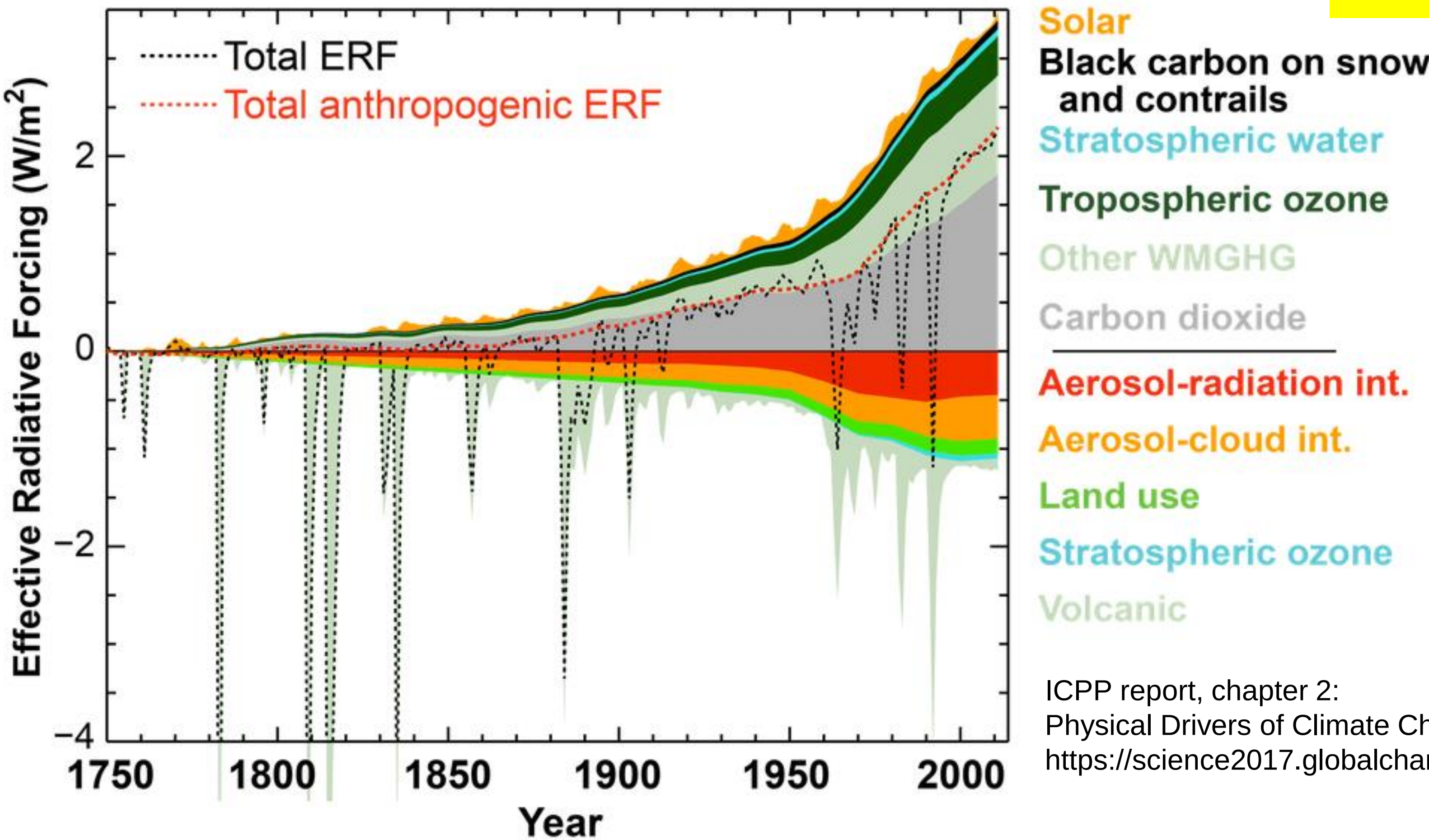
Conclusions

F. Wagner, Max-Planck-Institut für Plasmaphysik, Greifswald, Germany

H. Schmidt
M. v.d. Broek

Climate: radiative forcing in the energy balance of the Earth

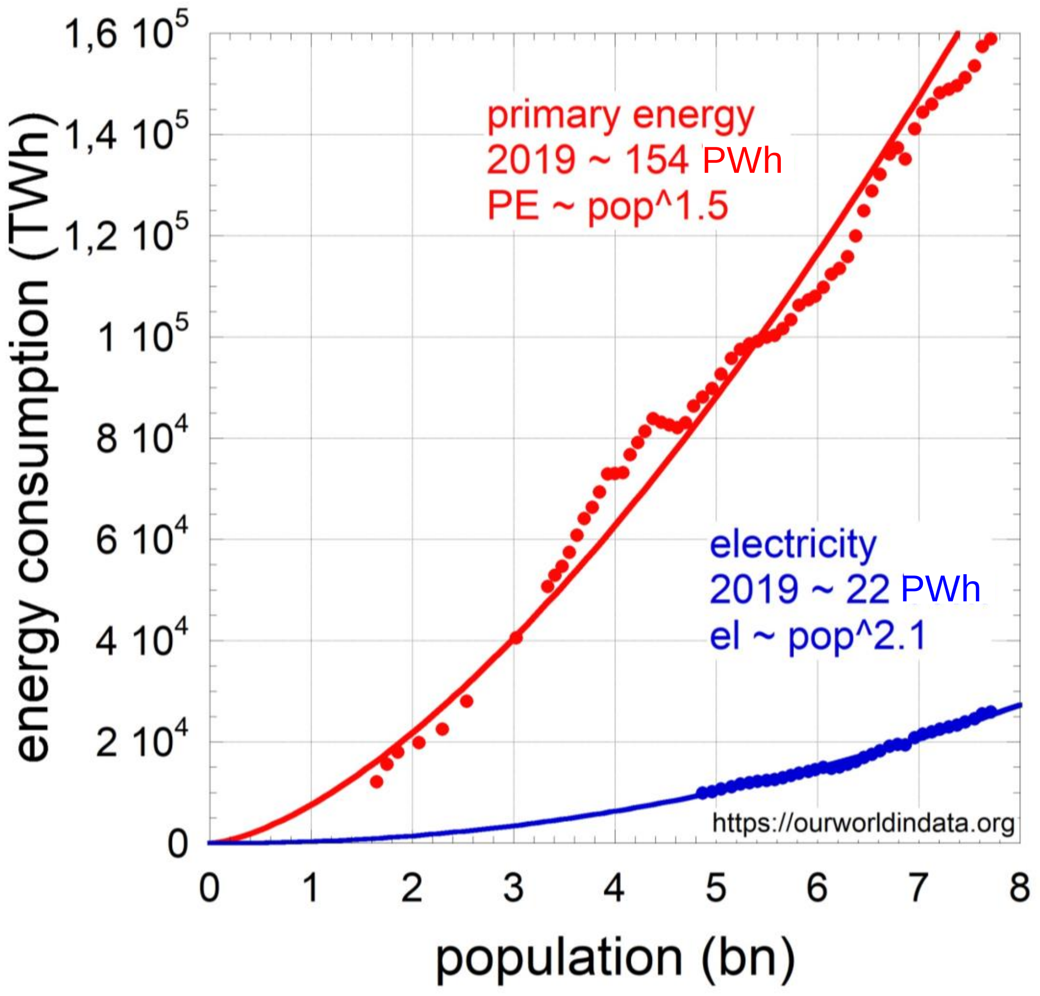


ICPP report, chapter 2:
Physical Drivers of Climate Change, Fig. 2.6
https://science2017.globalchange.gov/chapter/2/

antropogenic CO2 enrichment in the atmosphere
leads to the only quantitative explanation of global warming

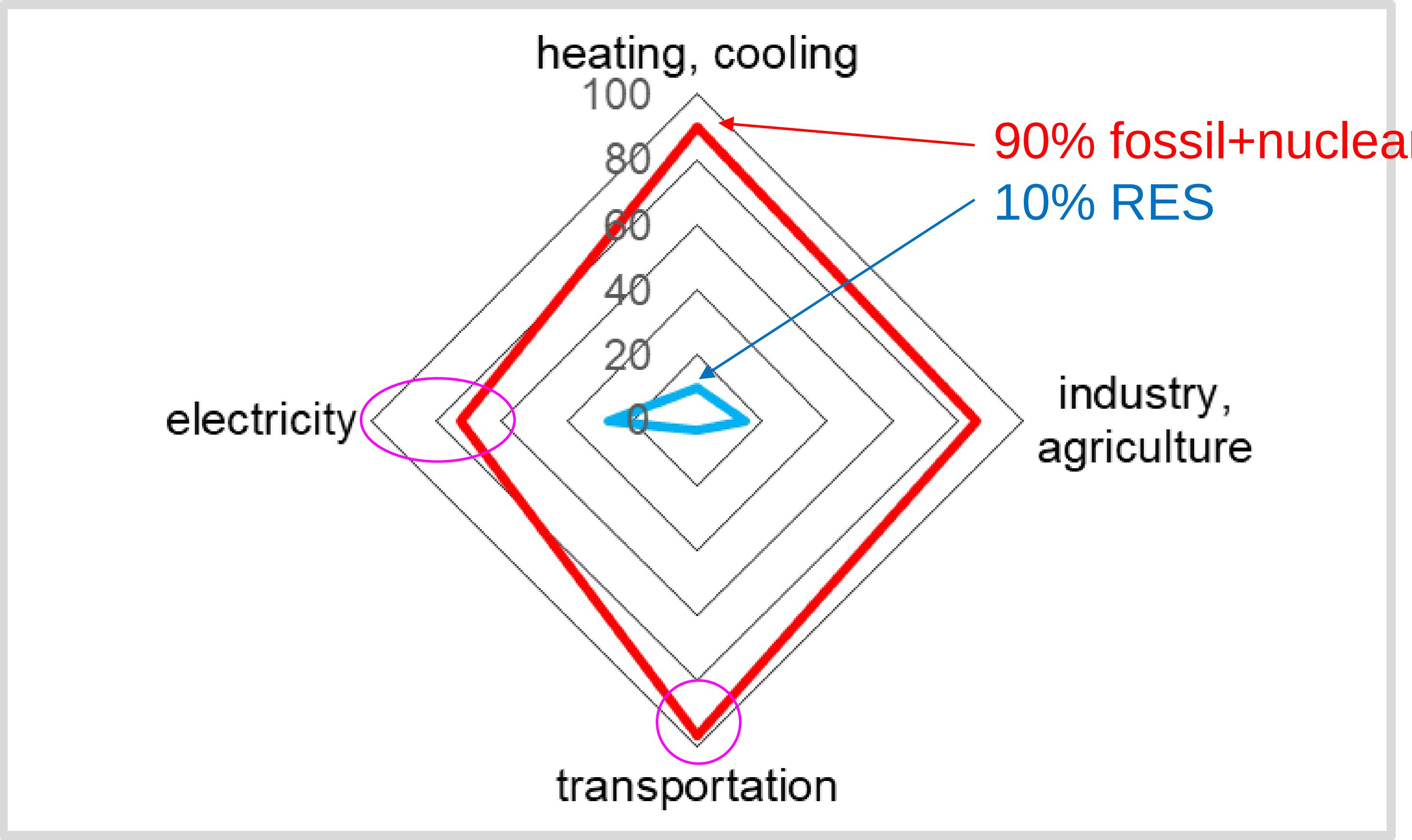
Primary problem: the growth of world population

The secondary problem: mankind´s energy consumption



The task of de-carbonisation

Normalised energy consumtion in 4 sectors (global situation), fossil and nuclear share and the role of renewables (RES)



Clean energy technologies – covered in this summer school

Continue with fossil fuels but using CCS technology (carbon capture and sequestration) → J. Craig

Fission with fast neutrons and breeder technology → S. Leray, M. Ripani

Nuclear fusion → J. Ongena, F. Romanelli

Renewable energies

- bio-mass → D. Thrän
- geothermal power
- ocean wave/tide power
- environmental heat
- wind (onshore, offshore) → H.J. Wagner
- solar power (PV, solarthermal) → S. Siebentritt; many students

Options for clean energy generation

Continue with fossil fuels but using CCS technology (carbon capture and sequestration) → not supported in many countries

Fission with fast neutrons and breeder technology → rejected in many countries

Nuclear fusion → will not be ready before end of this century

Renewable energies

- bio-mass → limited in use (nutrition), loss of bio-diversity, loss of insect population, …
- geothermal power
- ocean wave/tide power → limited to geographically qualified regions
- environmental heat → tapped on via heat pumps
- wind (onshore, offshore)
- solar power (PV, solarthermal) → can be scaled to large installations = TW-range

1. feature of energy transition: electricity becomes primary energy

chemical energy, other forms mostly generated via electricity

Workhorses of the transition: wind and PV power
- because of scalability

Problems:

(M. Tromp), E. Pellicer

(1) variable production → backup, later storage with secondary electricity

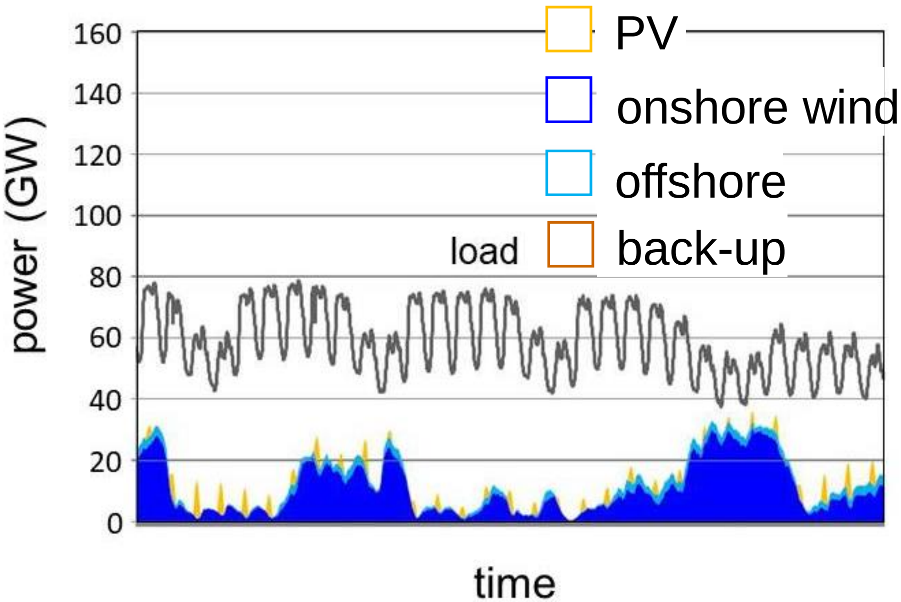
(2) low power density → potentials of national production

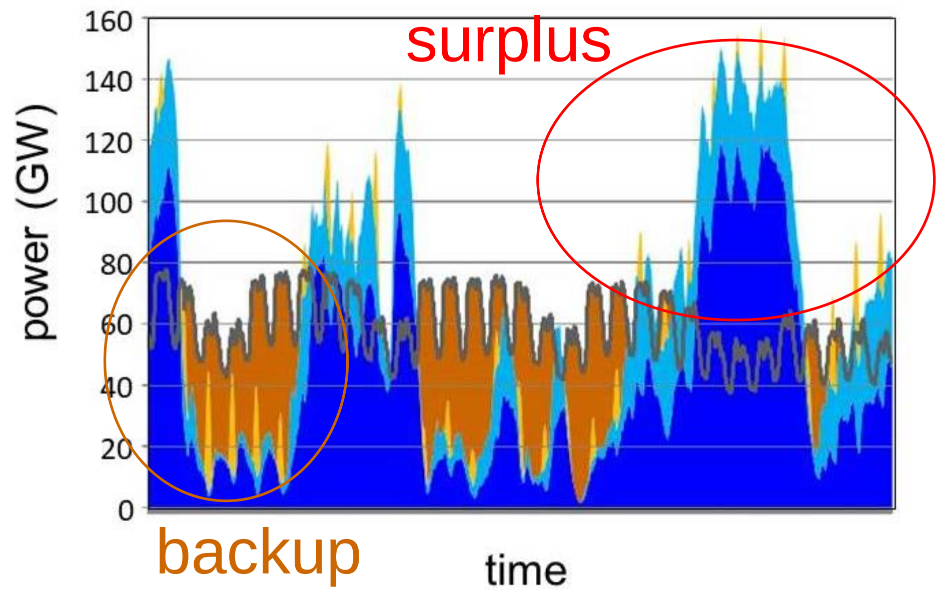
My examples here are taken from **Germany**
- can be seen as a laboratory for the use of renewable energies

1. Variable production

Germany, one month in winter 2018
Wind and PV produce 155 TWh
Net electricity consumption: 520 TWh

Upscaled to the 100% case:
wind and PV producing 500 TWh
(in addition: 20 TWh from hydro)





installed power
P_{on} = 53 GW; P_{off} = 6,4 GW
P_{PV} = 46 GW; P_{tot} = 105 GW

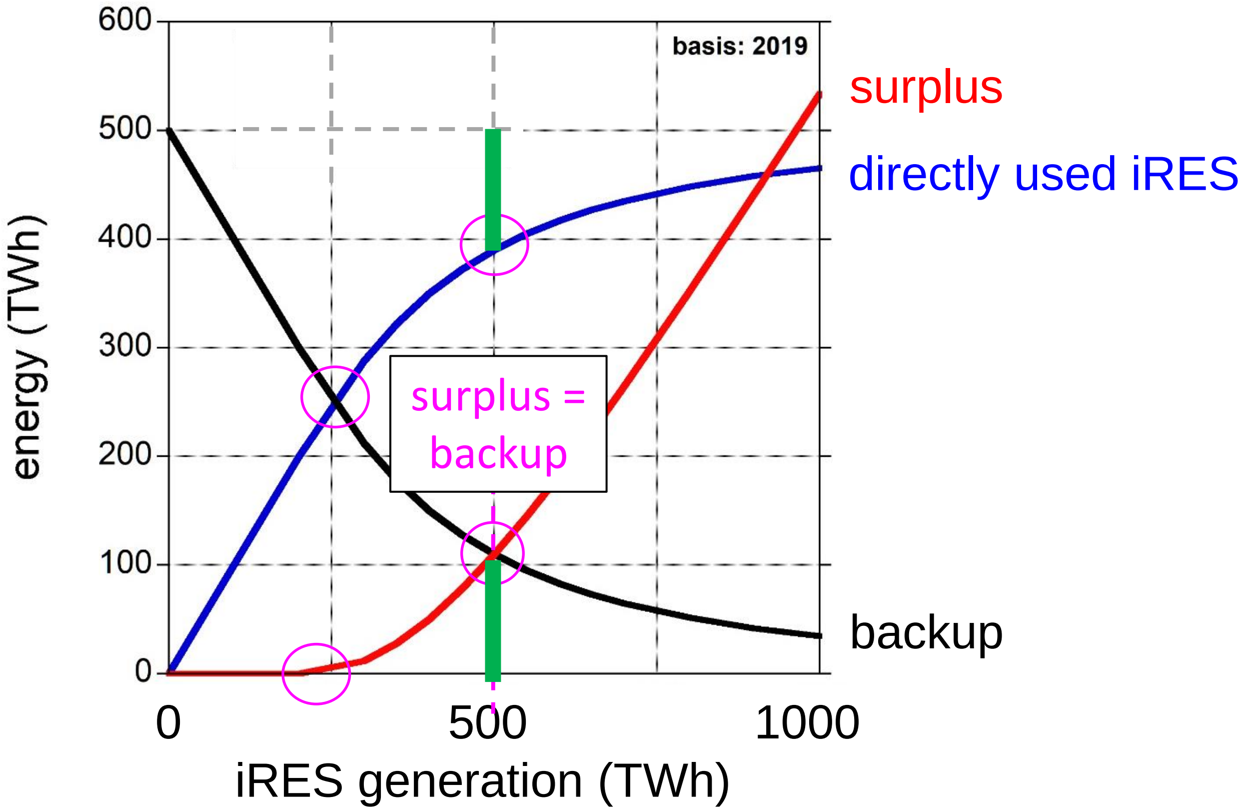
P_{on} = 151 GW; P_{off} = 40 GW
P_{PV} = 114 GW; P_{tot} = 305 GW

Conclusion: the energy transiton falls into two periods:
(1) the build-up period where back-up is needed – preferably nuclear + gas
(2) the final state of complete decarbonisation (in 2045 - 2050)

1. Variable production: key features

Reference: 100% case (iRES: 500 TWh; hydro: 20 TWh)

iRES = intermittent renewable energy



Directly used iRES + backup: 500 TWh

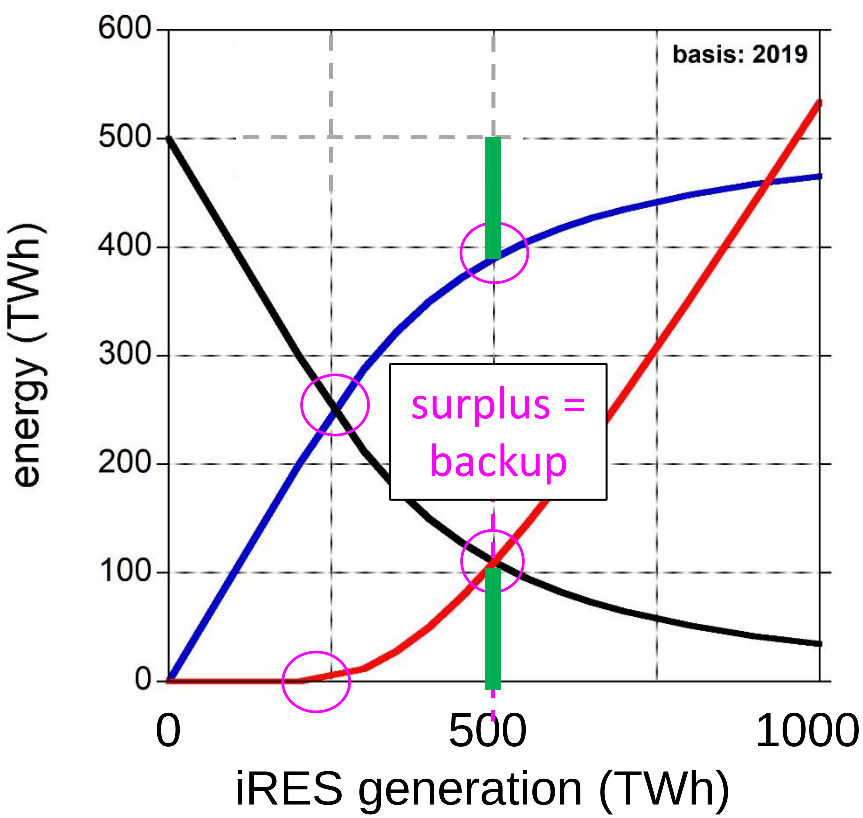
Directly used iRES saturates with increasing iRES generation: surplus

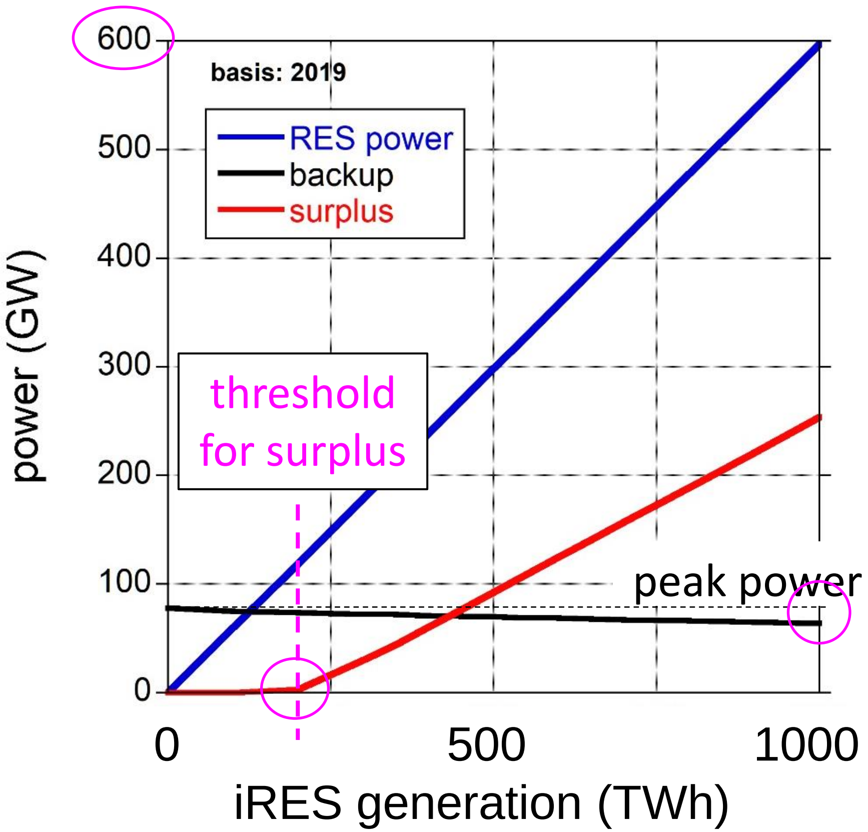
Backup energy decreases quickly with iRES

100% case: backup = surplus

1. Variable production: key features

Reference: annual electricity load = 520 TWh (500 TWh iRES, 20 TWh hydro)





High power levels

Surplus production starts when iRES contribute with ~ 40% of the annual load

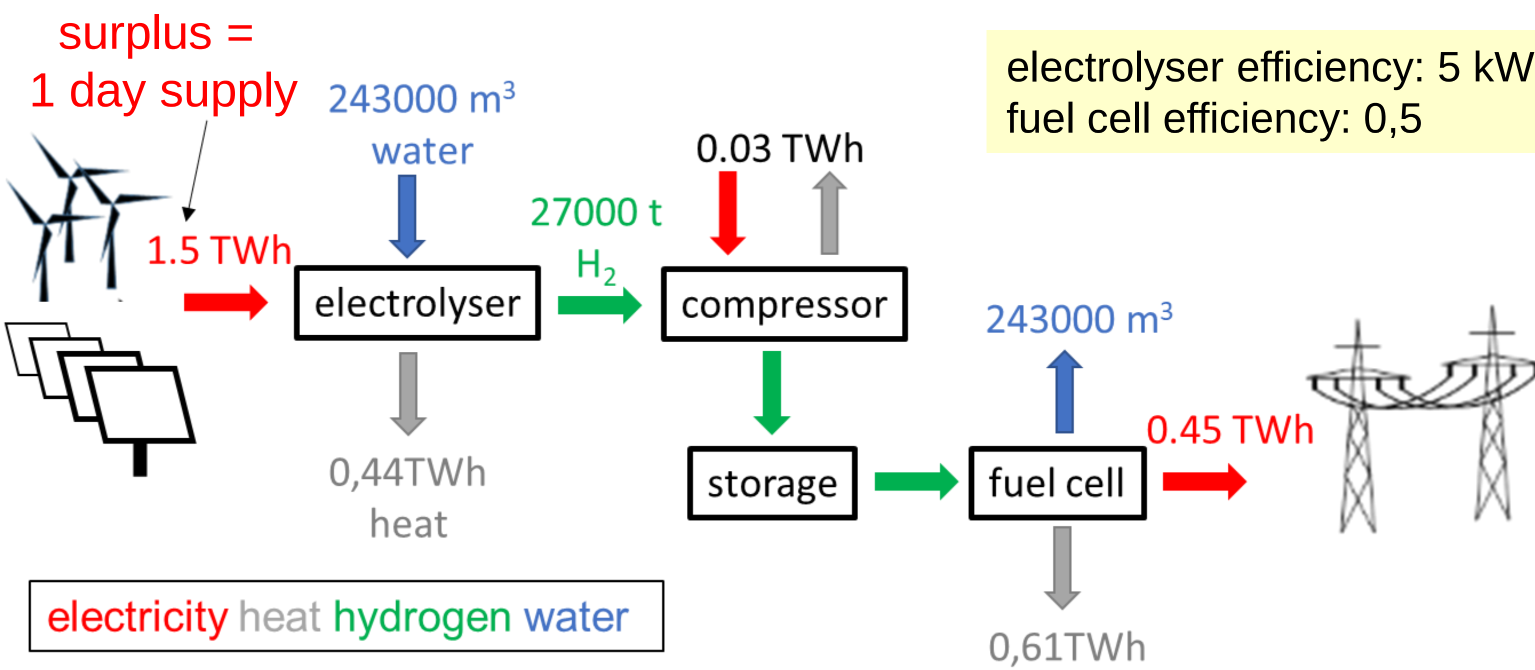
Backup energy decreases quickly with iRES; backup power remains high

Economic consequence: creation of a capacity market

1. Variable production: storage with losses

(1) Storage capacity for grid control → batteries   J. Scherpen, (M. Tromp)
(2) Seasonal storage: in the TWh capacity range → defines the technology: H_2
E. Pellicer

Scheme of CO2-free electricity generation: RES = (primary electricity) + surplus
→ hydrogen via electrolysis → H_2 storage → fuel cell = secondary electricity → grid



electrolyser efficiency: 5 kWh/Nm^3H_2
fuel cell efficiency: 0,5

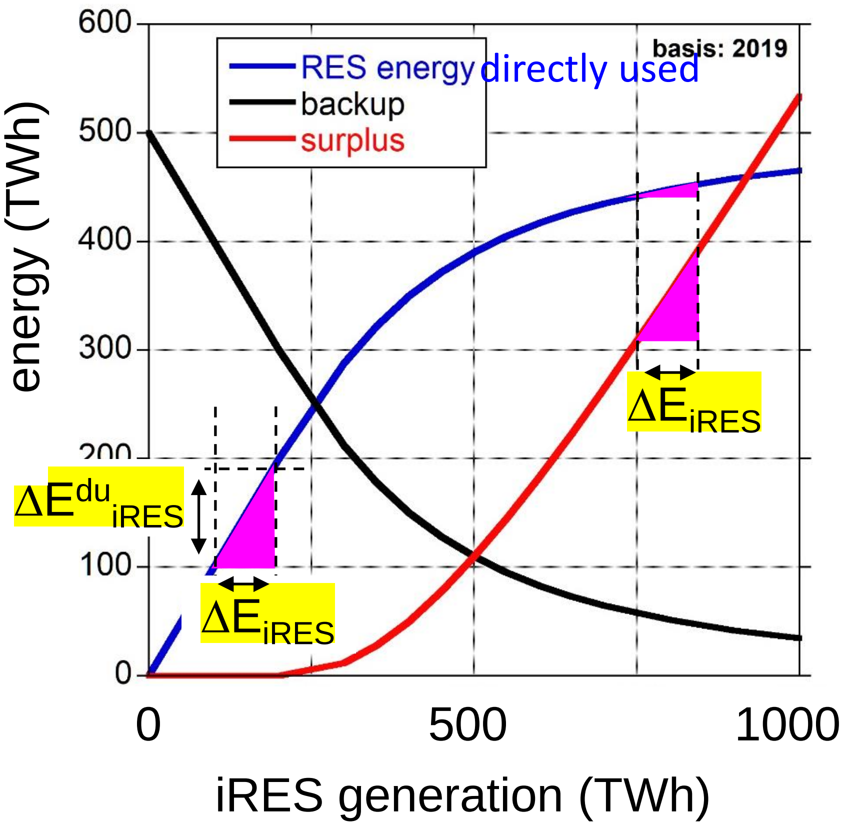
system efficiency: ~30% → secondary electricity will be expensive
27000 t H2 → storage concept (caves), distribution (pipes); no low-temp technology
243000 m3 water necessary ~ daily consumption of Munich

For details see: M. Wanner, Transformation of electrical energy into hydrogen and its storage
The European Physical Journal Plus DOI: 10.1140/epjp/s13360-021-01585-8

1. Variable production: cost structure

Transitional period: additional costs of backup system

The economics of iRES operation changes with installed power



Final state with H_2 storage: secondary electricity a factor of 3 more expensive

present-day grid-parity cost/levelized-cost arguments ignore an important issue
technology costs to be compared at high installations

2. Low power density of iRES; example: Germany

potentials: theoretical-, economic-, ecologic-, realisable potential

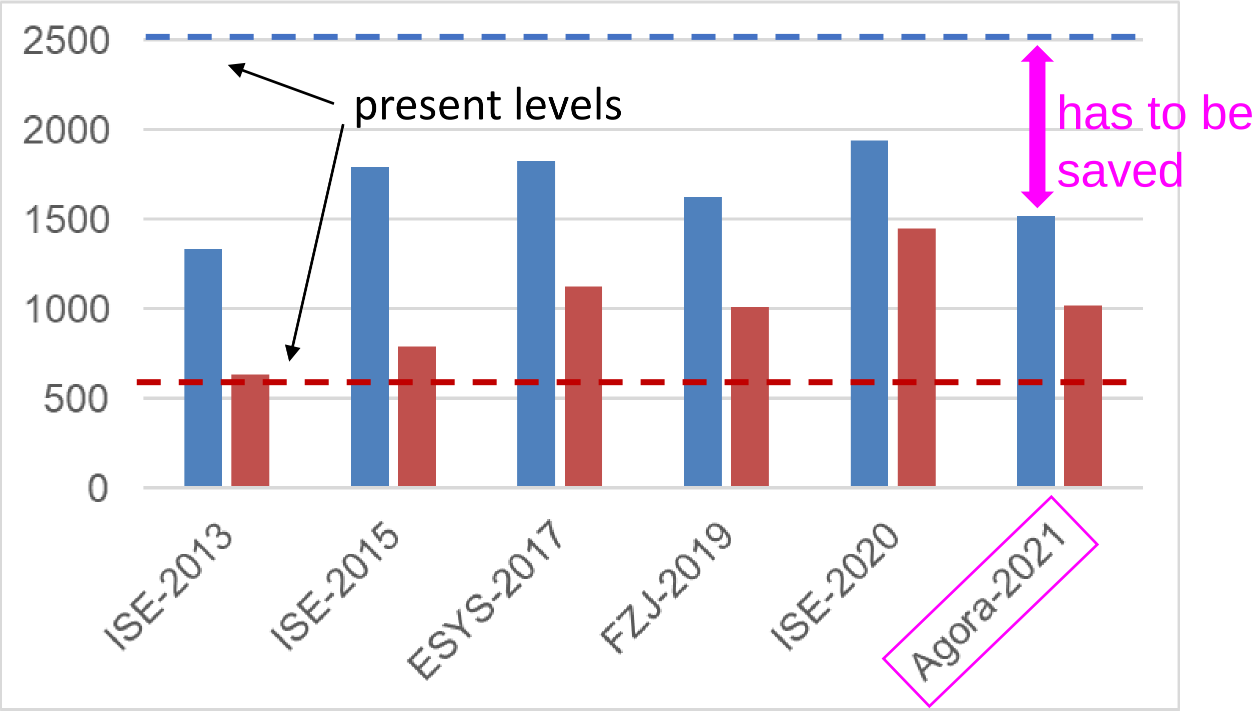
political and societal aspects determine the realisable potential

Assumptions of 6 recent **sector studies** for 2050 (CO_2-reduction 81%-95%)

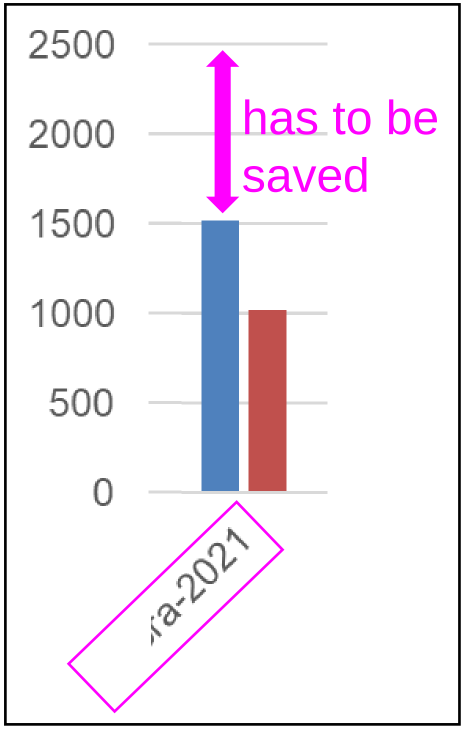
Sector-studies

ISE-2013
ISE-2015
ESYS-2017
FZJ-2019
ISE-2020
Agora-2021

end-energy (TWh) total electricity generation (TWh)



2. Low power density of iRES; example: Germany



has to be saved:

- improvement of energy efficiency
- change of industrial production processes
  - steel, cement, chemistry…
- expansion of public transportation
- thermal insulation of all houses
- reduced fertiliser use
- less meat production and consumption
- reduced national air-transport
- ….

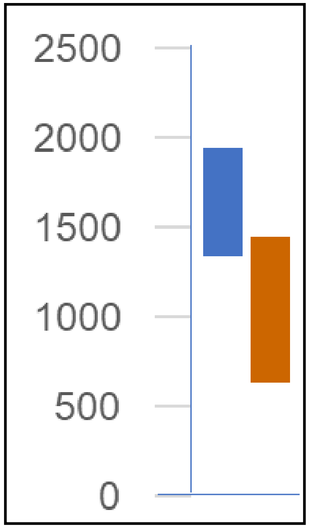
2. Low power density of iRES; example: Germany

Definitions of potentials: theoretical-, economic-, ecologic-, realisable potential

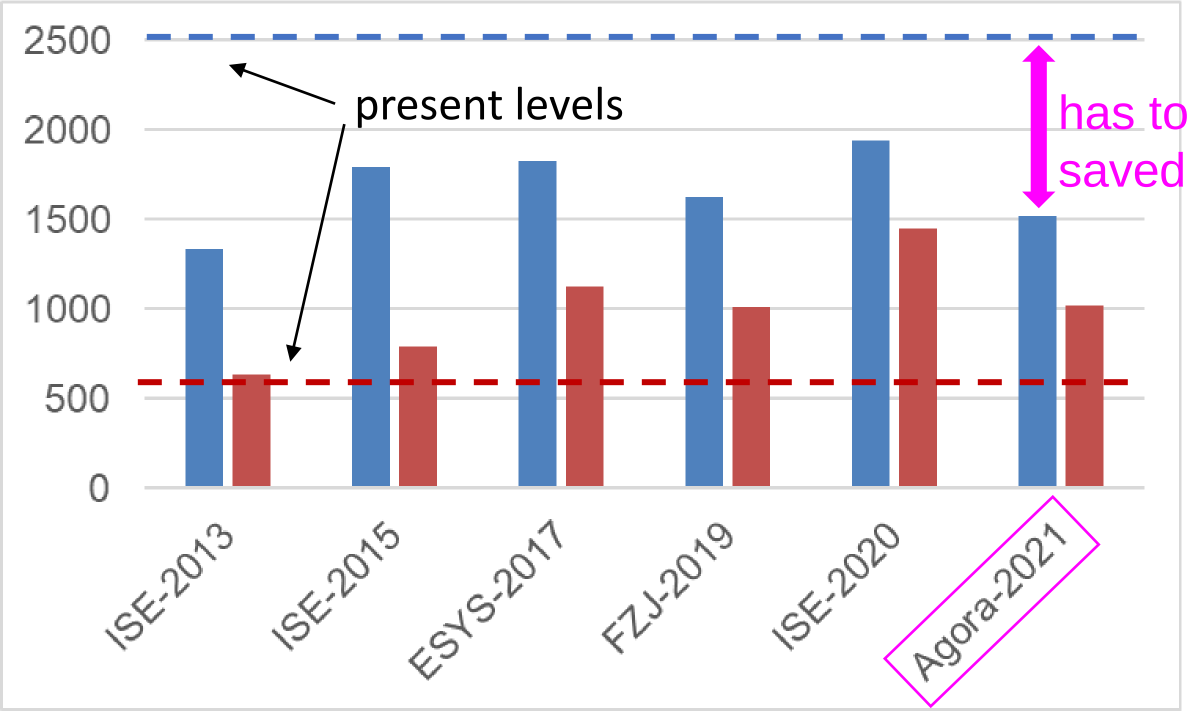
political and societal aspects determine the realisable potential

Assumptions of 6 recent **sector studies** for 2050 (CO_2-reduction 81%-95%)

end-energy (TWh) total electricity generation (TWh)



strong differences in targets



2. Low power density of iRES; example: Germany

Future electricity needs:

basic electricity:

- saving (↓), industry-4.0 (↑), digitisation (↑), smart systems (↑)… : ~ 520 TWh

electric mobility: ~140 TWh

heating using heat pumps: ~ 85 TWh

transformation of steel industry: ~144 TWh (H2 generation is a small part)

transformation of cement industry: 2.5-5 TWh

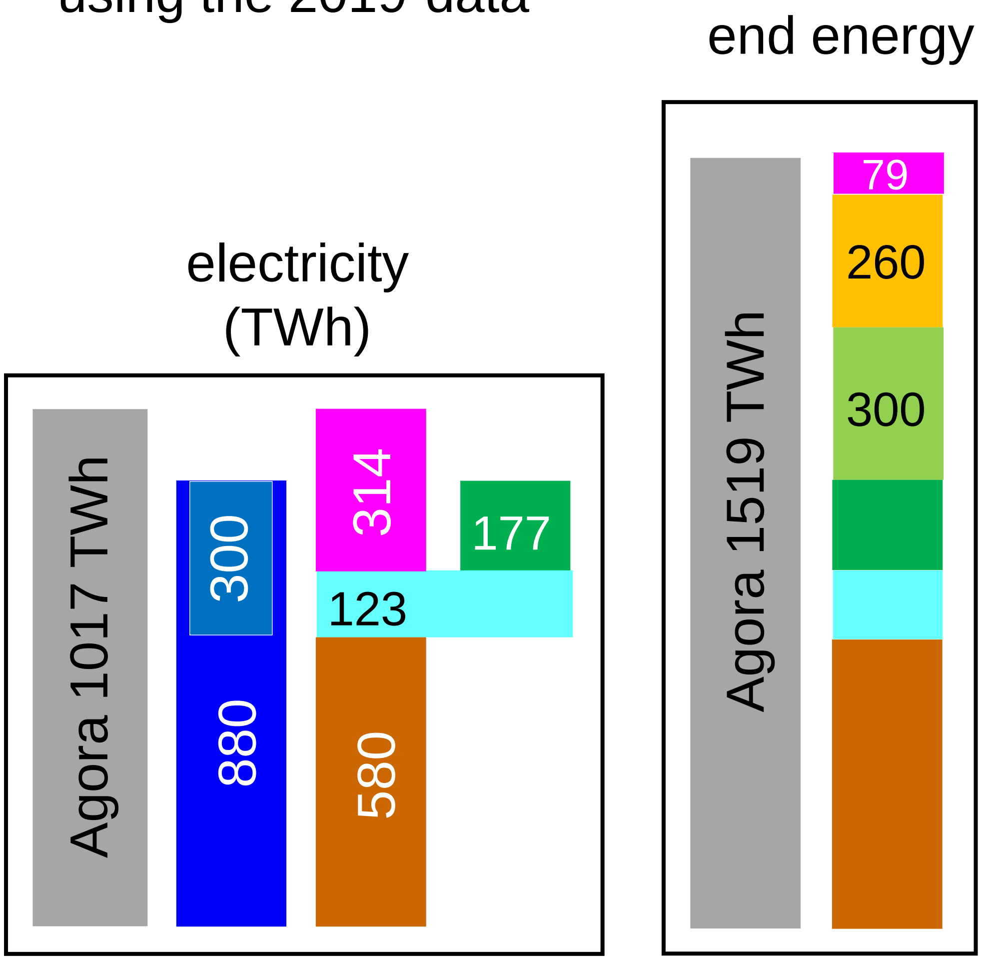
chemical industry: 628 TWh (claim of chemical industry association)

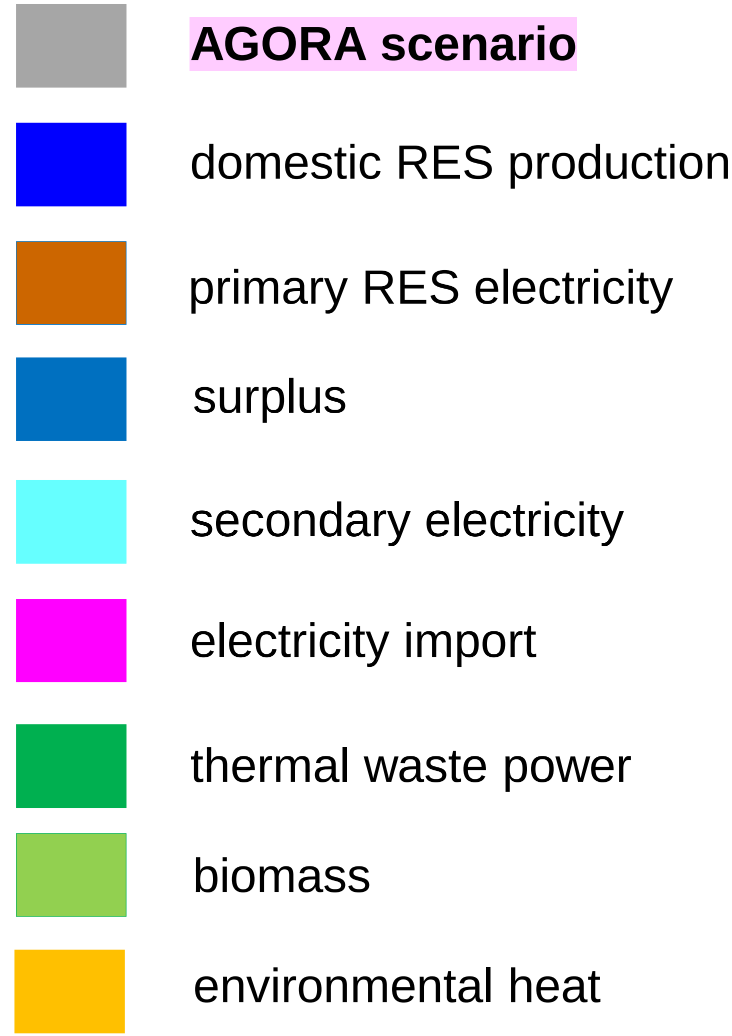
bitcoins: ?

We do not know, how much electricity we will need in the future

2. Low power density of iRES: The potential of Germany

1. case: closing the electricity demand with primary and seondary electricity using the 2019-data





No additional hydrogen production

2. Low power density of iRES: The potential of Germany

2. case: hydrogen production from surplus electricity

AGORA scenario

domestic RES production

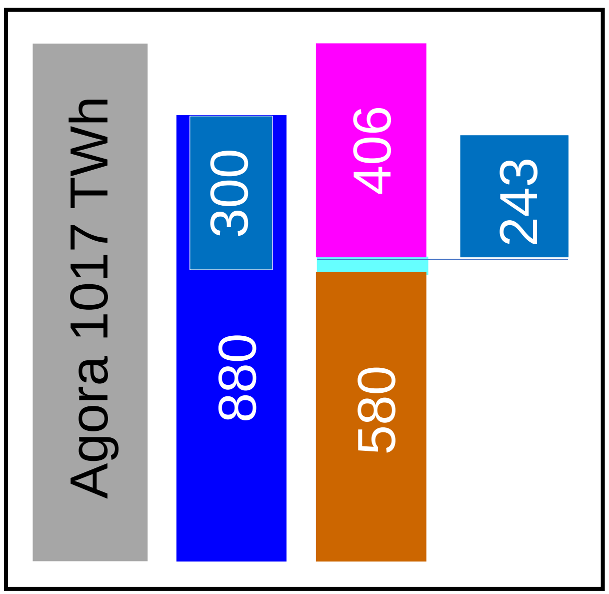
primary RES electricity

surplus

secondary electricity

electricity import

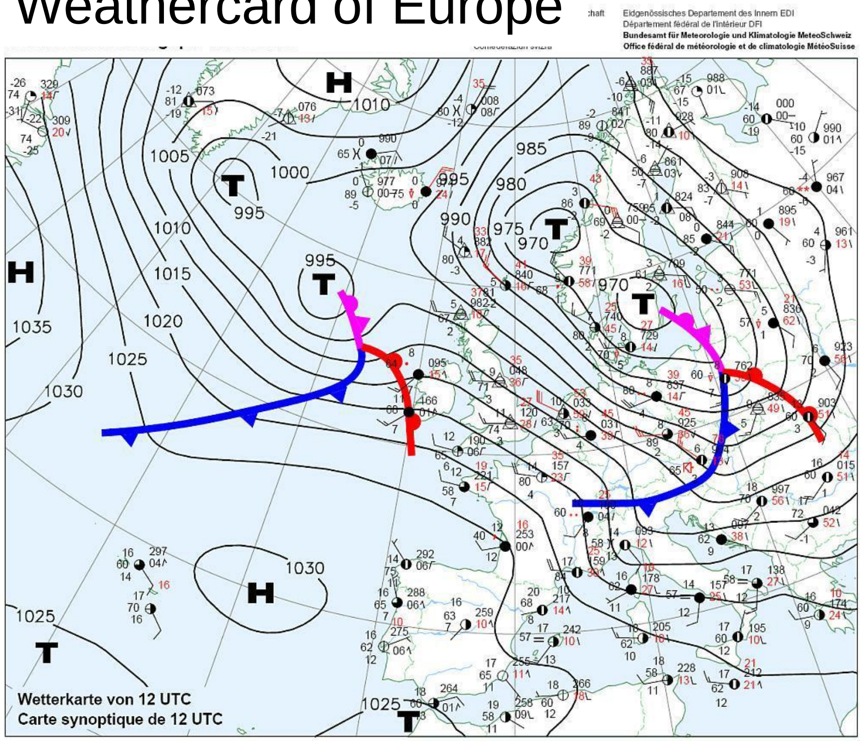
electricity (TWh)



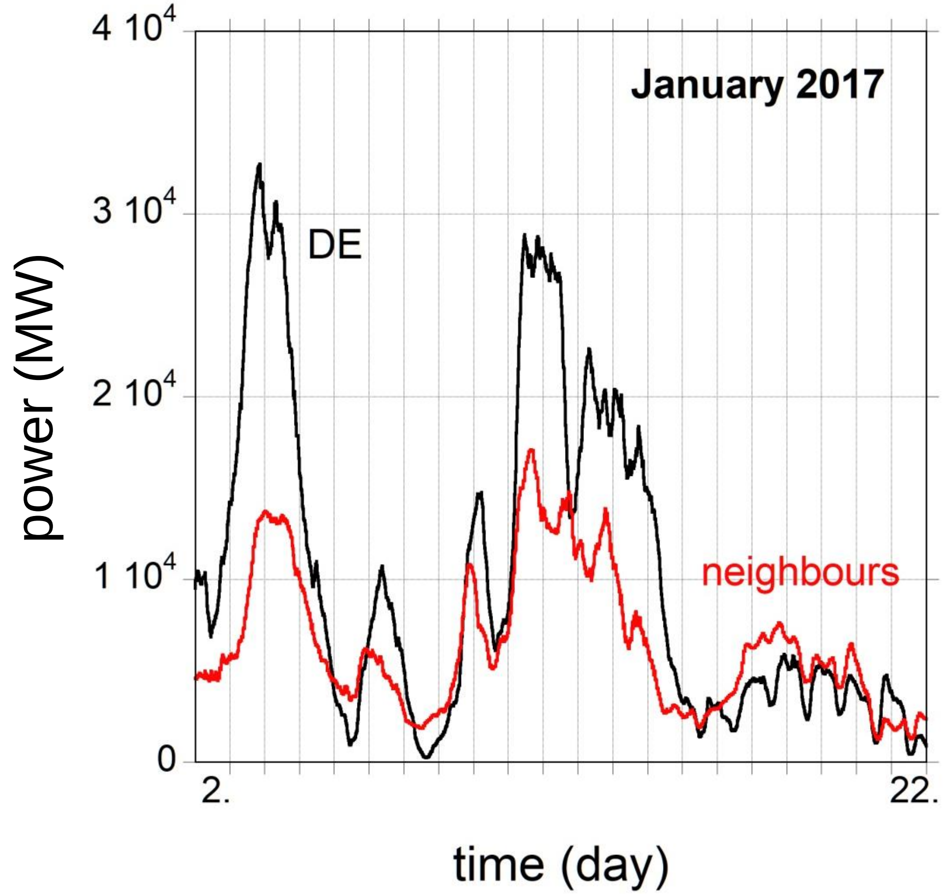
243 TWh yield 4,4 Mill t H2
What to do with it?
Steel industry: 1,8 Mill tons of H2
Chemical industry: 7 Mill tons of H2
Part of the H2 demand of industry can be met

2. Low power density of iRES: electricity import

Weathercard of Europe



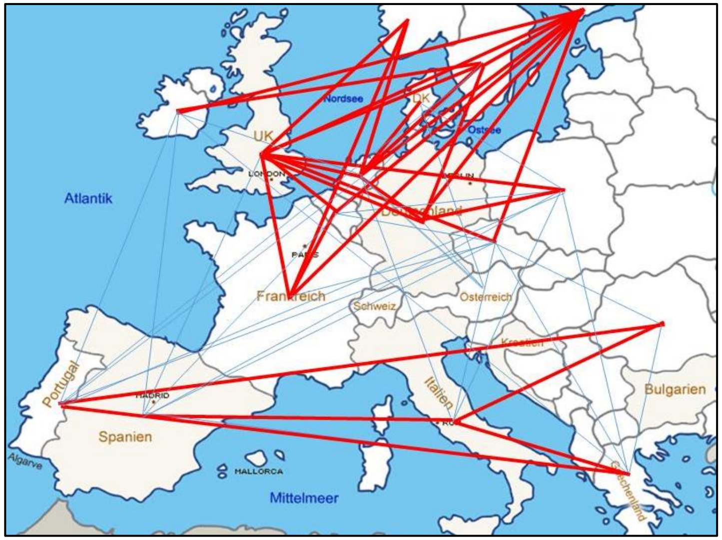
Onshore windpower



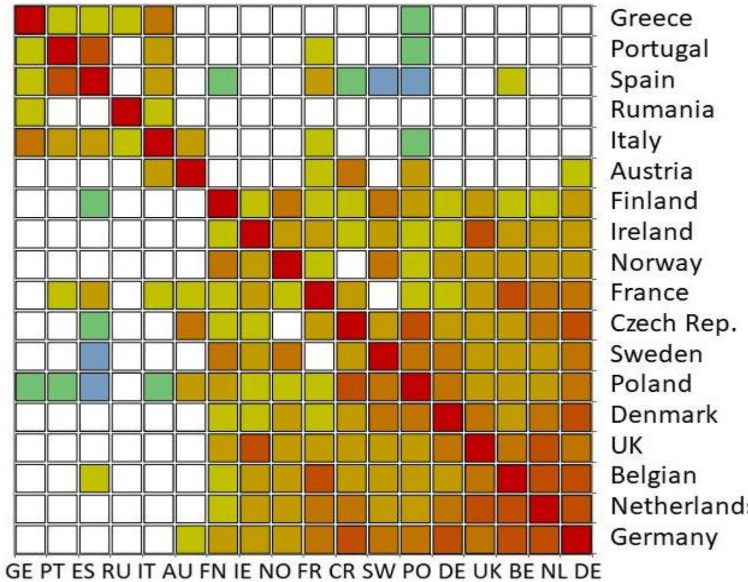
When Germany has wind, our neighbours have wind too, and vice versa

Consequences of the weather pattern over Europe

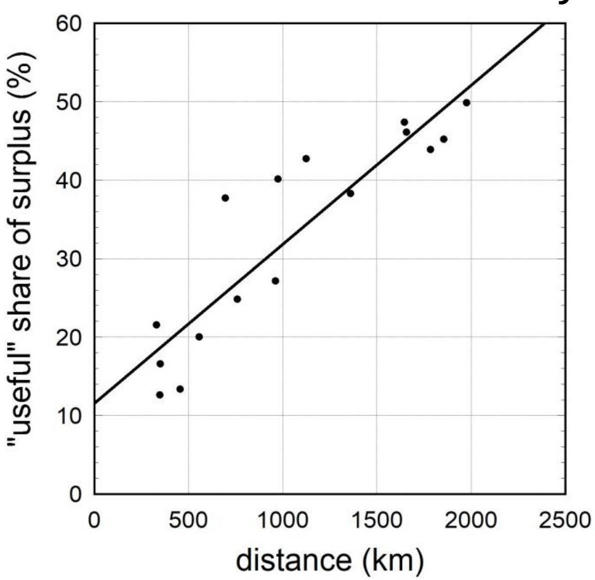
Two wind areas in Europe



Correlation matrix of wind power



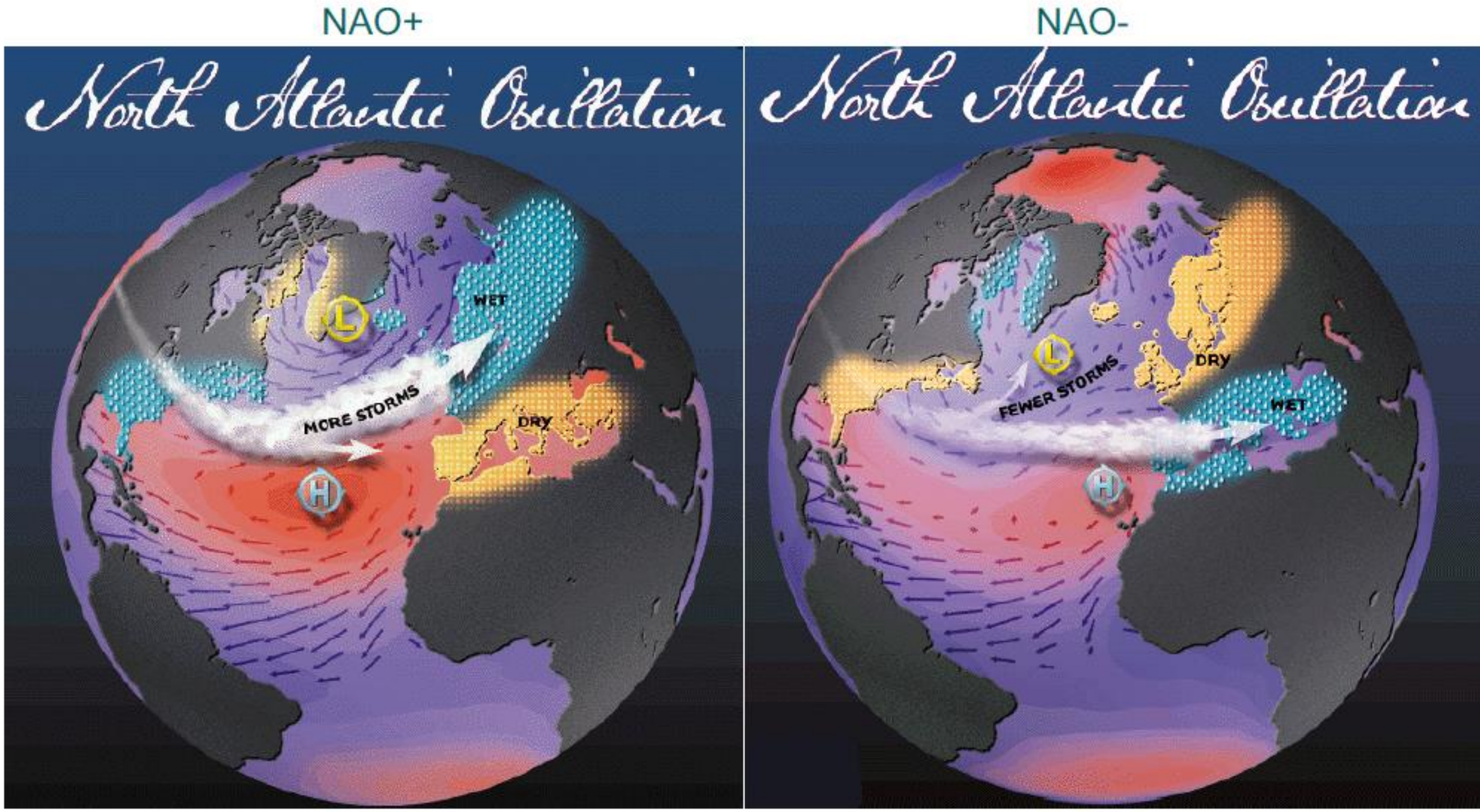
Who contributes when Germany is in need?



The countries at larger distance produce a higher share of “useful” surplus, which is available when Germany is in need (needs backup)

→ large transfer lines across Europe
→ interconnectors with high power capacity
(but not necessarily for one´s own sake)

H. Schmidt: North-Atlantic Oscilations



(http://www.ldeo.columbia.edu)

2. Low power density of iRES: German situation

Germany has to import large quantities of electricity

Direct import of electricity my not be possible

The import may therefore be in the form of hydrogen

Because of the transformation losses,

large power generation capacities have to be set-up elsewhere

In which regions? regions with water?

Transport to Germany? e.g. in ships

Japanese LH2 ships * : 1250 m3 LH2 ~ 90 tons ~ 1 Mill Nm3 H2 gas

One ship transports 3 GWh energy, yielding 1.5 GWh electricity (η = 0,5)

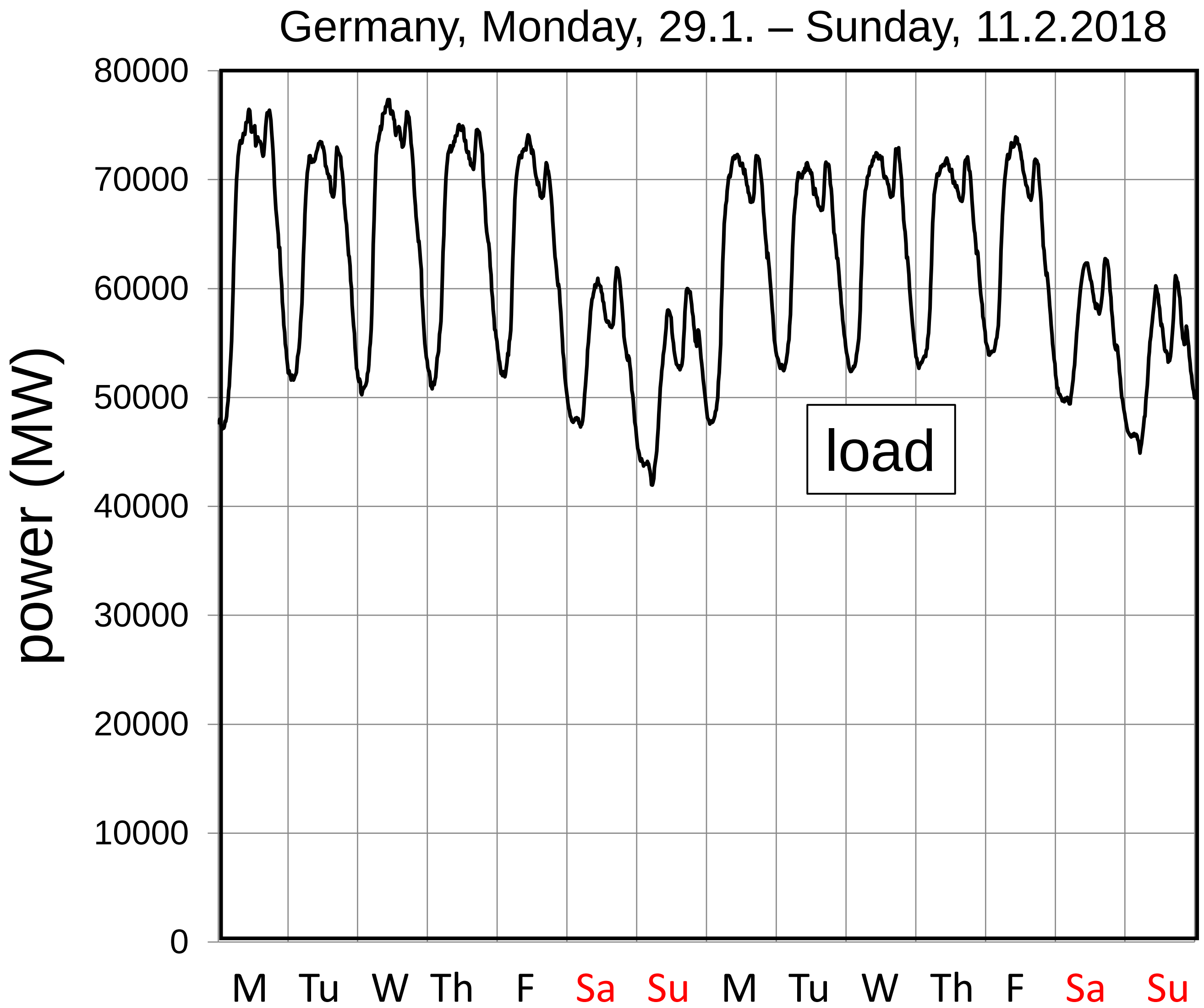
If the annual need is 100 TWh: 185 ships a day, 5000 land LH2 trailers a day

Does not seem to be the correct scheme → E. Pellicer, P. Rudolf

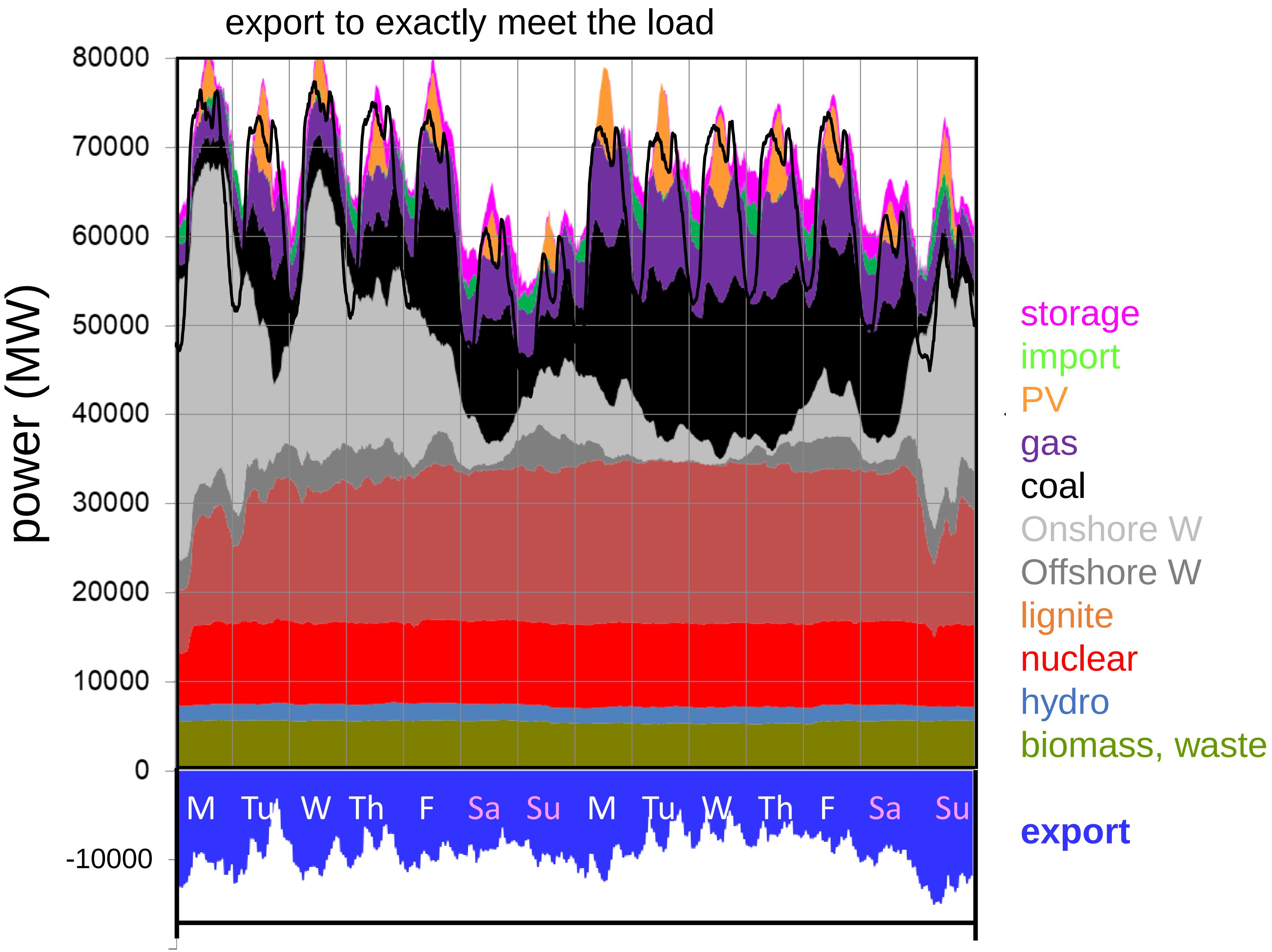
* Suiso
https://www.lr.org/en/insights/articles/world-first-for-liquid-hydrogen-transportation/

2. feature of energy transition: consumption follows generation

Present scheme: generation meets (exacly) consumption = load

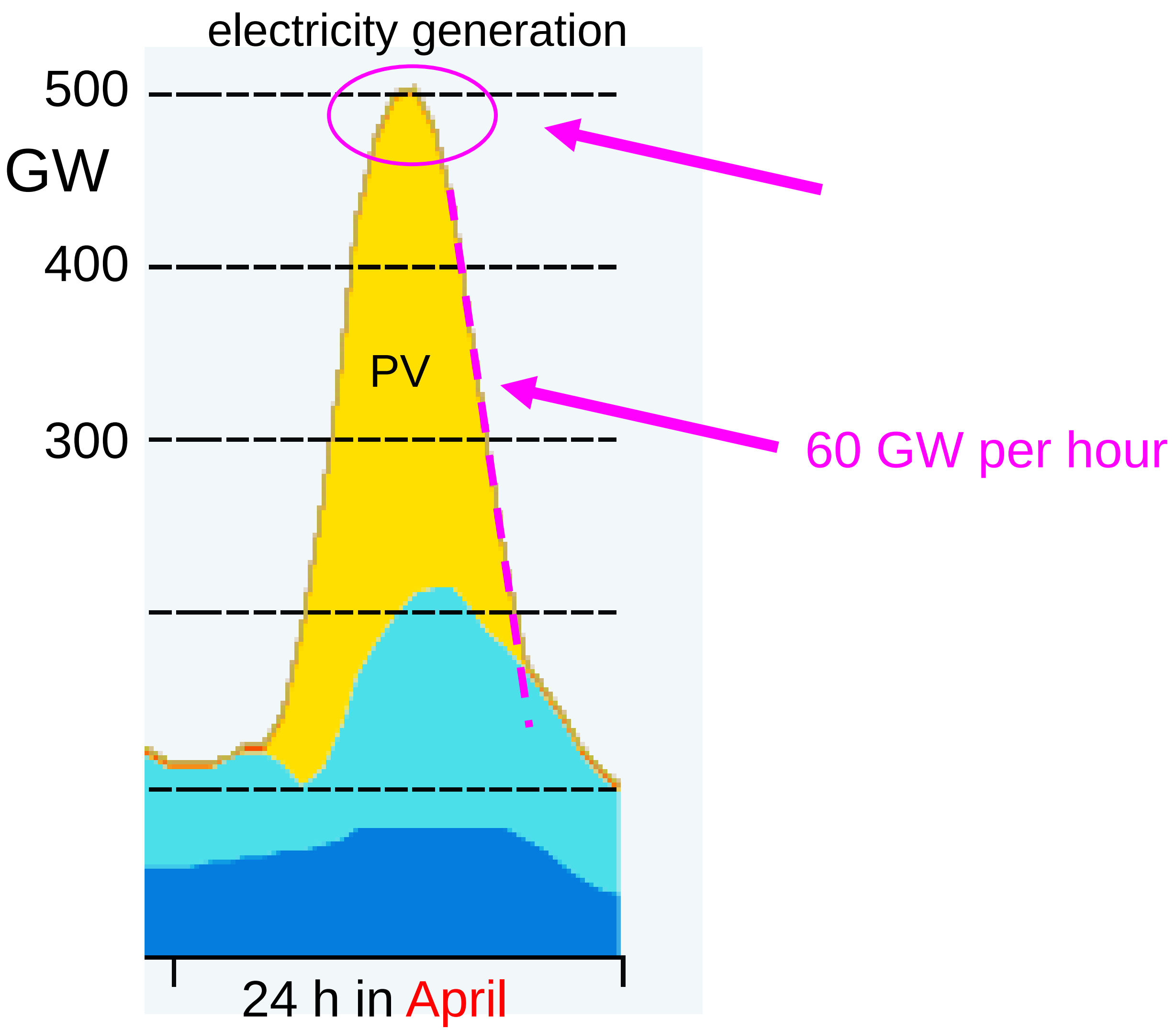


presently: generation technologies are consecutively added



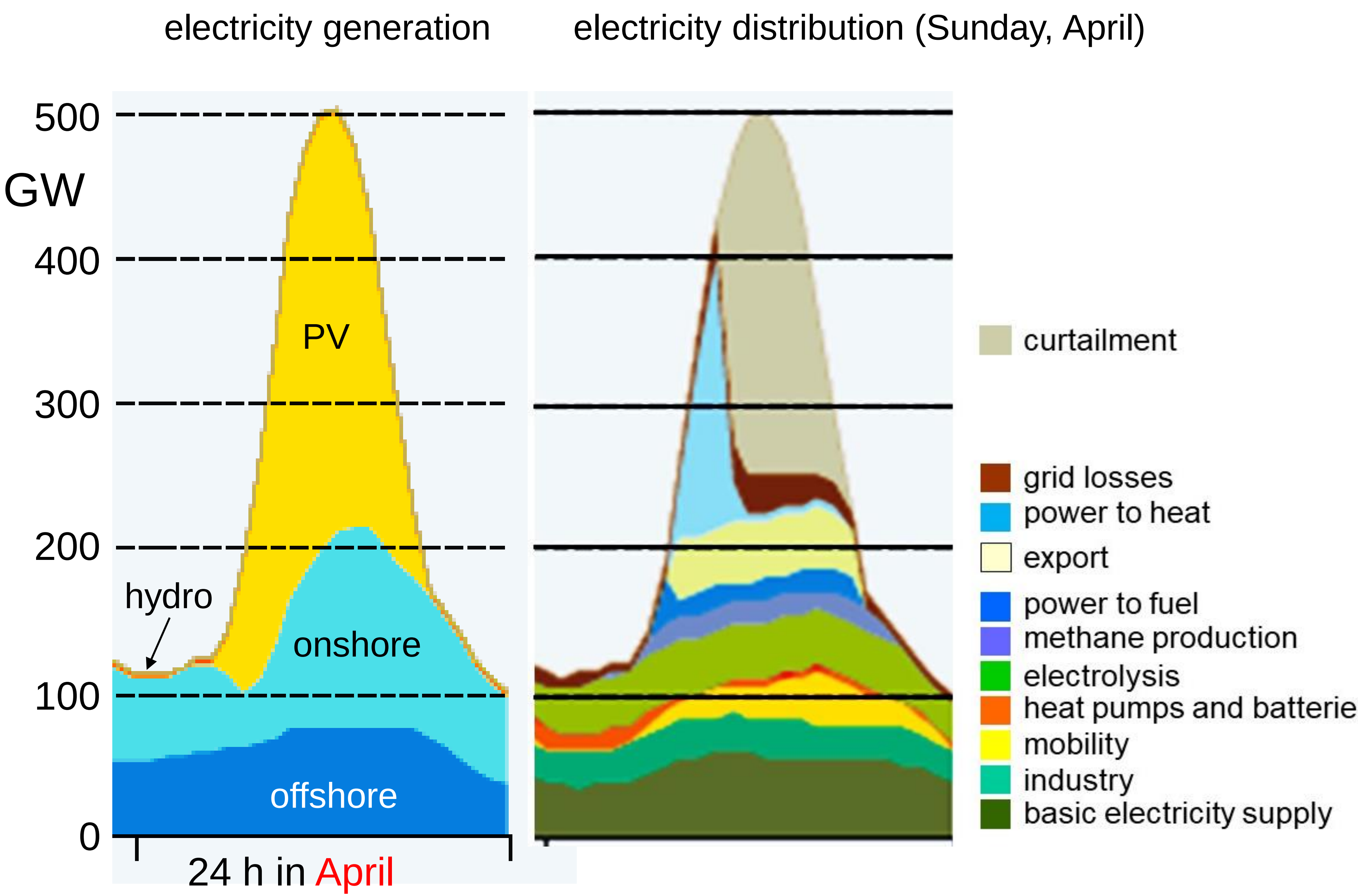
The situation in the future: generation first

The following example is taken from Fraunhofer-Institut für Solare Energiesysteme ISE Fig. 10 *, scenario „Reference“ with 677 GW installed iRES power (116 GW 2020)



* https://www.ise.fraunhofer.de/de/veroeffentlichungen/studien/wege-zu-einem-klimaneutralen-energiesystem.html

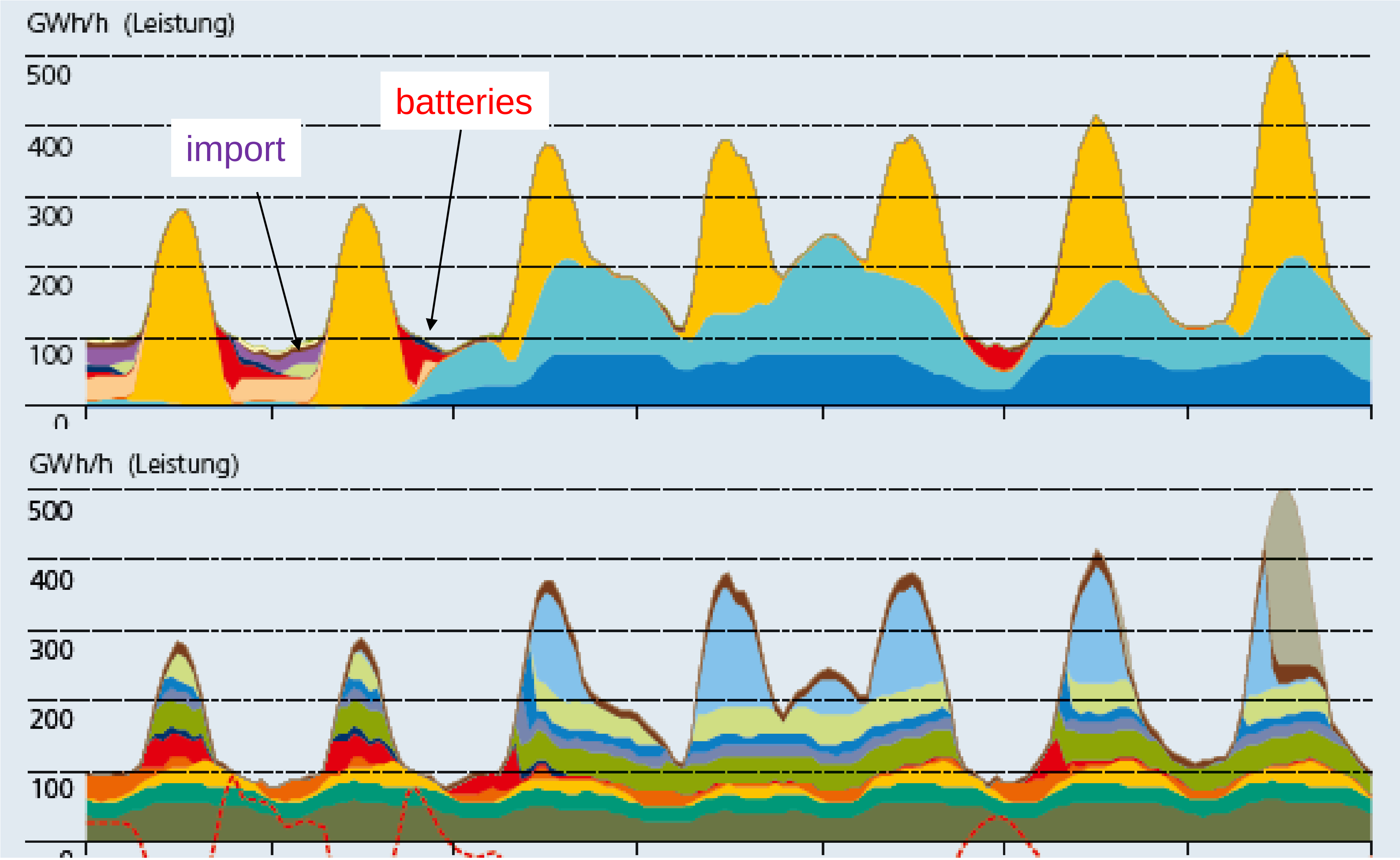
The situation in the future: consumers are consecutively added



* https://www.ise.fraunhofer.de/de/veroeffentlichungen/studien/wege-zu-einem-klimaneutralen-energiesystem.html

The situation in the future: generation first

- weekly variation of generation and distribution



The situation in the future: generation first
- weekly variation of generation and distribution

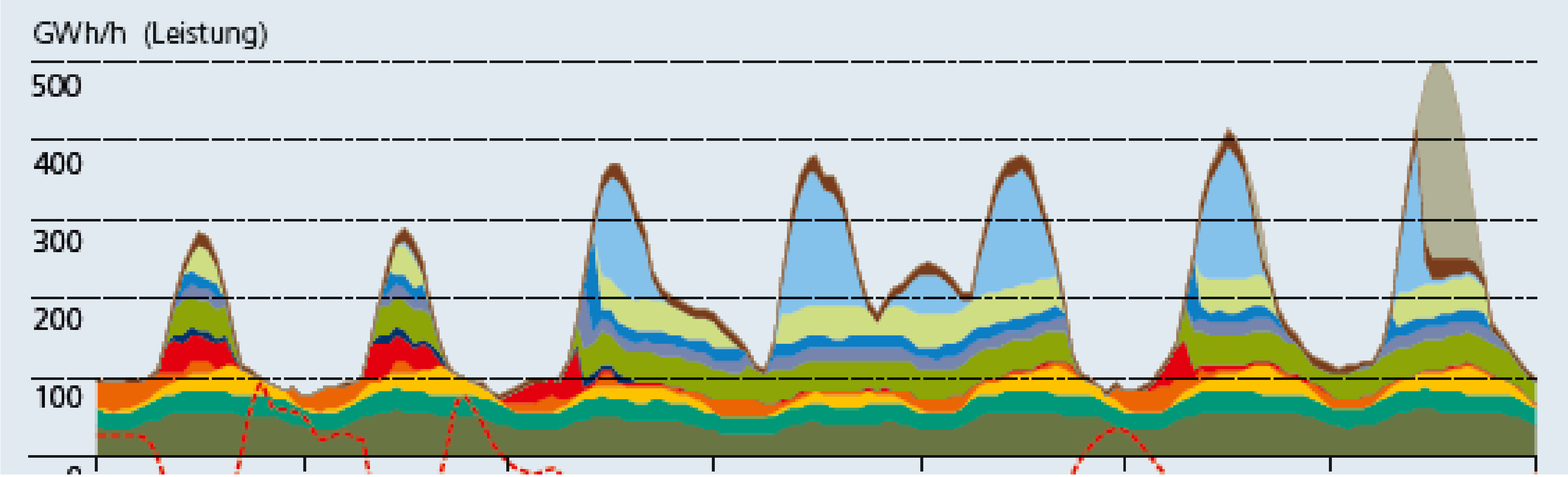
Order of magnitude numbers:

power to heat: ~160 GW
export, cross-border capacity: ~40 GW
electrolysis: ~ 40 GW
mobility: ~ 40 GW (PV → charging during the day)
heat pumps: ~ 30 GW
batteries: ~ 30 GW
industry: ~ 30 GW
basic-electricity: ~ 60 GW
batteries: ~ 30 GW

Distribution:
HV-grid, distribution grid
hydrogen network
possibly CO2 network
heat distribution network

BUT: Restrictions of consumers, depending on
day, week and season

Left to „smart system“



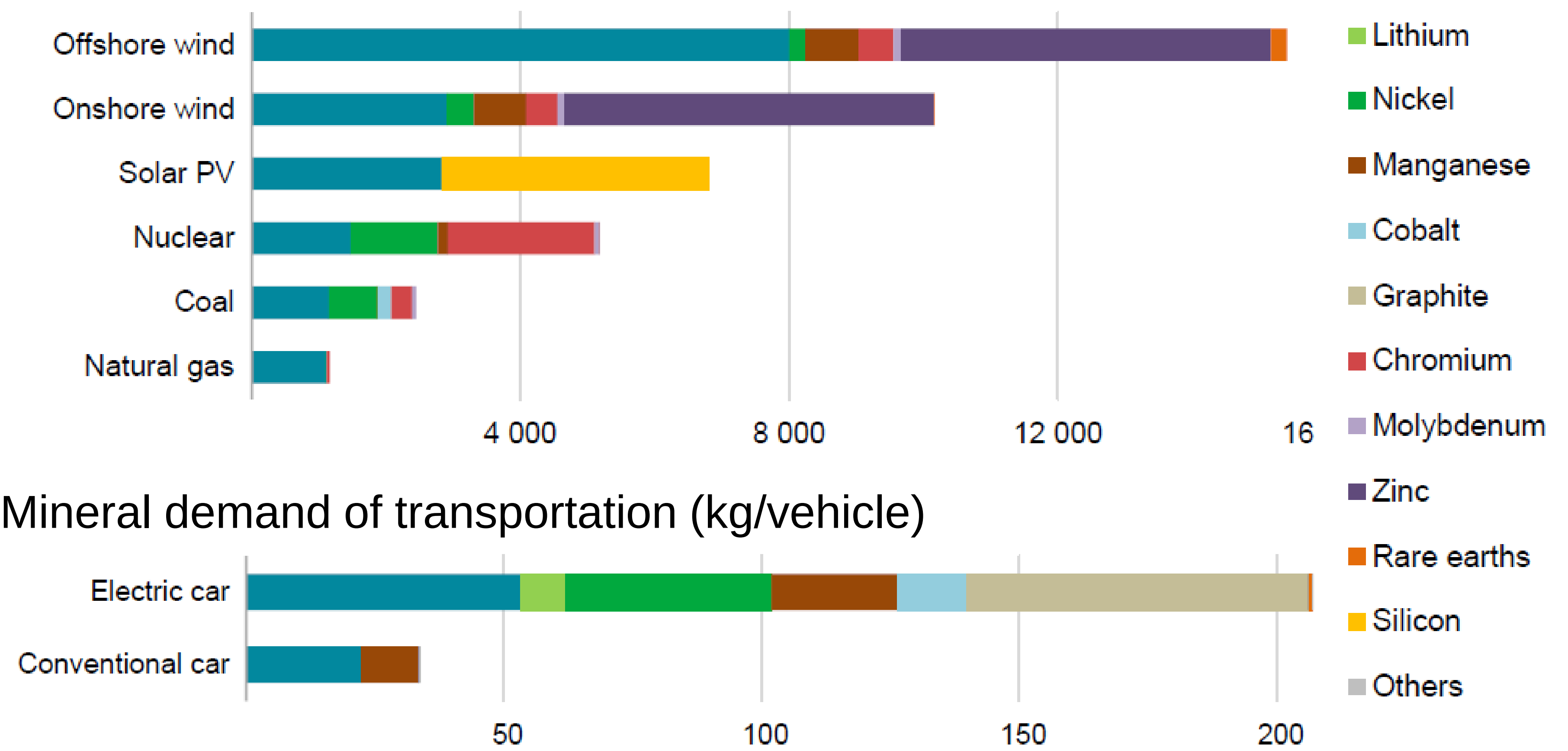
3. feature of energy transition: epoch of the minerals

- replacing the epoch of fossil fuels

(O. Vidal), P. Rudolf
J. Craig, E. Battimelli

Mineral demand of power generation (kg/MW)

Mineral demand of transportation (kg/vehicle)



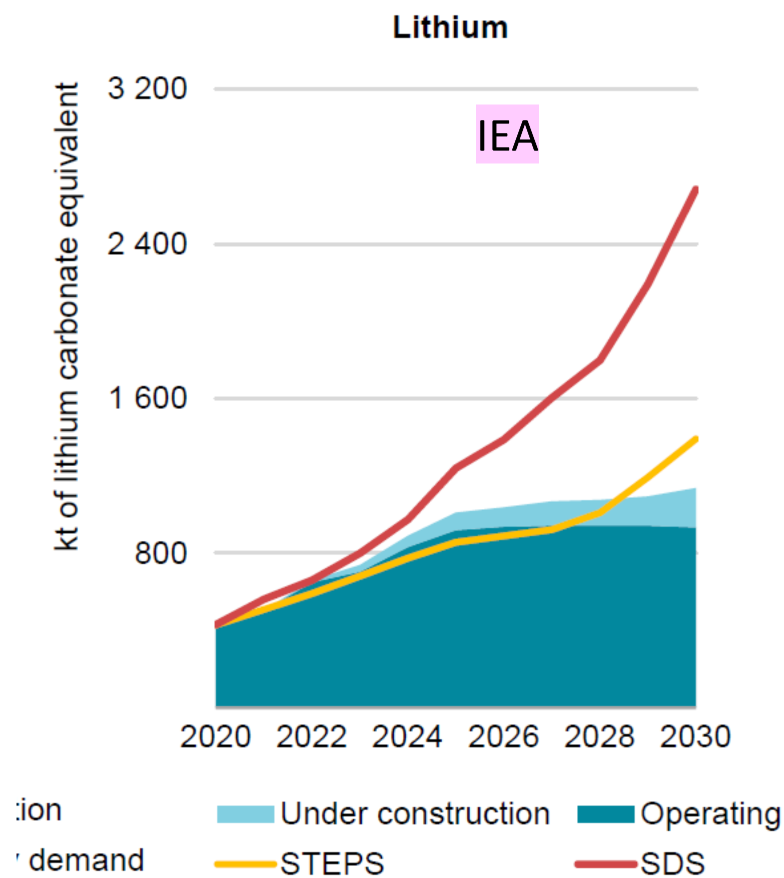
source: IEA 2021: The role of critical minerals in clean energy transitions

3. feature of energy transition: epoch of the minerals
- implications and issues

Mineral origin: concentration to less countries than in case of gas and oil

Processing: of these minerals is even more concentrated
e.g. nearly 90% of rear earth elements are processed in China

Acceleration of mining, e.g. lithium



Ore quality declining

Water needs in mining

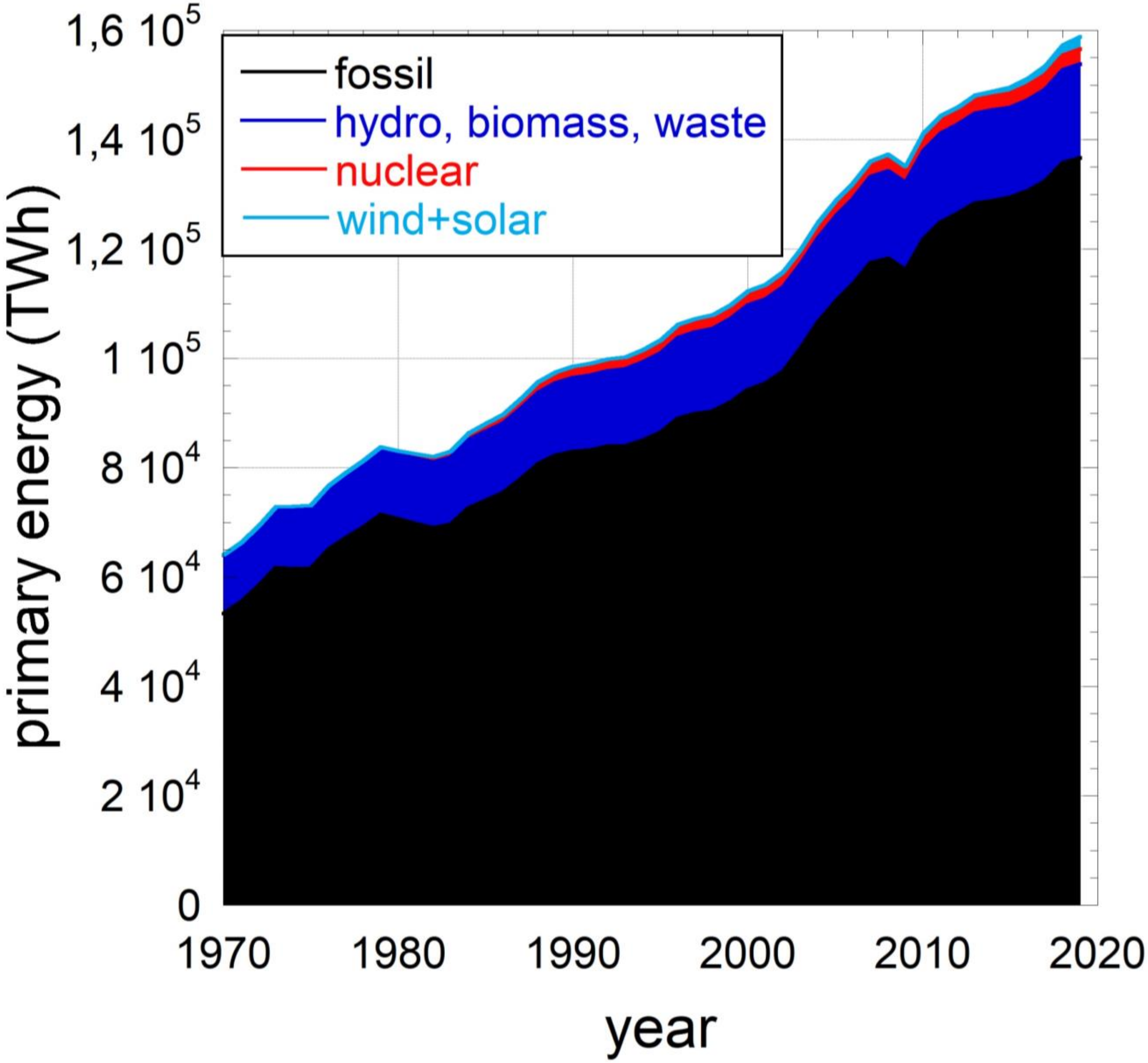
Importance of **recycling**

see presentation by Ankush Kumar

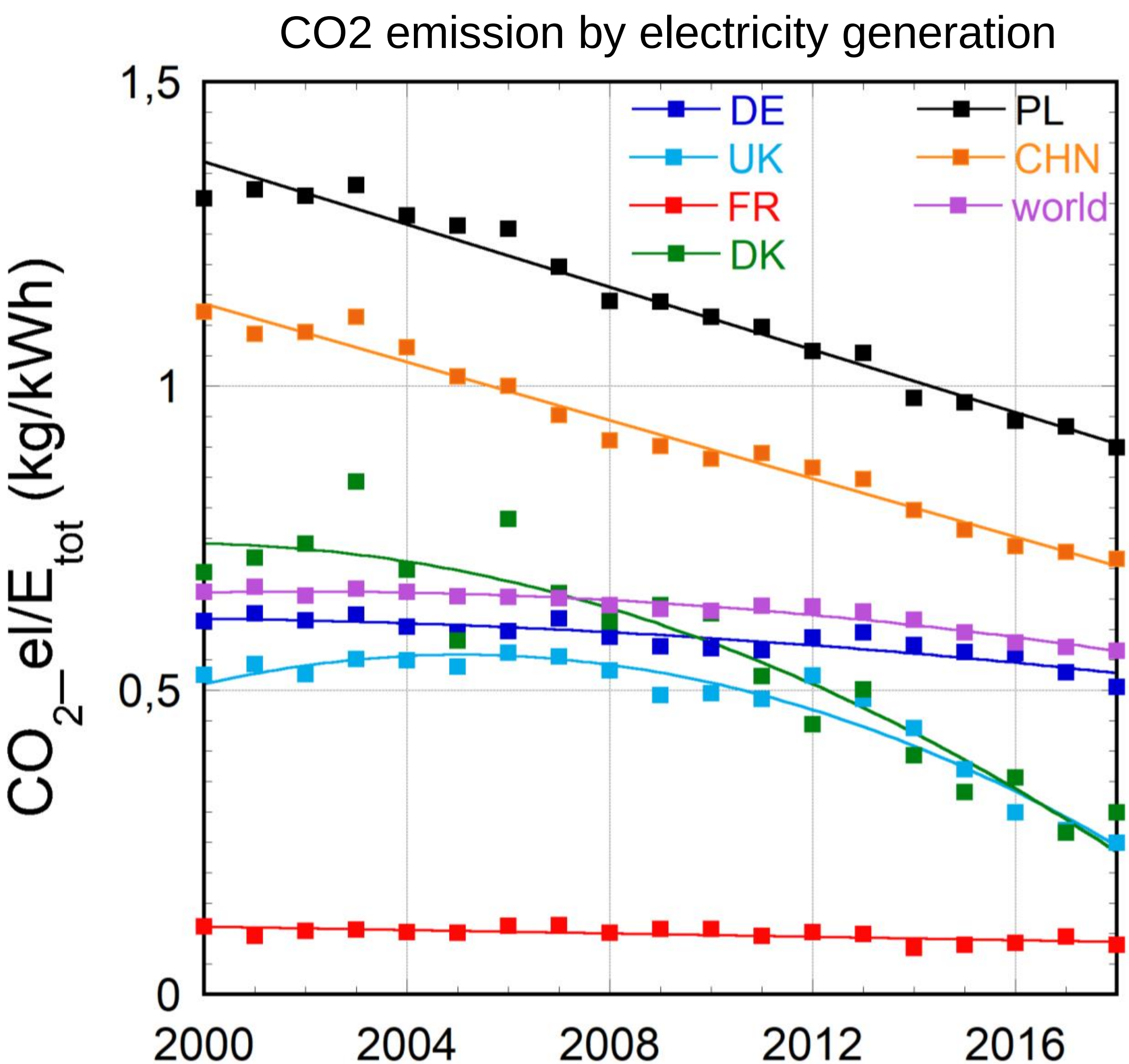
source: IEA 2021: The role of critical minerals in clean energy transitions

Discussion of a sequence of topics

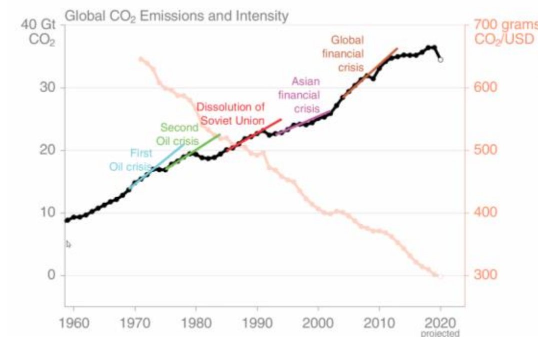
1. topic: the task of de-carbonisation – global view



1. topic: the task of de-carbonisation - global
- progress within 2 decades



M v.d. Broek:
The energy intensity decreases



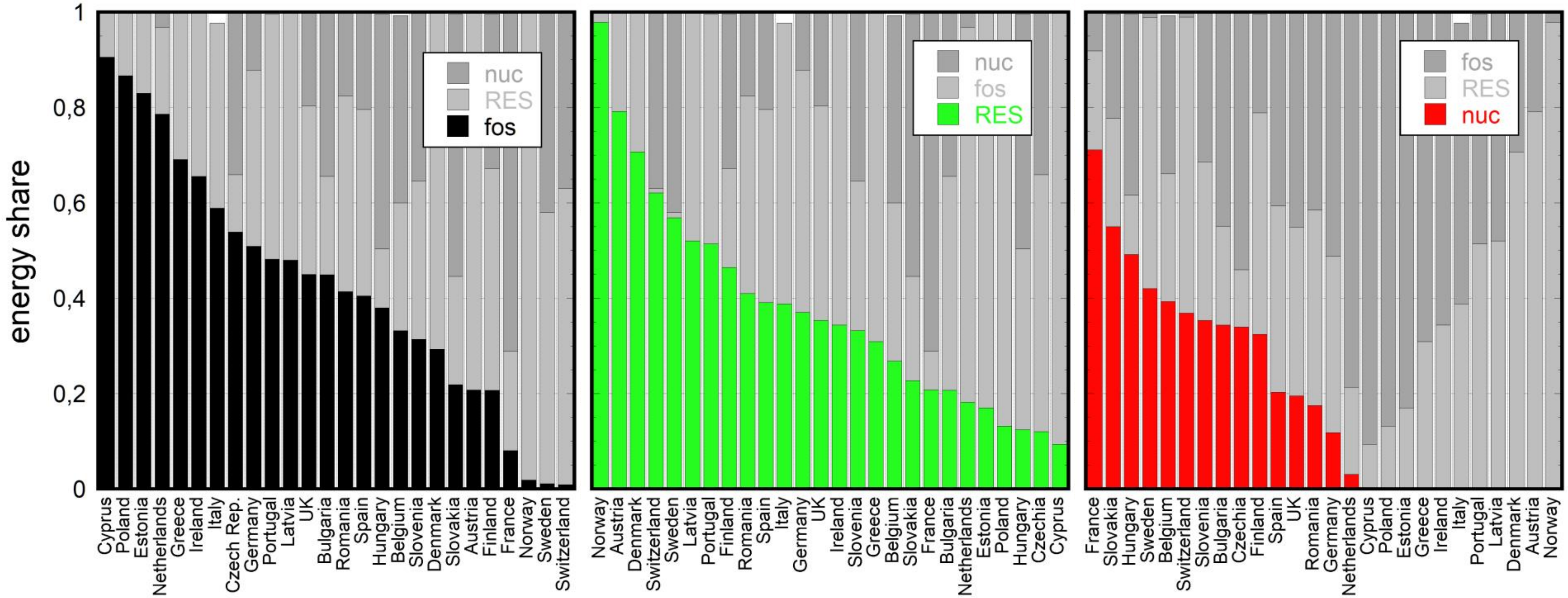
1. topic: the task of de-carbonisation – Europe

- electricity mix: The European situation 2018

energy share of fossile fuels

energy share of RES

energy share of nuclear power



1. topic: the task of de-carbonisation – Germany
- electricity generation in the 1st quater of 2021 and 2020

installations end of 2020

peak load	80	GW
onshore	54	GW
offshore	7,7	GW
PV	54	GW
biomass	46	TWh

comparison 2021 with 2020*

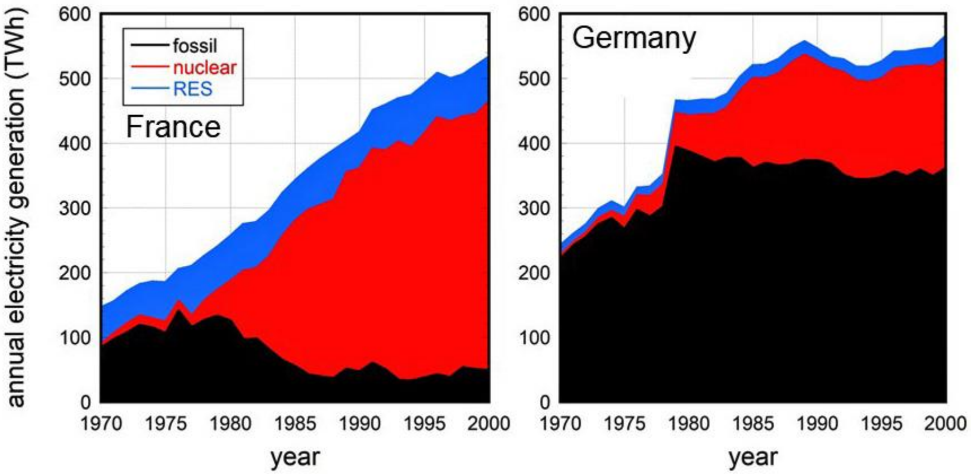
TWh	2020	2021	difference %
total	141,9	138,2	-2,6
wind	49,5	33,5	-32,3
PV	6,8	6,6	-2,9
biomass	7,9	7,7	-2,5
coal	31,5	39,9	+26,7
gas	18,2	22,5	+23,6
nuclear	16,4	16,8	+2,4
import CZ	0,5	1,6	+220,0

demonstration of the need of a backup system
in a fairly advanced transition state

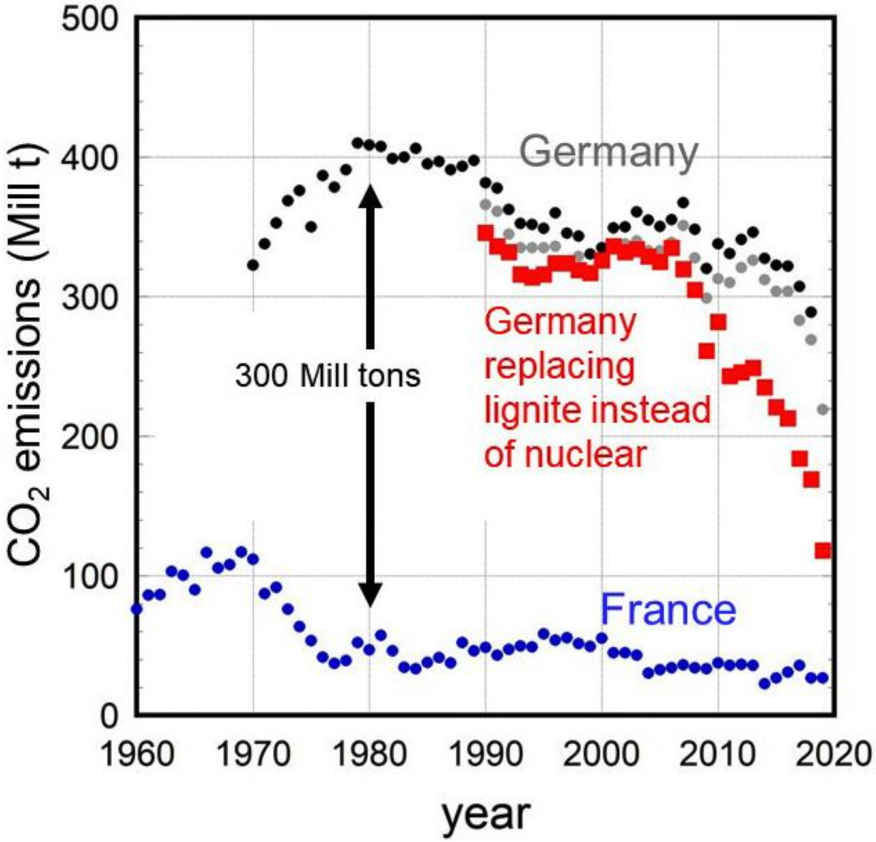
*https://www.destatis.de/DE/Presse/Pressemitteilungen/2021/06/PD21_275_43312.html

2. topic: Clean versus green energy – nuclear power

electricity mix of France and Germany



CO2-emissions from power generation



Nuclear power in Europe

see S. Leray

126 reactors in operation

Czech republic: to the existing 6 reactors, 4 should be added

Netherlands: the ruling party discusses plans to build up to 10 reactors of the SMR type

Switzerland: operation extended over 60 years

Belgium: termination of nucear power 2025; what will come thereafter?

France: Fessenheim stopped. EPR in Flamanville. Till 2035 nuclear power should drop to a level of 50%.

Sweden: Ringhals 1and 2 recently stopped; 6 power stations should operate for 60 years – up to 2040

Finland: EPR in Olkiluoto; start of operation 2022; plans for another plant exist.

Polen: plans to build 1.5 GWel up to 2033 and 6-9 GWel up to 2043.

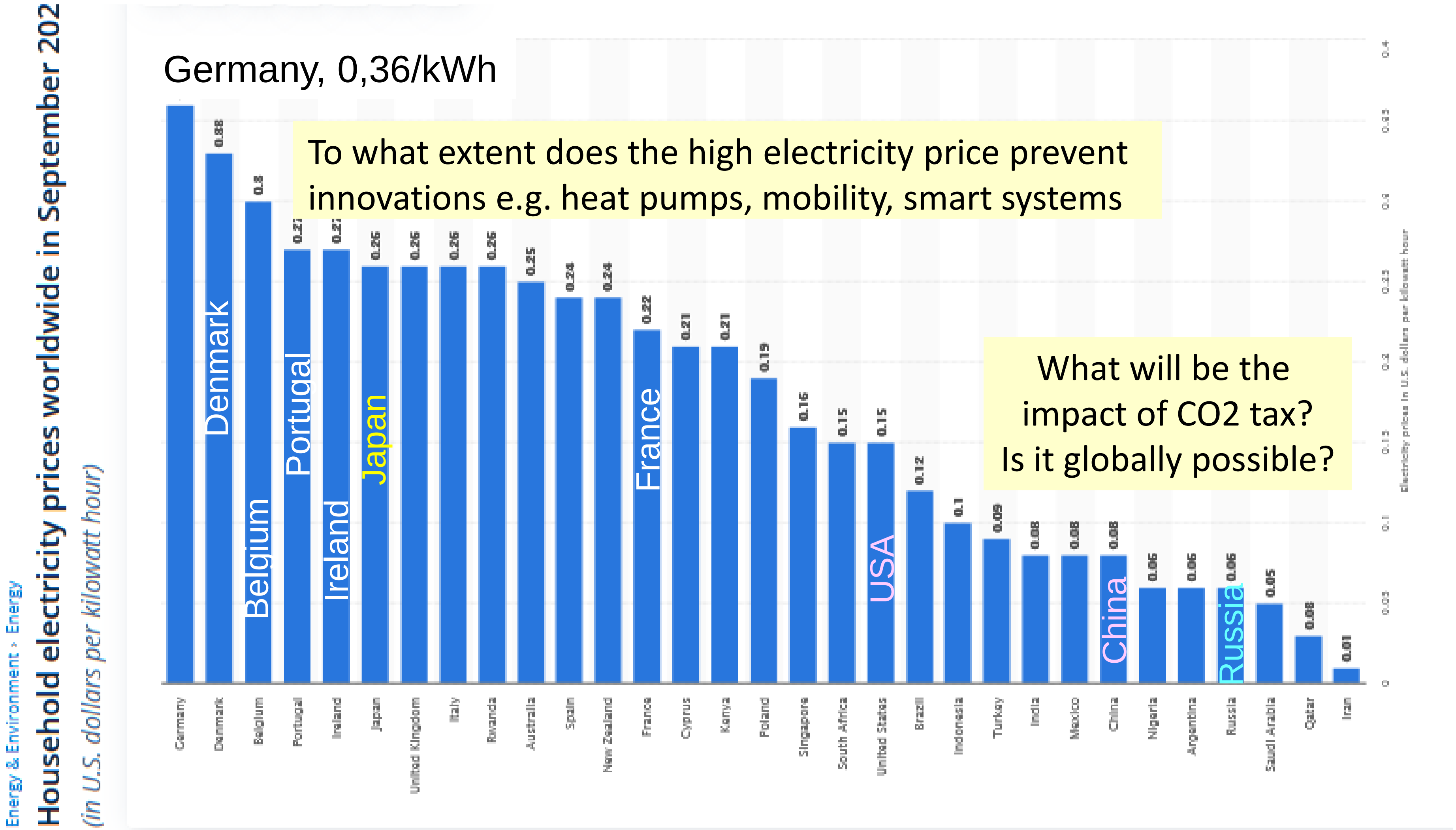
Belarus: one Russian VVER-1200 started operation; another one under construction there are plans to build 2 futher reactors.

Hungary: operation extended to 60 Jahre; plans for 2 new VVER-1200.

UK: 2 Gen III EPRs at Hinkley Point C in Somerset under construction

plans for 2 EPR in Sizewell site and 2 Chinese CGN in Bradwell, Essex.

3. topic: economic consequences
- costs of household electricity

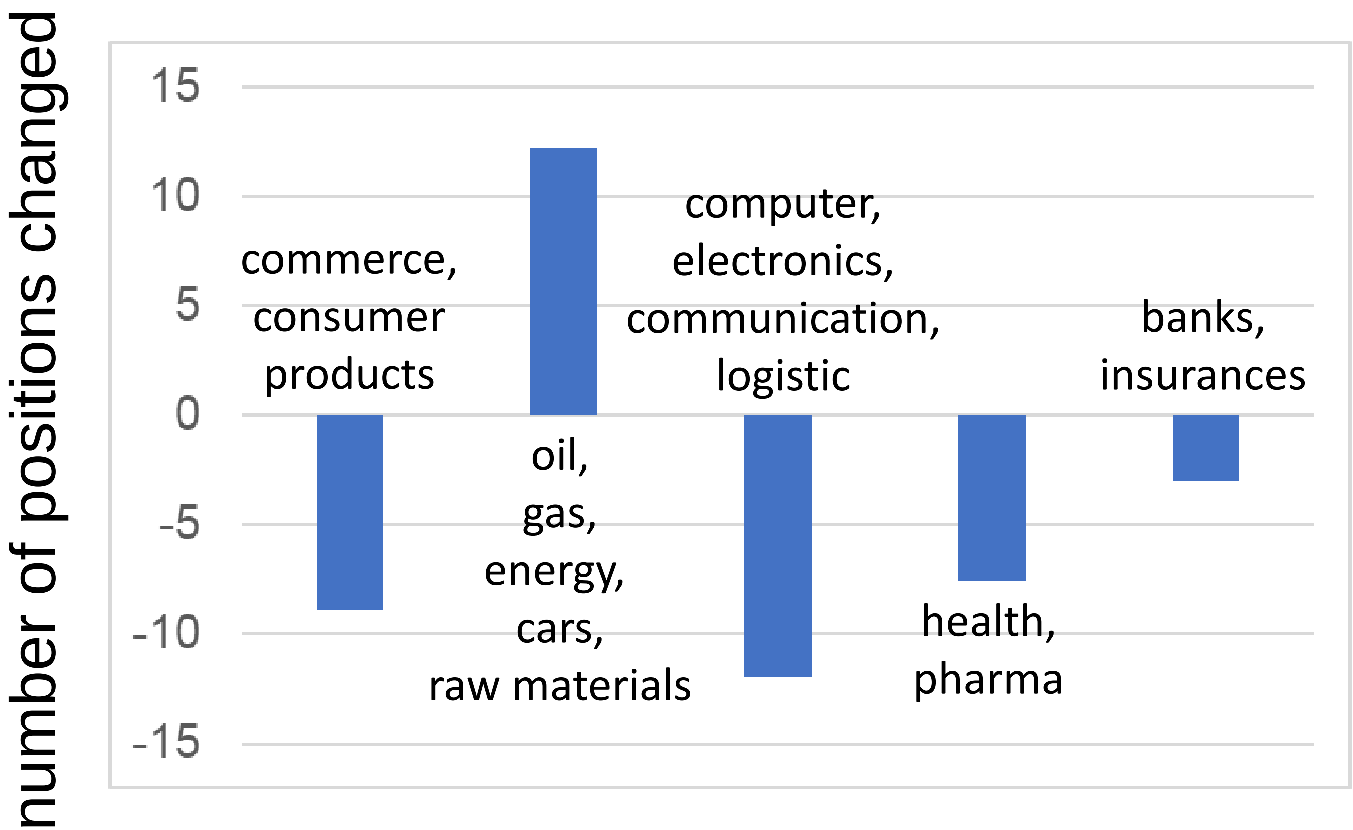


https://www.statista.com/statistics/263492/electricity-prices-in-selected-countries/

3. topic: economic consequences
- the rating of corporations

see J. Craig: reaction of investors on the Dutch Shell verdict

average change of position from 2019 to 2020
of the globally 100 highest-sale corporations
(F.A.Z., 7.7.2021)



3. topic: economic consequences
- market versus regulation

Fundamental issue: to what extent is the transition governed by the market
    or regulated by government
        e.g. subsidy versus tradeable CO2-fee

The energy transition increases the extent of public investments
    new technologies (e.g. steel) cannot compete on the market
        „difference contracts“ should pay the compensation
        quota should be defined for „green steel“

CO2 price will increase all commodities → compensation of social effects
    (see Gilets Jaunes movement in France)

Trade with countries with lower or no CO2 pricing → carbon border adjustment, CBAM
    CBAM to steel, aluminium, cement, fertiliser, electricity import
    Russia will be affected most
    expected counter-measures: will affect export nations like Germany
        or, in case of Russia, the gas import dependence of DE (nord-stream 2)

Considerations of a „carbon border adjustment mechanism“
indicates mistrust - not all countries will pursue the agreed-upon climate goals

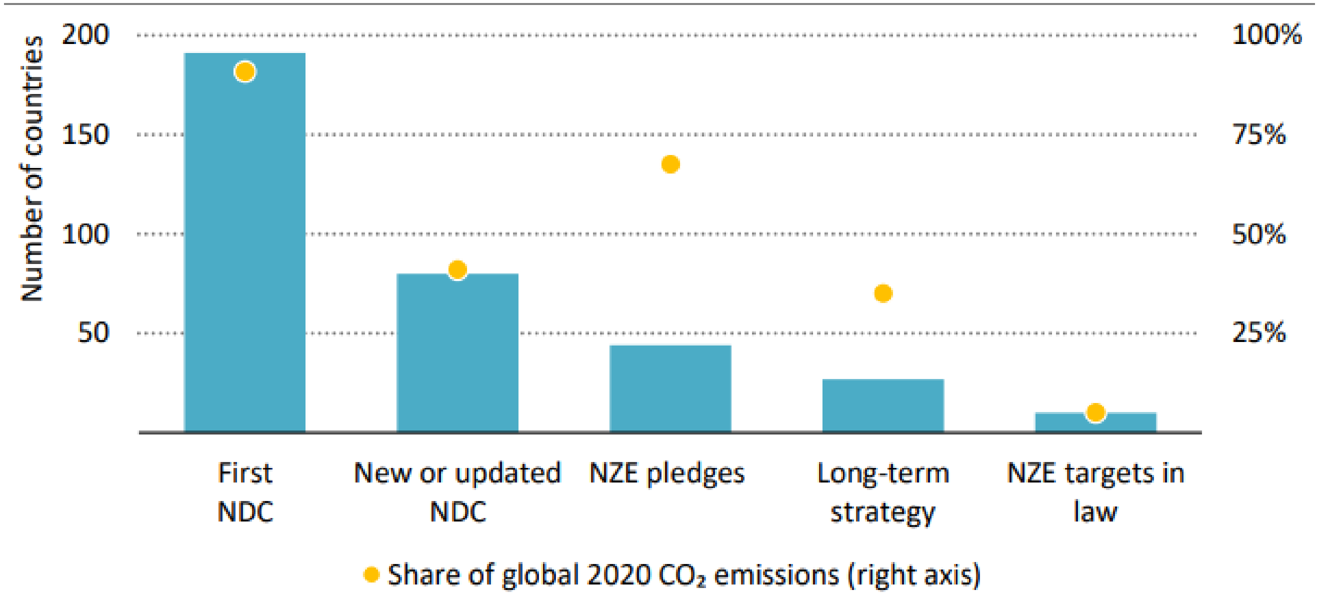
4. topic: Will there be sustainable global consensus?

- Nationally Determined Contributions: NDC

as follow-up of Paris

2016 – first round of contributions: 191 countries
2021 – 2nd round: 80 countries
2021 – 6 years after Paris: 10 countries with NZE targets fixed by law
(NZE: Net-zero emissions)

Figure 1.1 ▷ Number of countries with NDCs, long-term strategies and net zero pledges, and their shares of 2020 global CO_2 emissions



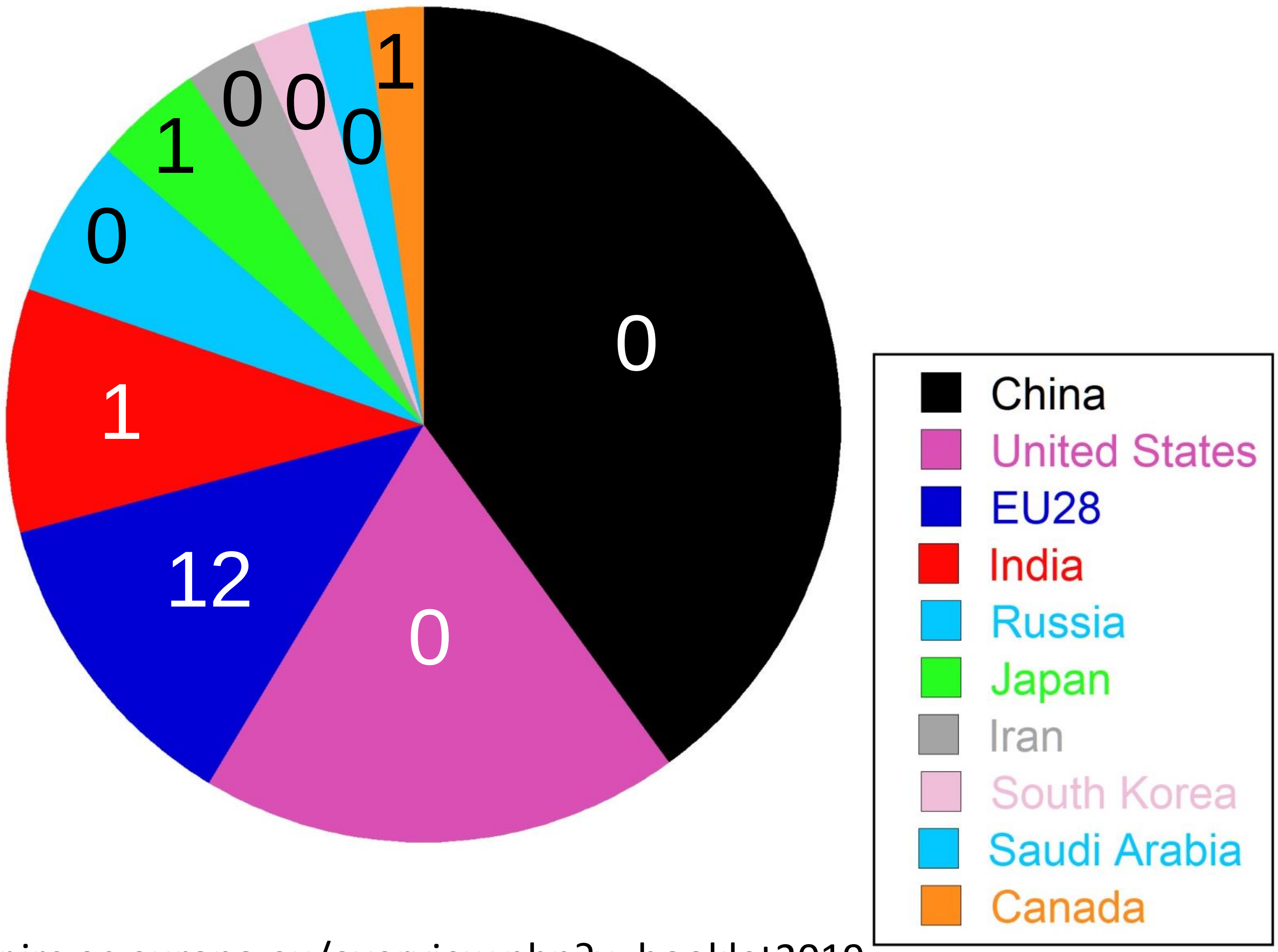
https://www.iea.org/reports/net-zero-by-2050

4. topic: Will there be sustainable global consensus?

- COP conference organisation

COP: conference of the parties – UN climate conference, watches over the Paris agreements

Share of CO2-emission and frequency of COP conference organisation



https://edgar.jrc.ec.europa.eu/overview.php?v=booklet2019

5. topic: Mitigation and adaptation – how to share the efforts

Global efforts, according to IEA: Ch. Buchal

electricity generation: 26778 TWh (2020) → 71164 TWh (2050)
(2020: 790 Mill people without access to electricity)
PV: 737 GW → 14458 GW
Wind: 743 GW → 8265 GW
nuclear power: 415 GW → 812 GW
concerns: other political priorities, limited financial resources, 100reds of coal power plants are under construction in China, India, Indonesia, Africa – lifetime 40 years, the economic power of fossil fuel companies/countries…

Urgent adaptation measures:
cooling and irrigation in large and small scales
prevention against long-lasting heat waves, forest fires, flooding periods
health prevention because of climate change
insurance issues (see flooding in Germany these days)
…..

In the longer run: higher dikes… I leave it to your phantasy

Who cares about adapation measures for the 3rd world countries?

Final wrap-up

Decarbonation is the major global task of this and the next generations

Maybe, such a goal leads to a better global cooperation and understanding

This hope requires a good understanding of all aspects of the transition process

Wind, PV, biomass have to provide the lion`s share

The major political/societal issues concentrate on inclusion of fission and CCS
I think the exclusion of these two options is wrong,
to stop related research is even wronger*

Because of the urgency but also the conflicts with nuclear power
the public is highly sensitive to all aspects of climate and energy transition

As a consequence: the energy field is highjacked by populists also

The only countermeasure: basic understanding of the whole energy field

This is the purpose of this school – and you leave it with a specific responsibility

* I am aware that this superlative degree does not exist in English