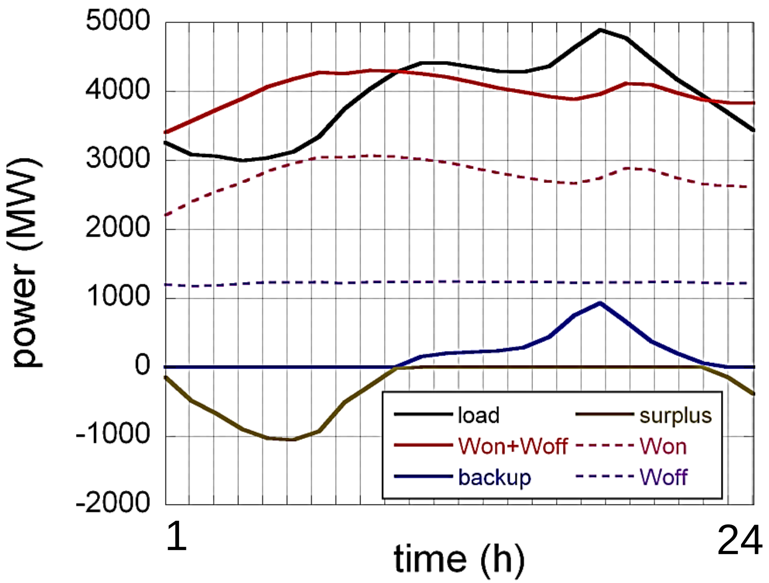
advantage of optimal mix



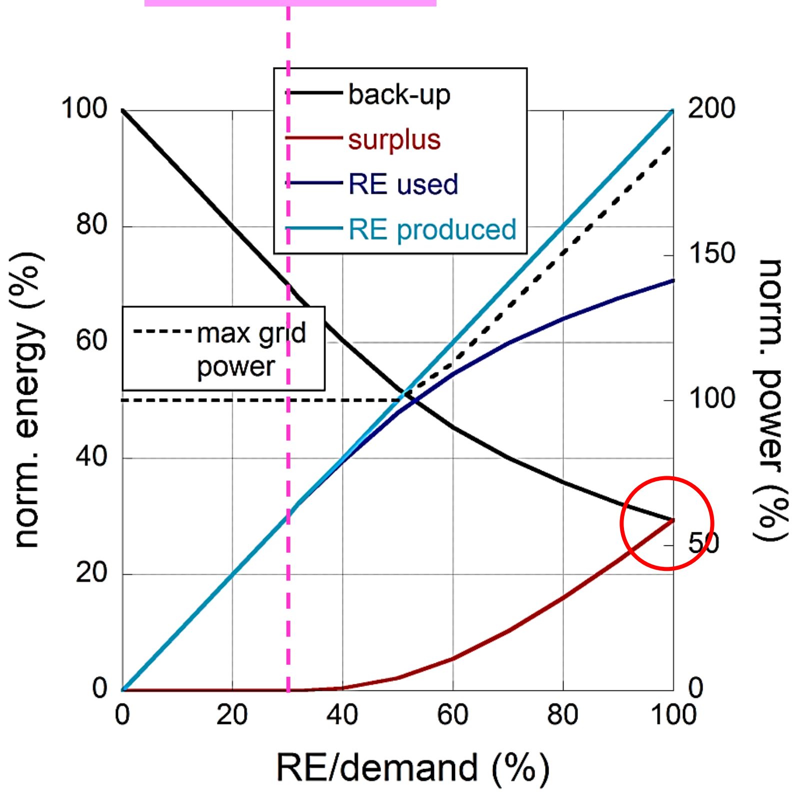
- Production of surplus at a high power level
- 100%-case: back-up energy = surplus energy
- Even for the 100 % case a thermal back-up system is needed as long as storage is not available

The 100% case of Denmark

The 100% case in Denmark:
21.12. 2013



Dk situation



surplus = net export
equal to
back-up = thermal power

ref. P.-F. Bach

21 December 2013	MWh
Gross consumption	94.118
Net export	48.975
Wind energy production	96.161
Thermal production	46.933

Specification of the 100%, optimal mix case

Germany

P_{Won} = 176 GW ; P_{Woff} = 33 GW; P_{PV} = 97 GW → $P^{RE}_{installed}$ = 306 GW

P_{load} = 83 GW; $P_{back\text{-}up}$ = 73 GW

W_{Won} = 271 TWh ; W_{Woff} = 135 TWh ; W_{PV} = 94 TWh; W_{RE} = 500 TWh

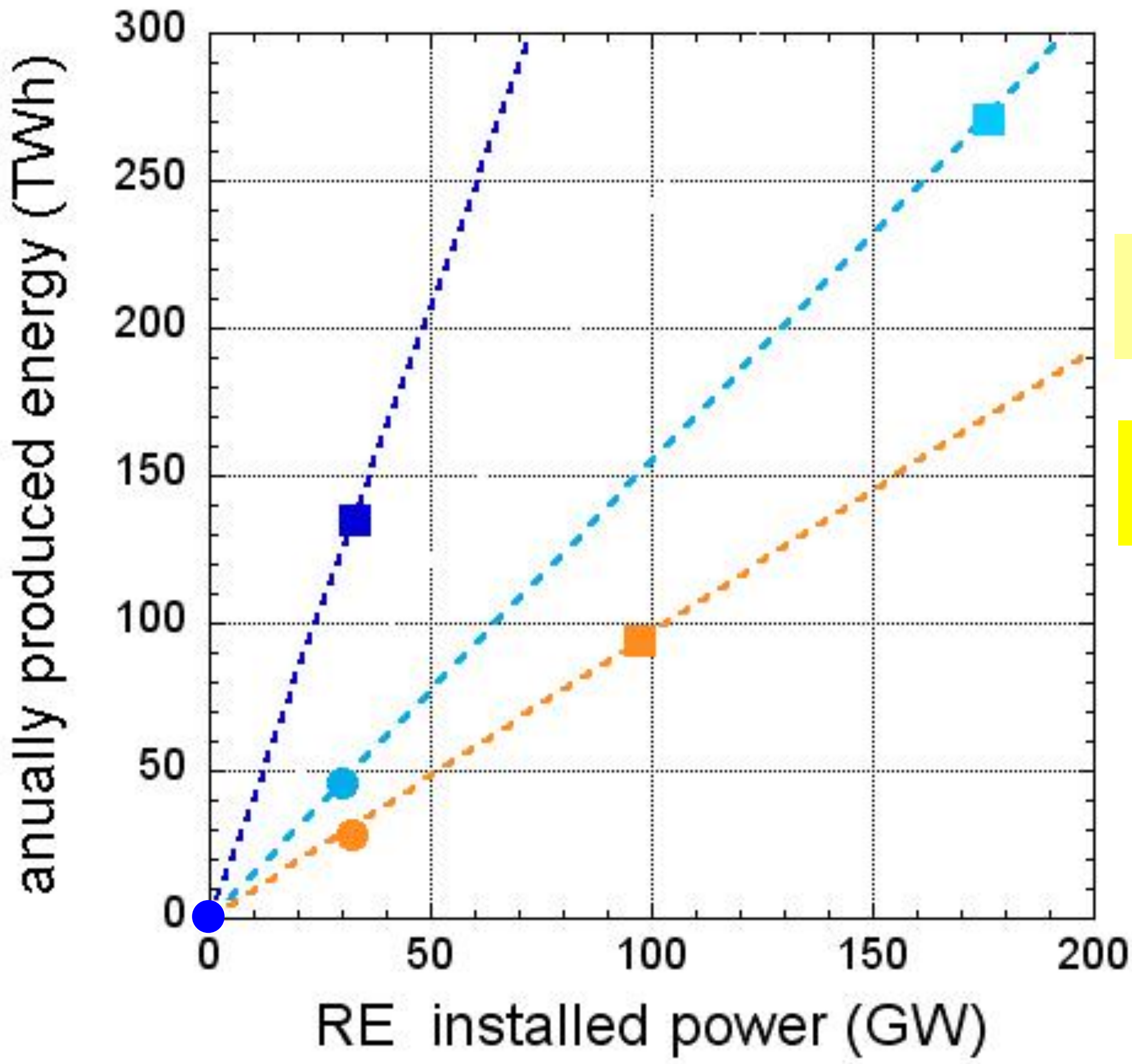
$W_{back\text{-}up}$ = 131 TWh; $W_{surplus}$ = 131 TWh

12% reduction of back-up power

The total installed power (306 + 73 GW) compares with the load of the EU: ~ 400 GW

The surplus corresponds to the annual demand of Poland

2012 compared to „100%, opt. mix. - case“

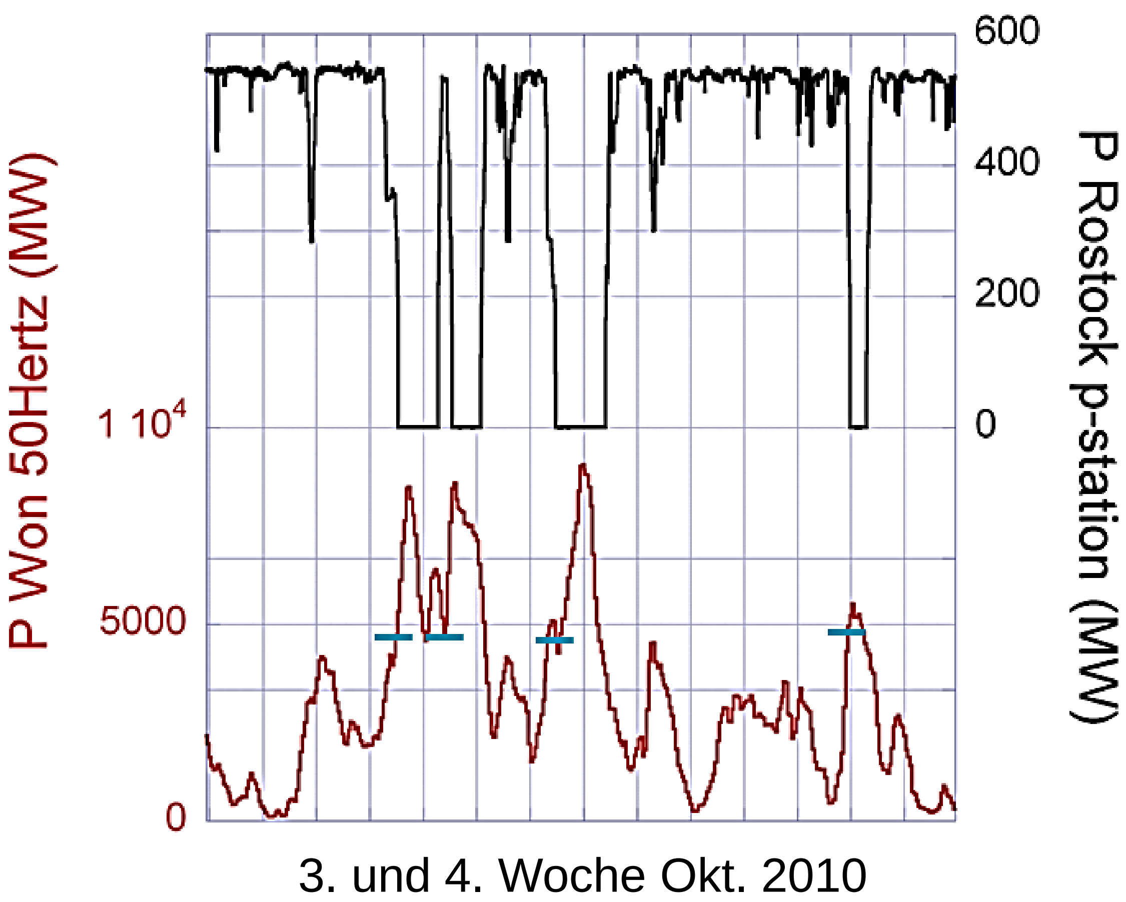


● situation 2012
■ optimal mix, 100% case

The „Energiewende“ is still in its infancy

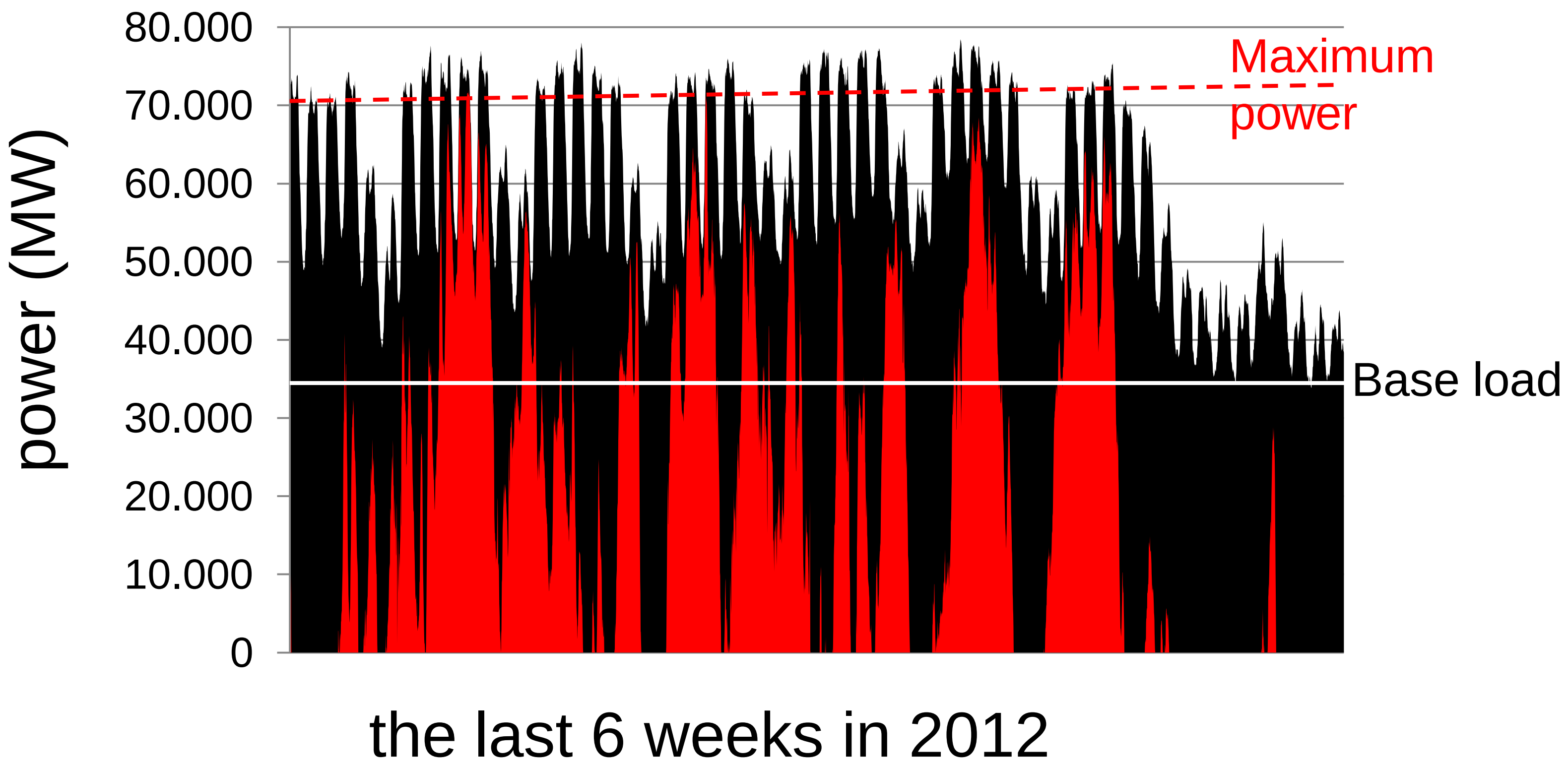
Back-up system

Operation of the Rostock coal power station
Anti-correlation of thermal power and wind power (50Hertz)



← wind level where the power station switches off

Back-up system



The power of the back-up system remains high

It has to meet the full dynamic range from 0 to nearly peak load

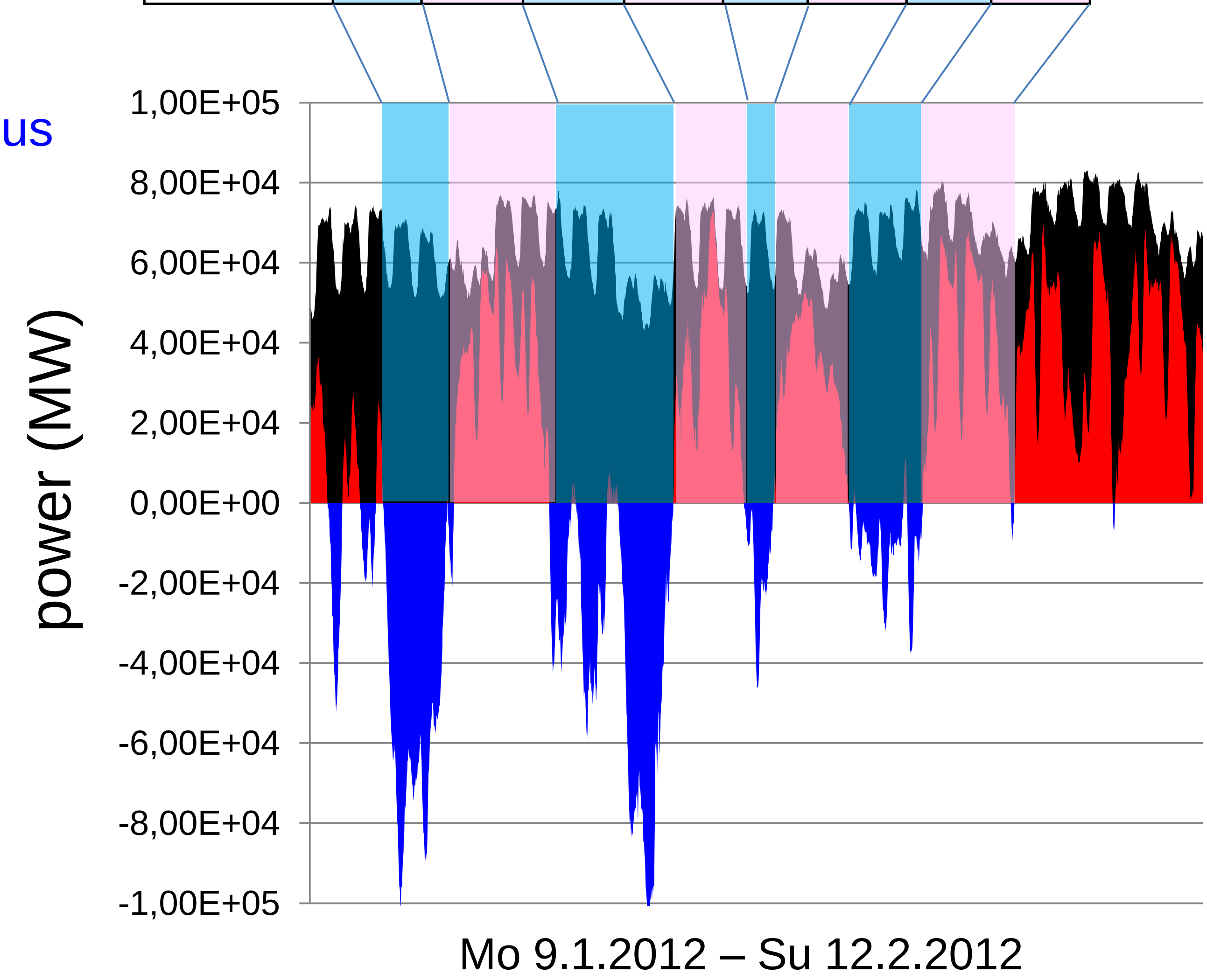
The power gradients increase strongly

Storage

100%, optimal mix case

black: Last
red: back-up
blue, negative: surplus

h	66	90	117	67	27	71	70	83
TWh	3.7	-3.5	4.5	-2.5	0.5	-2.4	0.8	-3.4



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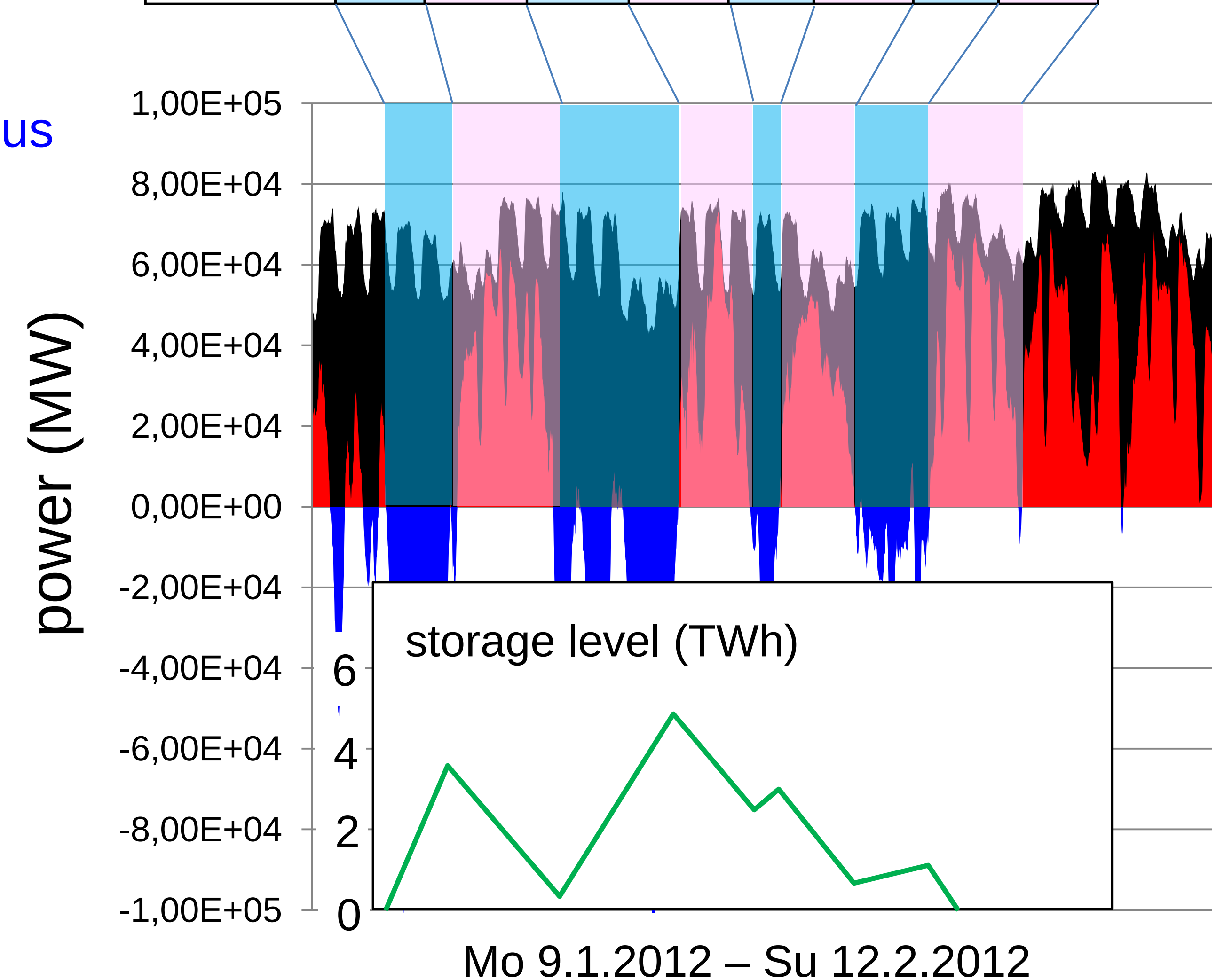
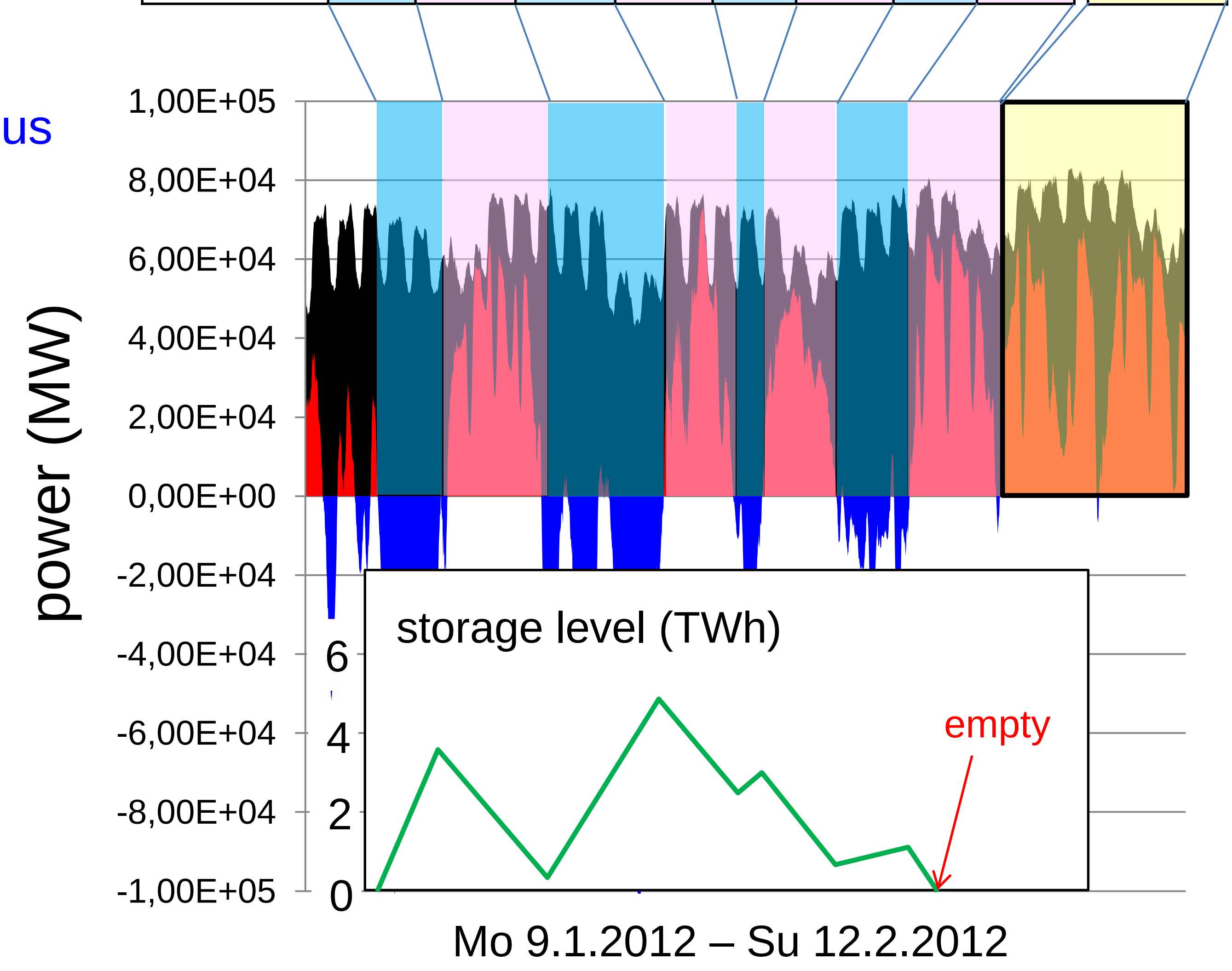


Storage

100%, optimal mix case

black: Last
red: back-up
blue, negative: surplus

h	66	90	117	67	27	71	70	83	**181**
TWh	3.7	-3.5	4.5	-2.5	0.5	-2,4	0.8	-3.4	**-7.1**



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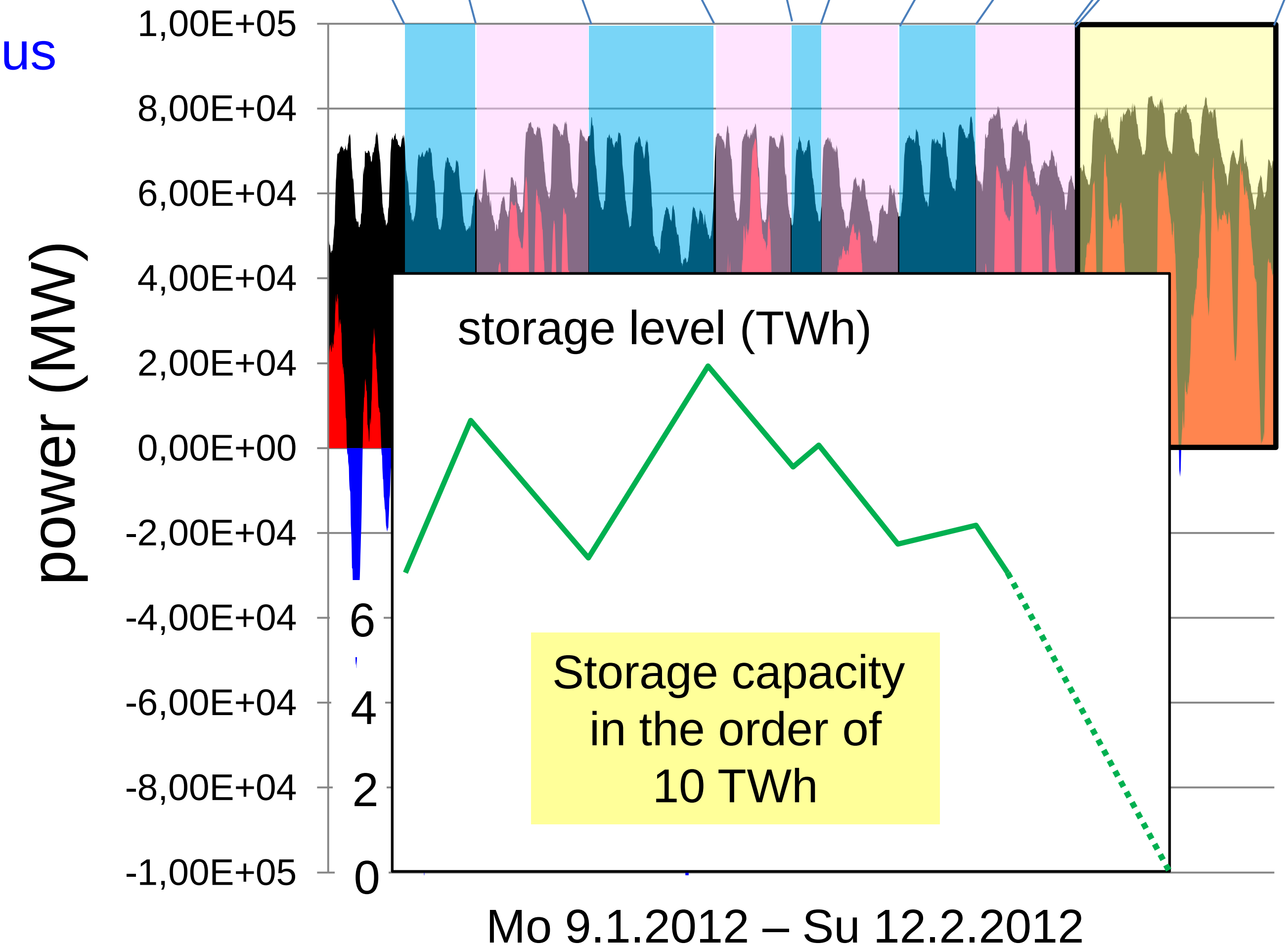


Storage

Present pumped water storage situation: ~ 50 GWh, ~ 7 GW

To replace the back-up system, the 100%, optimal mix case demands a storage of 33 TWh = 650 x presently installed capacity of Germany

A target storage value could be: **5 TWh**.
Only chemical storage possible; technology not available at large scales

Such a system would consist of:

P_{RE} not changed (P_{Won} = 176 GW ; P_{Woff} = 33 GW; P_{PV} = 97 GW)

$P_{storage}$ = -123 (+73) GW; $P_{back\text{-}up}$ = 71 GW (-15%**)** for **42** TWh (131 TWh)

Capacity factors of system (%):

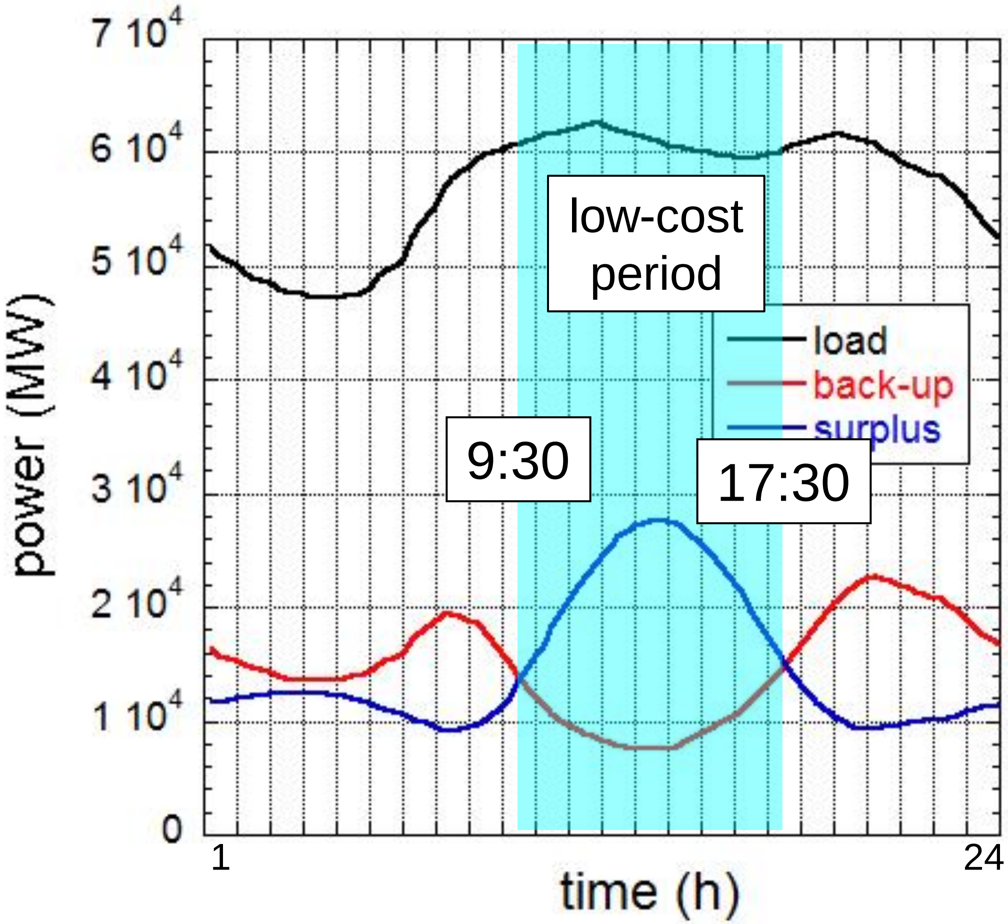
Won	Woff	PV	storage	back-up
18	47	11	22	6

Problem: no component operates economically

Demand-side management

Principle: shift economic activities into low-cost periods

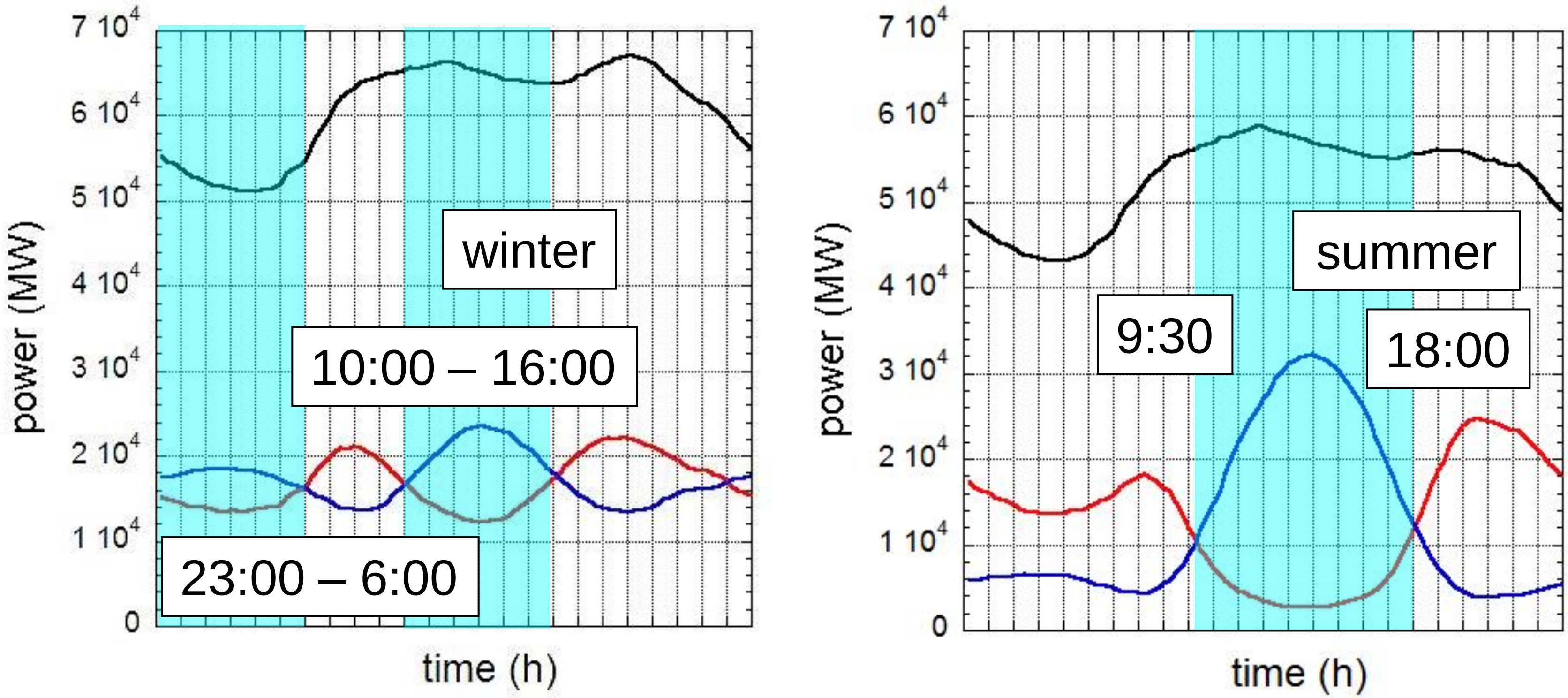
Average of daily variation of load, back-up and surplus



Low price period is during the day, not the night !

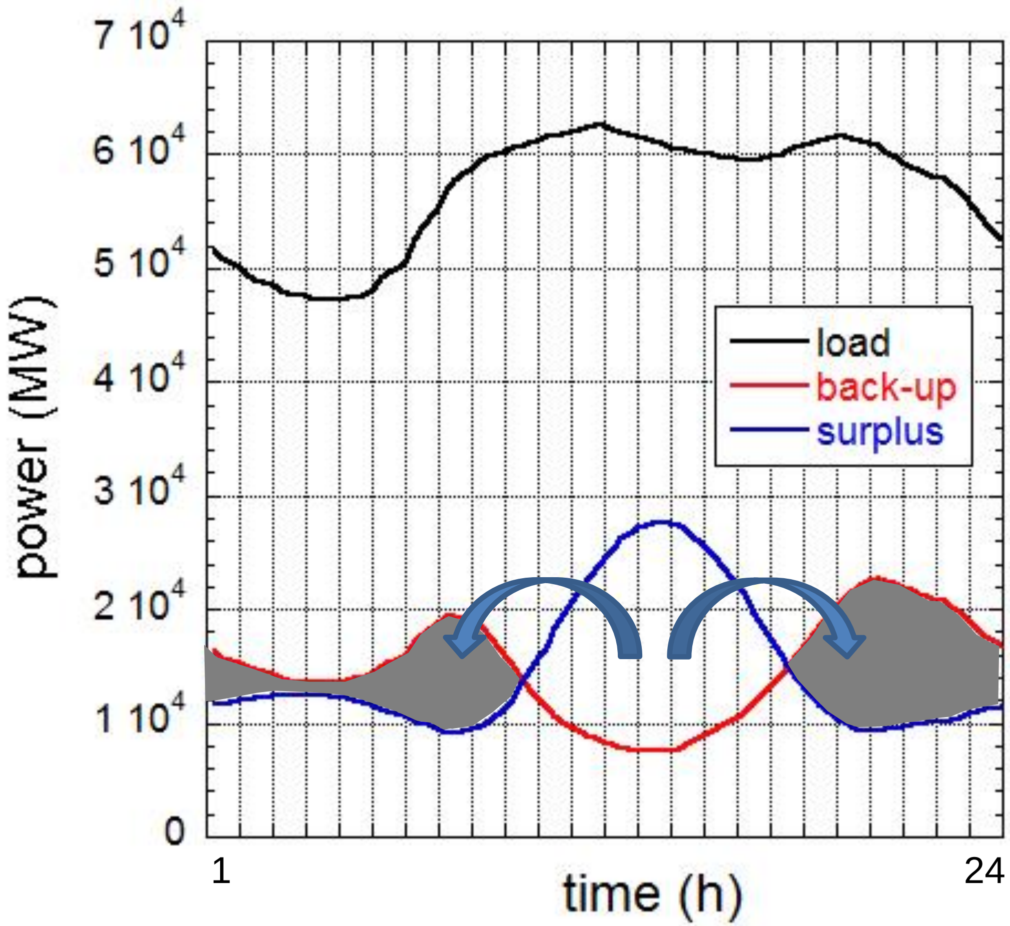
Demand-side management

Comparison winter - summer



Demand-side management

Use of daily storage

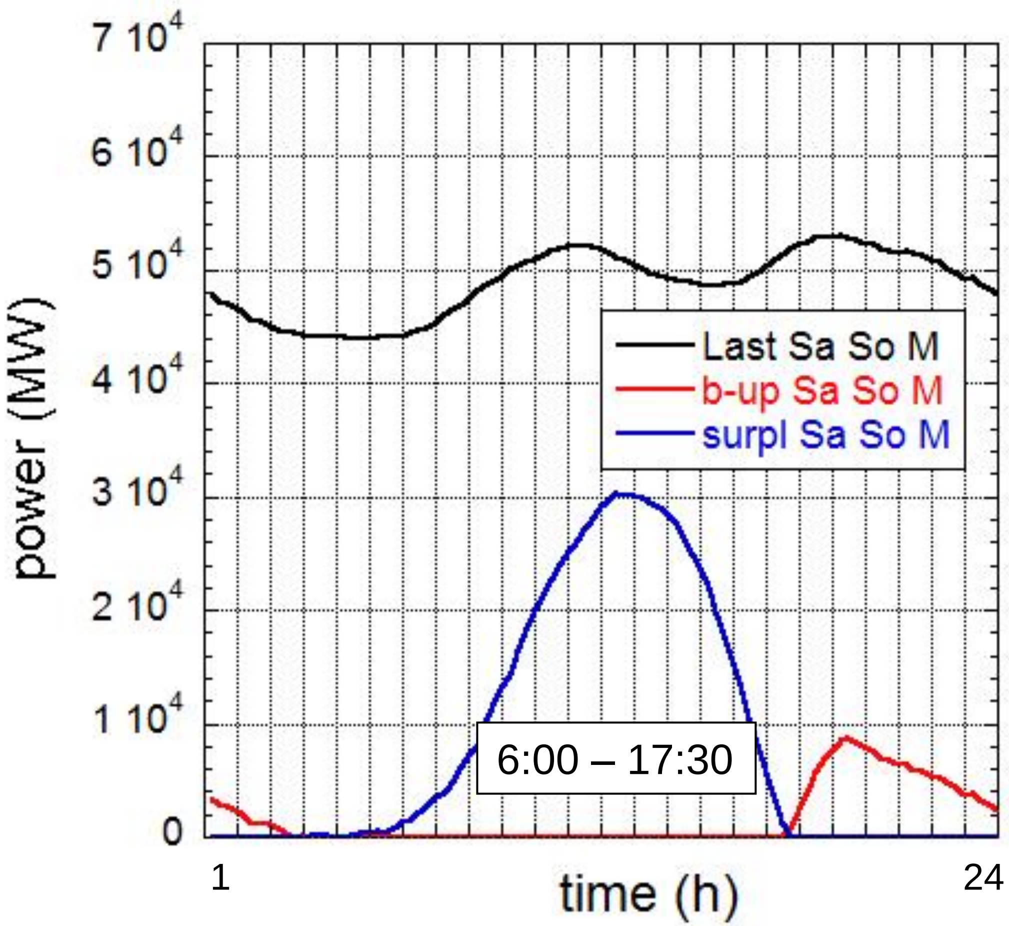


Storage capacity: 0.3 TWh

Reduction of back-up system:
131 → 103 TWh

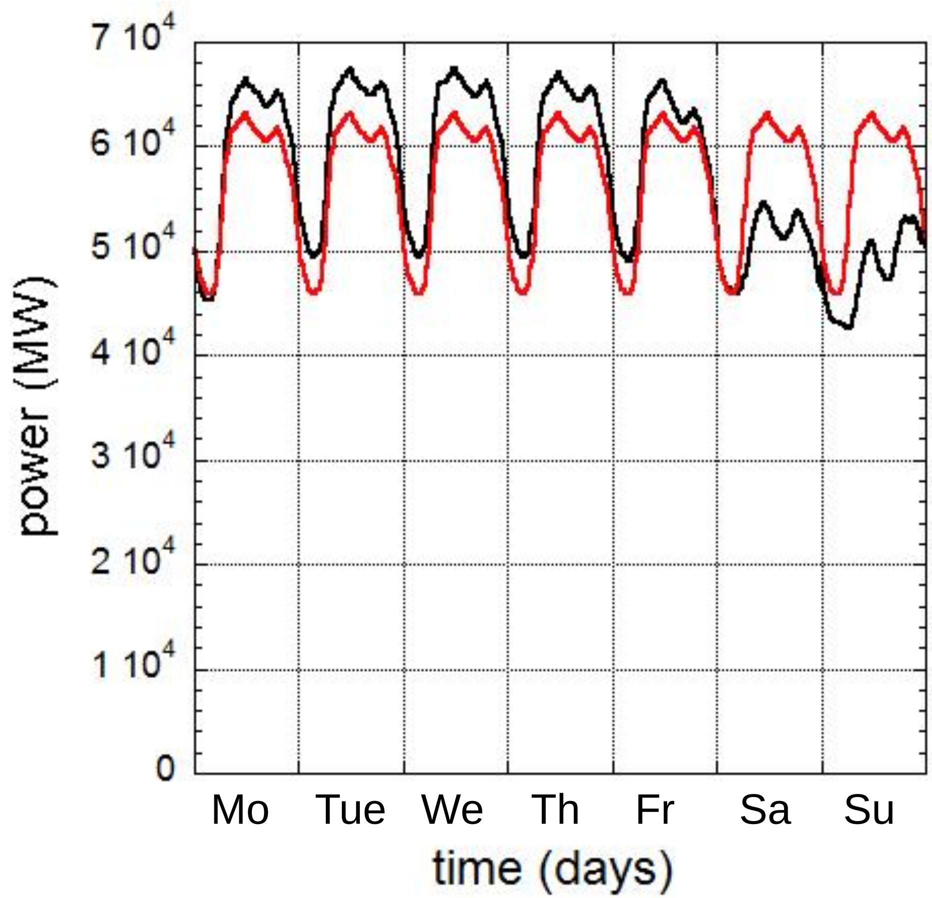
Demand-side management

Situation during weekend



Demand-side management

Situation during weekend



Full integration of weekends:

Additional use of RE: 7.9 TWh

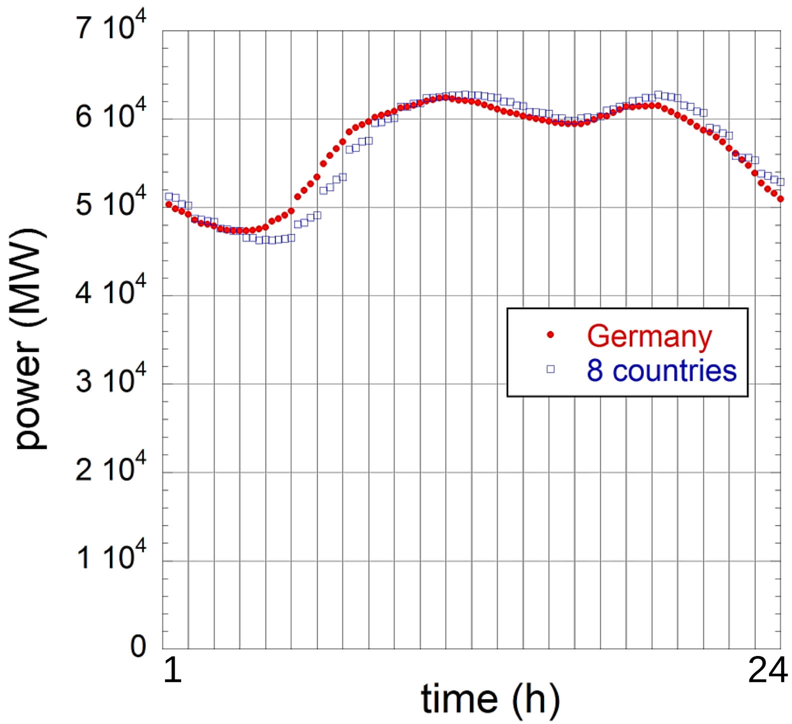
Peak-load: 83 → 63 MW

Reduction of back-up system:
131 → 123 TWh

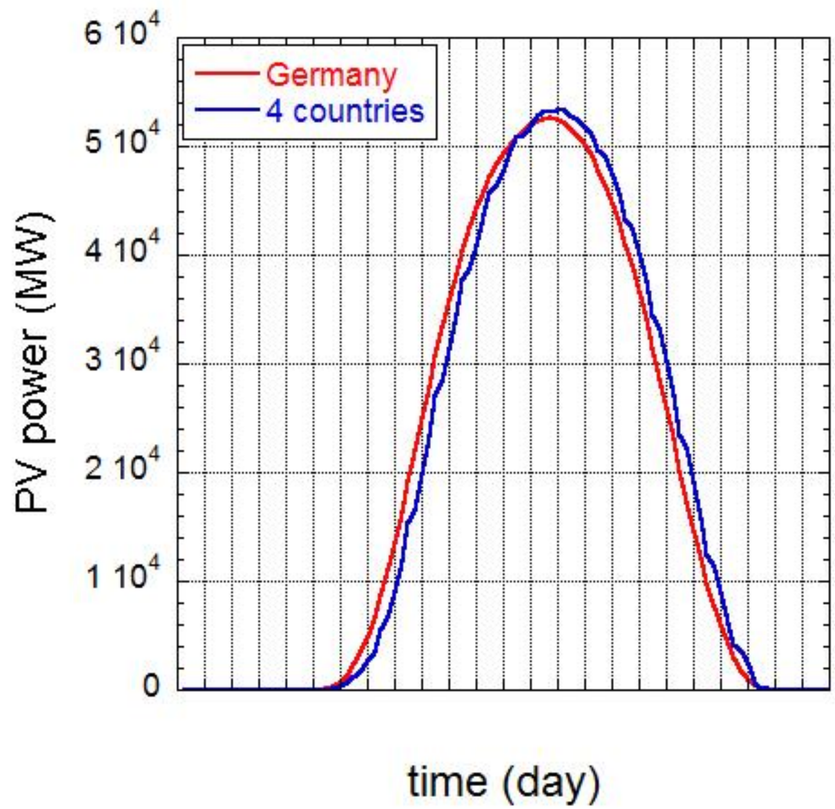
Integration of weekends has about 1/3 the effect of a storage which is larger than the present one by a factor of 6

The benefits of an EU-wide grid

Average load of Germany compared to the normalised load (normalised to energy) of 8 countries: **Spain, France, Irland, UK, Belgium, Germany, Czech Rep., Denmark**



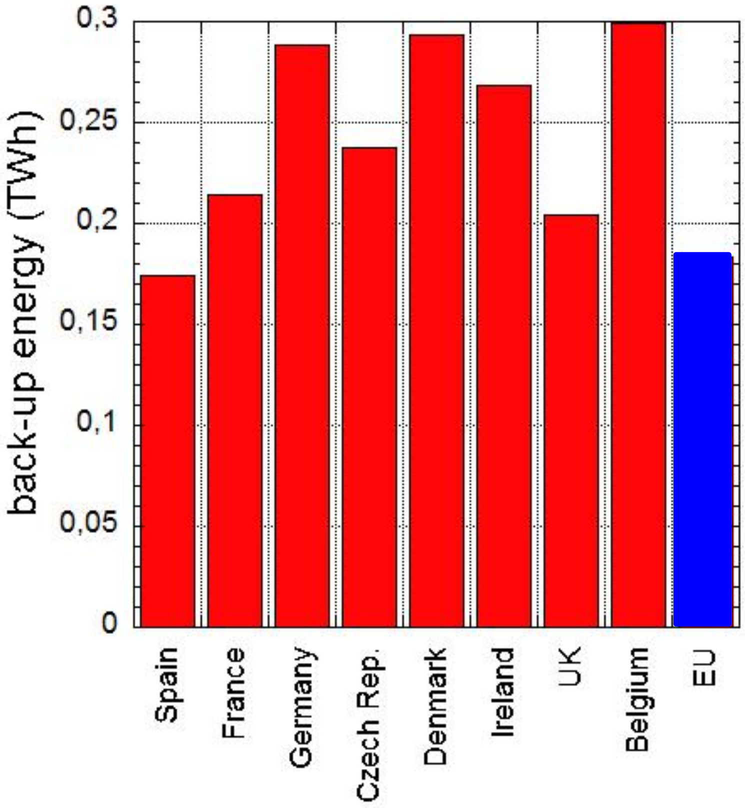
Average PV power of Germany compared to the normalised PV power of 4 countries: **Spain, France, Germany, Czech Rep.**



Result: shift but no strong averaging effect

The benefits of an EU-wide grid

Back-up energy needed to produce
1 TWh
- in the 8 countries
- or jointly in EU



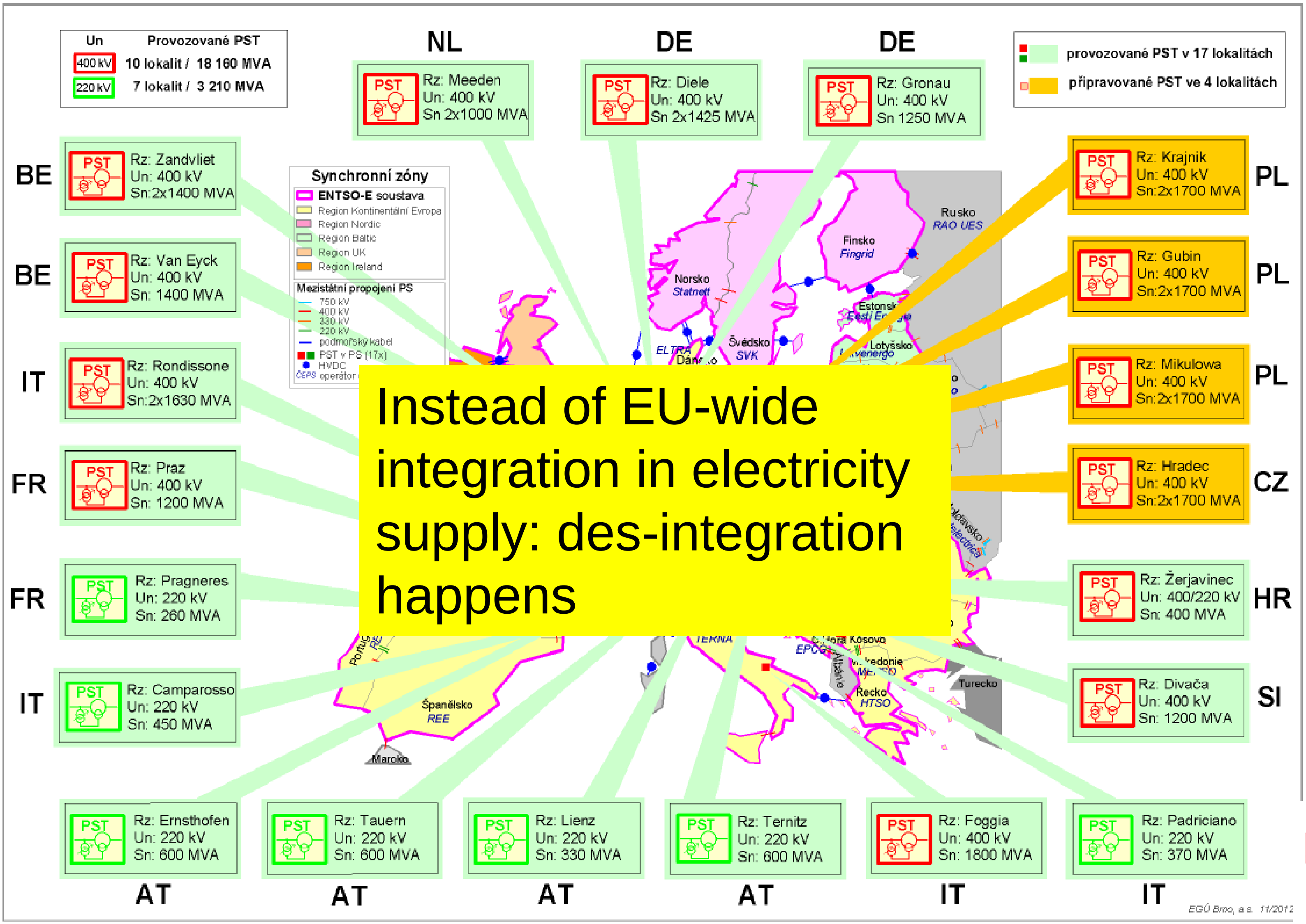
Benefit:
Back-up energy for EU (TWh)

Countries individually: 446
Countries jointly: 323

Total load: 1761 TWh

Phase Shift Transformers define borders

PST (Phase Shift Transformer) recommended and planned in ENTSO-E transmission grids



Instead of EU-wide integration in electricity supply: des-integration happens

recommended
planned

Conclusions w.r.t. intermittent sources

Wind and PV electricity is possible in large scales if the necessary space is allocated

Large power to be installed – comparable to the load of Europe → **high costs**

A supply system exclusively by wind and PV: **does not seem to be possible**

Back-up system required in all scenarios: **little saving in thermal power**

Ironically: CO_2-emission rises in spite of a RE capacity ~ the power demand

High surplus power peaks and energies: **what to do with ?**

- Suppress → further degradation of economic operation
- Use for power-to-gas: high prices of secondary electricity
- Use for heating: winter production: 76 TWh (private heating: 550 TWh)
- Use for cooling: summer production: 55 TWh (cooling needs: 20 TWh)
- Store for electric cars: 100 TWh required

Conclusions w.r.t. intermittent sources

Storage (for surplus power):

large-scale technology, not yet available

operation not economic

difficult to motivate from the CO_2 saving point of view

Components operation not economic → today: **no new gas power stations**

Electricity supply cannot be organised under market rules → **capacity market**

Unfavorable operation of all technical systems → **increased costs and CO_2**

CO_2 reduction by RE: **not to the levels as already achieved by others in EU**

No favorable conditions for demand-side management:

day-time activities will intensify: maybe, new markets will develop

best options: use of weekends

storage by car batteries: surplus during the day not the night

Supra-national supply improves situation: **will it ever be realised?**

Technology change

from red to blue
Blue: RE, fusion, fission
with breeder

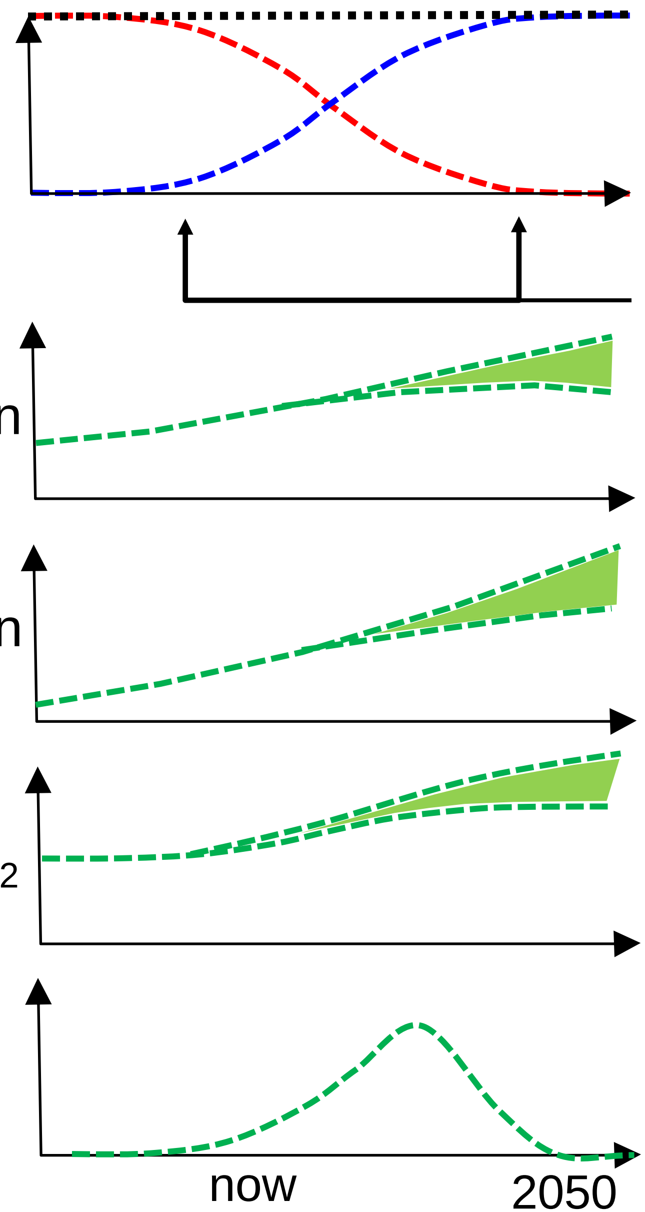
Δt: costs

Increase in world population

Increase in energy consumption

Increase of CO_2

Other issues:
technology
economy
system costs
competitors



Keep all options open !

Conclusions

The exclusive use of RE has limitations and leads to shortcomings.

Therefore, the most obvious question will be whether and how an electricity system based on intermittent sources can be improved or supplemented.

This will be a question classically posed to research and engineering because these disciplines have found the ways in the past to liberate mankind from the imponderabilities and perils of nature.