Systemic Gray Areas of the Energy Transition [in Germany]

Curves, Figures, Interpretations

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Preface

Paris Agreement (2015):

CO_2 neutrality (= Net-Zero) until 2nd half of the century.

- Recommendation: … until 2050.
- Possible interpretation: … until 2099.

EU Climate Law (2021) and Green Deal (2019 ff.)

- 2050: Net Zero CO_2 Emissions.

Germany, Climate Protection Act (2021) („Electricity“ + „Chemistry“!)

- 2040: 10% emissions compared to 1990.
- 2045: 0% emissions (← „Climate Neutrality“).
- 2050: <0% emissions

Remark

- All the numbers given in the following refer to the **German** situation.
- To get a first idea or feeling what the numbers would mean for Hungary, simply divide them by ≈**10**.

Residents:	83.4×10^6	↔	9.6×10^6	8.7:1
Area:	353,260 km^2	↔	91,248 km^2	3.9:1
Primary energy consumption:	≈3,300 TWh/a	↔	≈300 TWh/a	**11.0:1**
Gross electricity consumption:	≈500 TWh/a	↔	≈45 TWh/a	**11.1:1**

General Information about the German RE System 2045

... according to official data[1)]

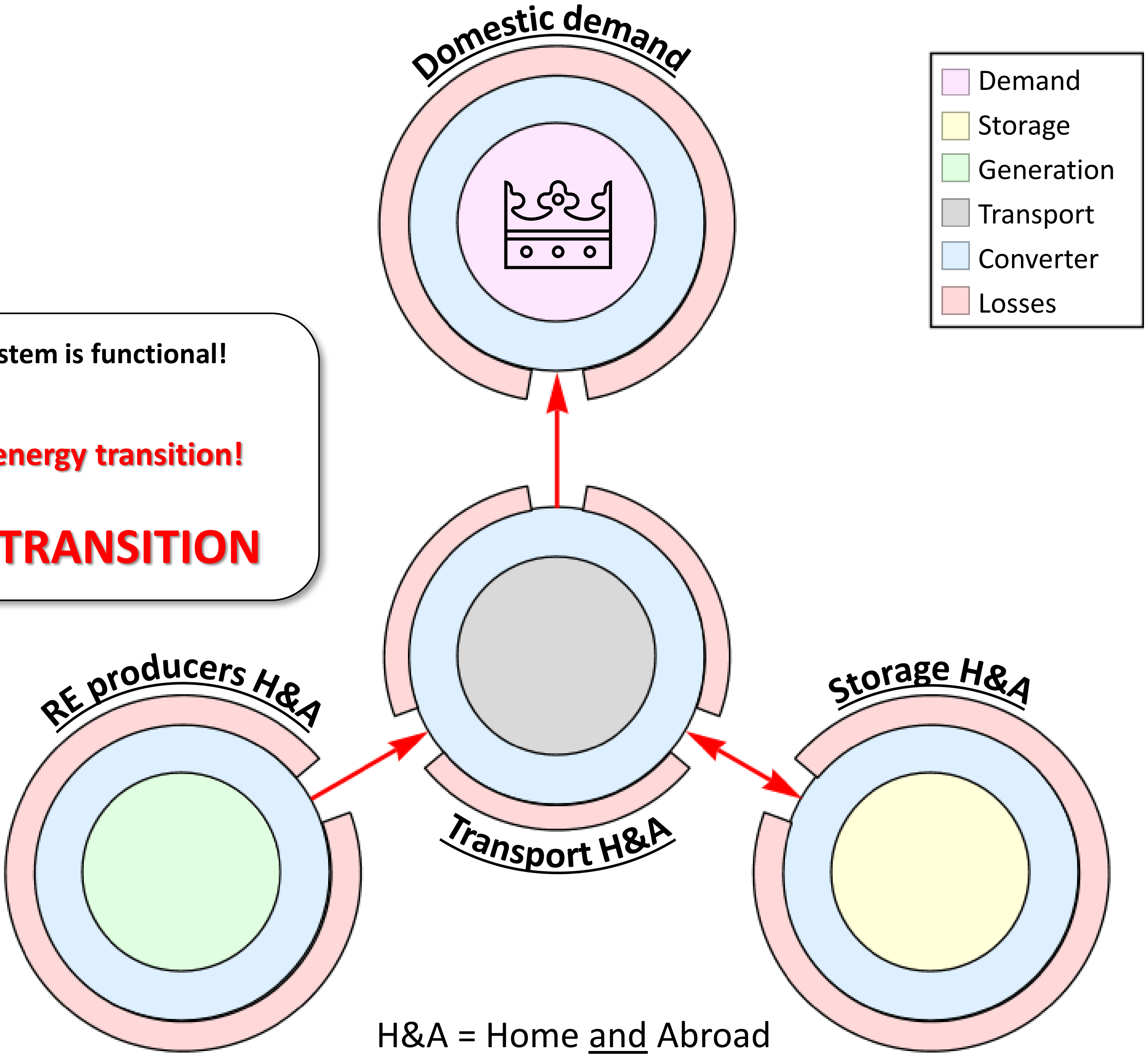
[1)] In particular, "Scenario A" of the 2037/2045 scenario framework approved by the Federal Network Agency in 2022.

Rough scheme RE supply 2045

All elements must be adapted to each other so that the overall system is functional!

The weakest element determines the progress of the energy transition!

⇒ GRAY AREAS OF GERMAN ENERGY TRANSITION



Biomasse	biomass
elektrisch	electricity
GHD	commercial, trade and services
Haushalte	households
Industrie	industry
Solar	solar energy
stofflich	material
thermisch	thermal energy
Verkehr	transportation
Wärme	heating
Wasser	hydropower
Wind	wind power

Foreign countries must play a significant role in Germany's 2045 energy supply!

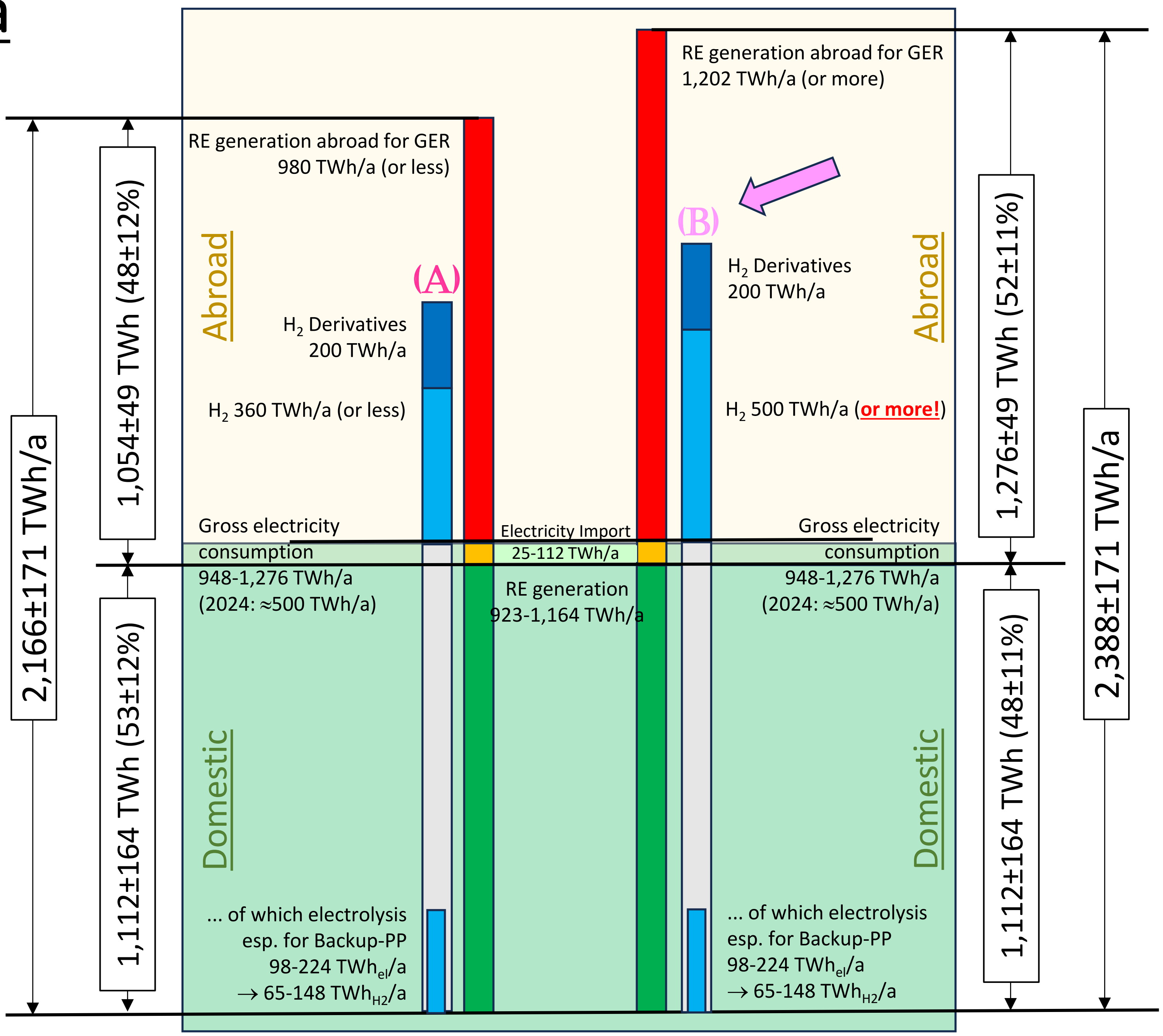
Foreign participation in Germany's RE supply:

- ≈Fifty-Fifty! (wind, solar, hydro)
- Latest by 2045!

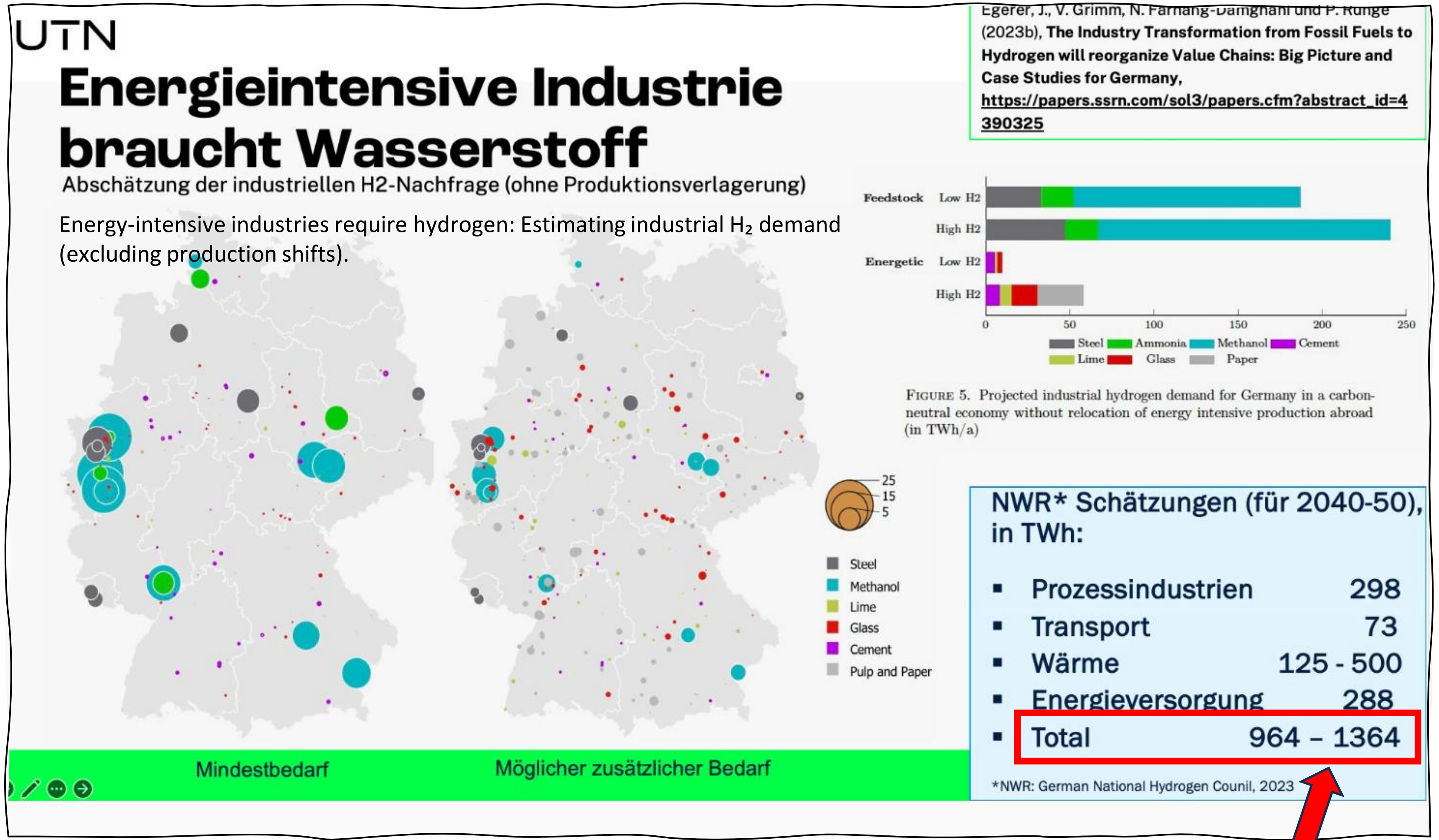
Estimates about H_2-storage requirements:

- >100 TWh for H_2 backup power plants.
- ≈75 TWh for imported H_2.
- ≈175 TWh overall H_2 storage capacity.
- +???-TWh 90-day national energy reserve.
- Available:
  <33 TWh, **all** German gas cavern storages.

Domestic electricity data according to NEP (2025).
Hydrogen data according to Hydrogen Import Strategy of BMWK (2024).
Hydrogen storage data estimated by the author (compare below).



+≈250 TWh/a biomass, environmental heat, etc.



Estimates of the „German National Hydrogen Council“ are remarkably higher.

→ Process Industries
→ Transportation
→ Heat
→ Electricity (incl. 107±42 TWh/a domestic H_2)
→ Total

→ 1,164±200 TWh_{H2}/a
→ 1,764±300 TWh_{el}/a:
→ Dom. 161±63 TWh_{el}/a
→ Abr. 1,603±307 TWh_{el}/a

Viewgraph, dated 31.10.2025, Prof. Dr. Veronika Grimm, Member of the German Council of Economic Experts.

$$\frac{\text{Renewables worldwide to generate } H_2 \text{ only for Germany}}{\text{German renewable electricity generation}} = \frac{1603 \pm 307\ TWh_{el}\ /\ a}{1000\ TWh_{el}\ /\ a} = 1.6 \pm 0.31$$

⇒ 62:38 rather than 50:50

In the following ...

- ... The considerations are *(almost)* restricted to <u>domestic renewable electricity generation</u> and its system-related handling.
- The topic of "hydrogen import" is *(almost)* <u>not</u> part of these considerations.

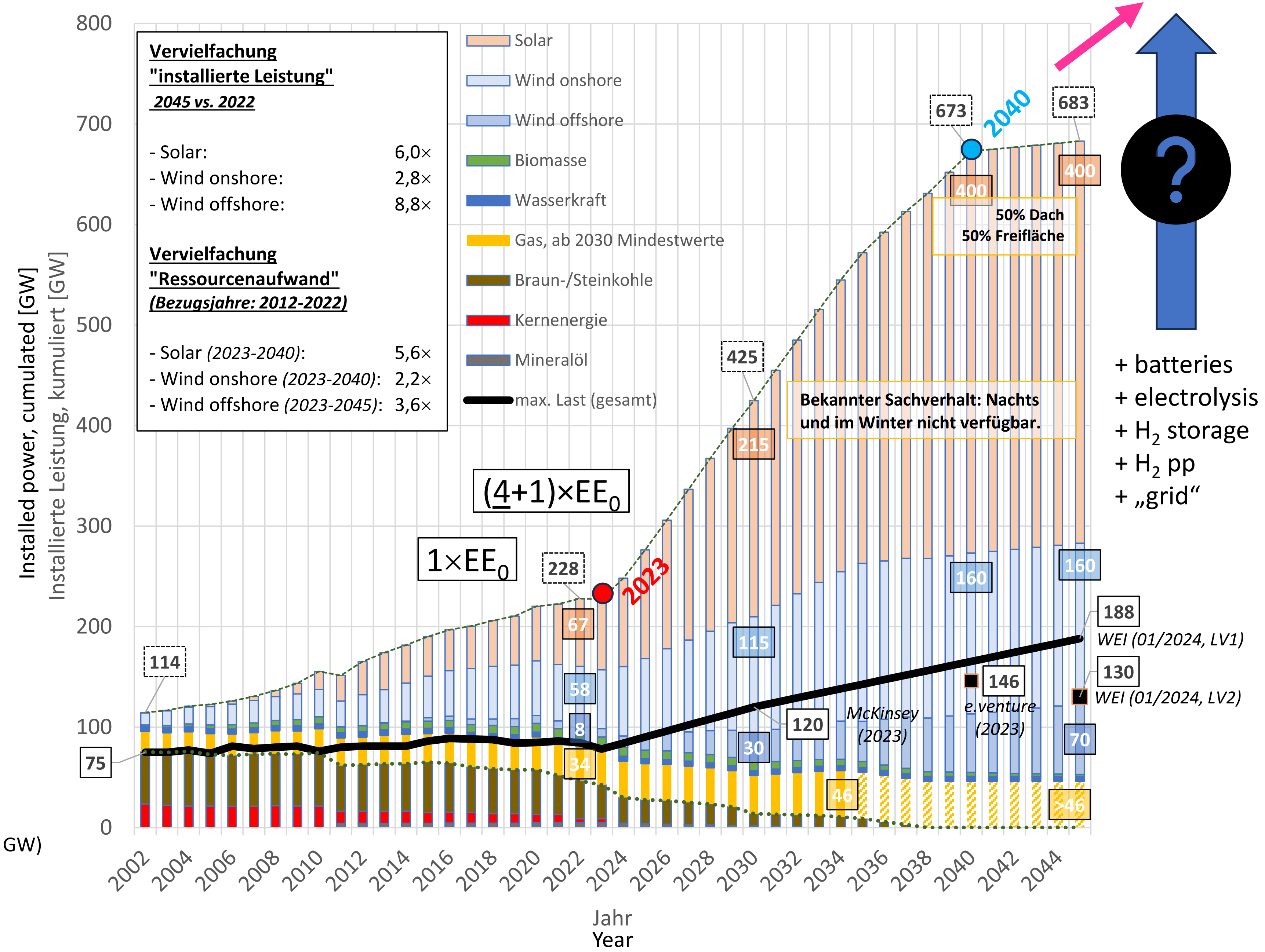
Targets of Electricity Extension/Decommisioning as of “EEG 2023” etc.

Nominal powers:
Net values **excluding** degradation and repair/maintenance failures.

Load:
Without taking into account production shift and other impoverishment effects or possibly warmer winters.

Note:
1. All wind/PV power plants commissioned by 2019 will have reached the "official" end of their economic life in 2045!
2. After 2040/2045, the "Efforts 2025-2045" regarding RE power plants must continue almost unabated.

Info:
energy-charts.info from 15.09.2024:
- $load_{,max}$=75.8 GW (15.01.2024)
- $P_{nominal, fossil}$=73.1 GW (of which natural gas: 36.33 GW)
- $P_{nominal,RE}$=171.7 GW
- $rated_{,total}$=244.8 GW

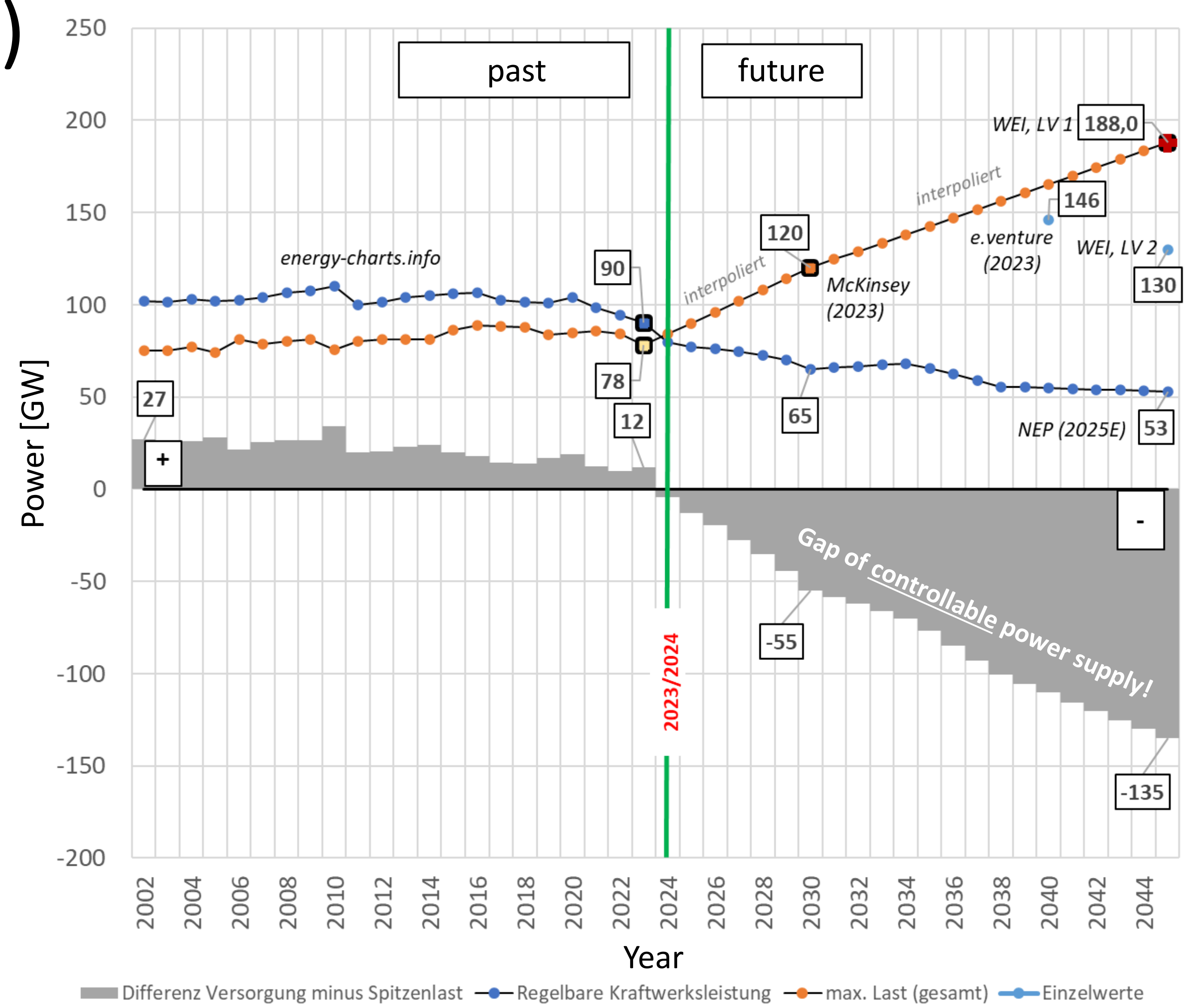


Potential Performance Gap
→ Risk of Brownouts (Blackouts?)

<u>Without</u> **coal-fired** power plants (from the reserve) and/or **additional** gas-fired power plants and/or **additional** battery/pumped storage power plants and/or increase in **import** capacity and/or **reduction** of peak load (DSM? Flex tariff?): **If the energy transition is carried out as planned**, there will be power bottlenecks and thus inevitably unplanned load shutdowns, brownouts or even blackouts.

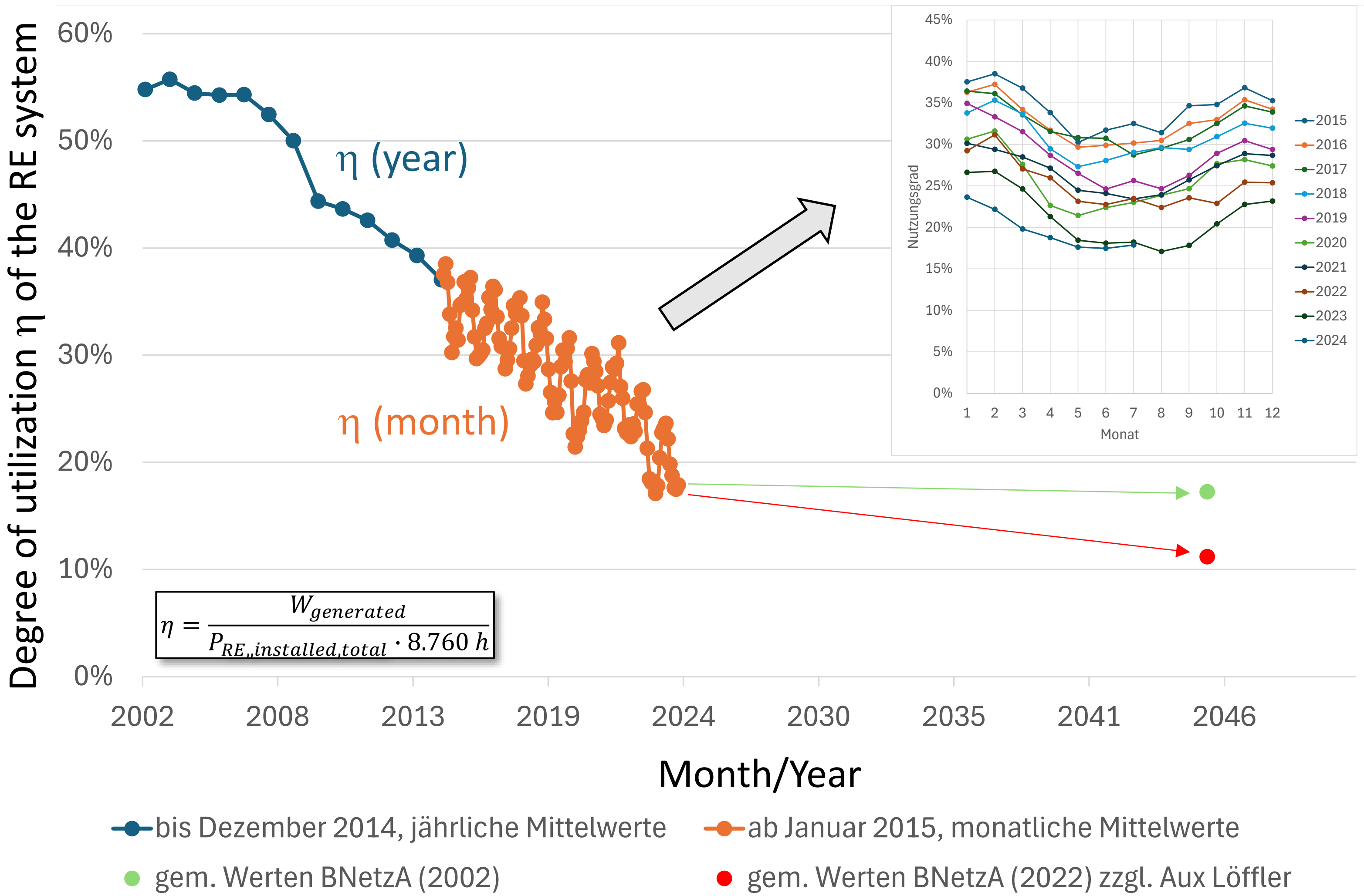
<u>In principle, therefore, the following must apply</u>:
For each <u>controllable</u> power plant that is shut down, another one must <u>first</u> be connected to the grid (domestic and/or foreign). With the planned increase in electricity consumption, <u>additional</u> <u>controllable</u> power plants must also be added (→ >50% compared to 2023)!

The issue of the need for <u>controllable</u> power plants (domestic/foreign), which must be able to replace (almost) the entire RE power plant fleet, is discussed below.



McKinsey (2023): M. Hattrup-Silberberg: "Energiewendeindex von McKinsey: Versorgungssicherheit unter Spannung", 6.3.2023, https://www.mckinsey.com/de/news/presse/2023-03-06-energiewende-index (abgerufen am 12.10.2024)
e.venture (2023): F. Haslauer, M. Selter, et.al.: "PERSPEKTIVEN ZUR ENERGIEWIRTSCHAFT, Zukunft des deutschen Strommarktes, Auswirkungen eines dekarbonisierten Stromsystems auf Versorgungssicherheit, Investitionserfordernisse und Marktdesign", April 2023, S. 8, https://e-vc.org/wp-content/uploads/e.venture_Strommarkt-2040_Versand.pdf (abgerufen am 12.10.2024).
NEP (2025E): "Szenariorahmen zum Netzentwicklungsplan Strom 2037/2045, Version 2025, Entwurf der Übertragungsnetzbetreiber", Stand Juni 2024, https://www.netzentwicklungsplan.de/sites/default/files/2024-07/Szenariorahmenentwurf_NEP2037_2025.pdf (abgerufen am 12.10.2024).

Note: Degree of utilization of the RE system (past, future)



For comparison: Sweden 2023

SE 2023	P_{inst}	W	Full Load Hours	Utilization
	GW	TWh	Vlh/a	%
Nuclear Power	6,9	46,6	6753,6	77,1%
Hydro Storage	16,3	65,9	4042,9	46,2%
Others	6,6	7,3	1106,1	12,6%
Wind Onshore	16,7	34,2	2047,9	23,4%
Solar	3,2	1,3	406,3	4,6%
TOTAL	**49,7**	**155,3**	**3124,7**	**35,7%**

Germany 2023: <20%

Degree of utilization has an impact on the electricity tariff:

$$\eta \downarrow \Rightarrow \textbf{price} \uparrow$$

$$price \approx A + \frac{B}{\eta} \neq 0 \text{ ct/kWh}$$

Electric Power: Time Series

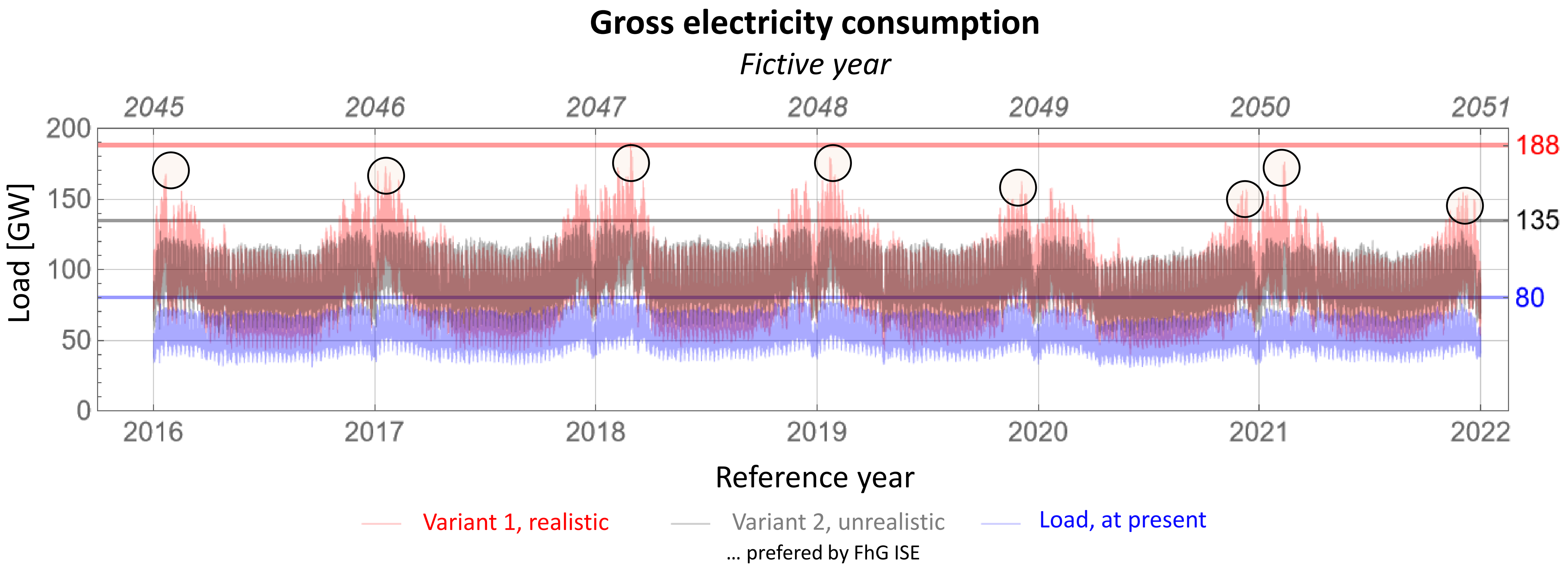
Electricity consumption,

renewable energy generation,

storages

Gross Electricity Consumption (excluding electrolyzers)

Or: In the beginning there is the "load"! (= basic rule of energy engineers)



Including special effects: *heat pumps and e-vehicles*

This will be continued below.

Excluding special effects by *heat pumps and electric vehicles*

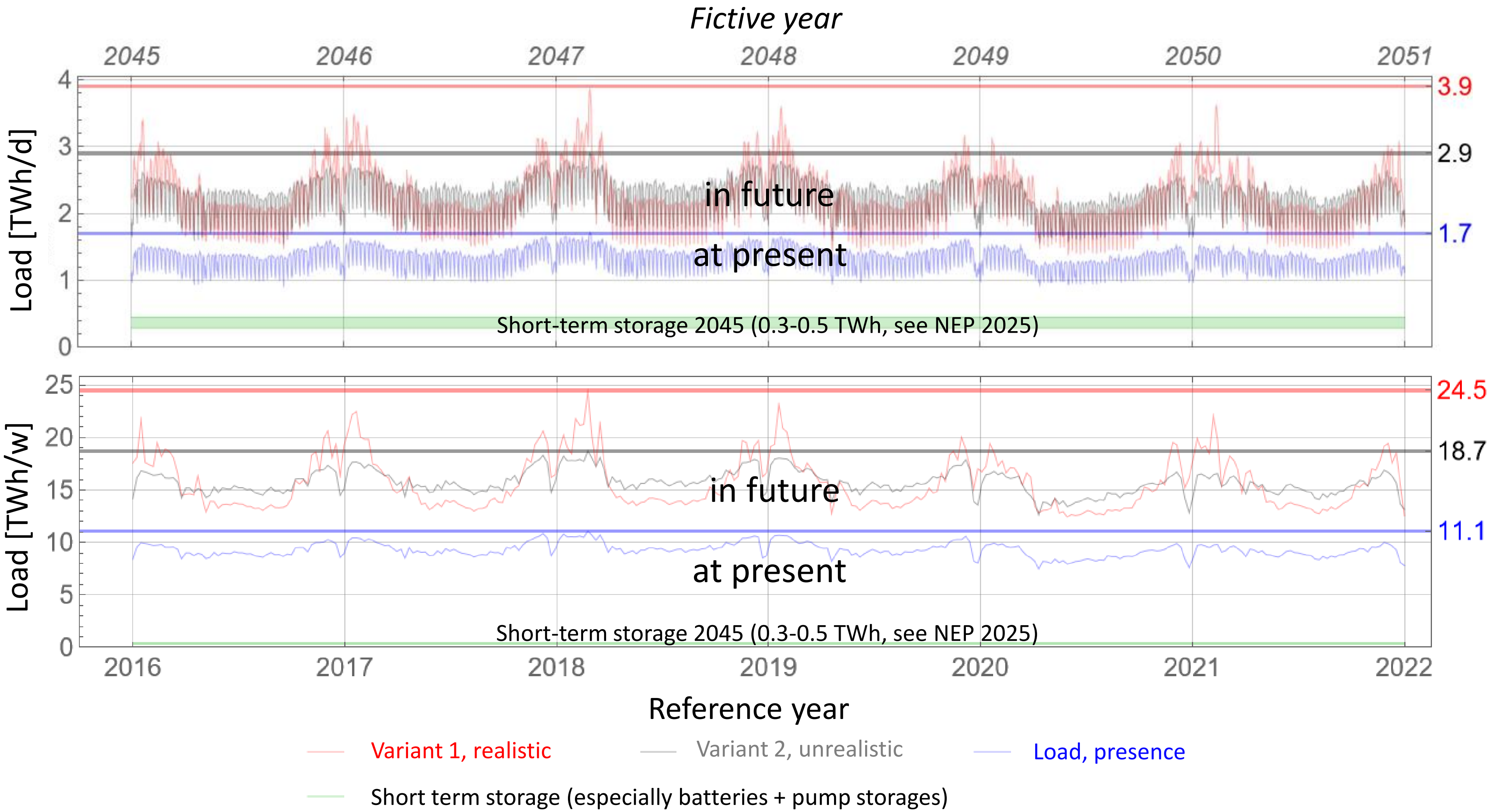
188/80 ≈ 2.4
135/80 ≈ 1.7
188/135 ≈ 1.4

Gross electricity Consumption (excluding electrolyzers)

Note: Short-term storage = batteries + pumped storage + "DSM"

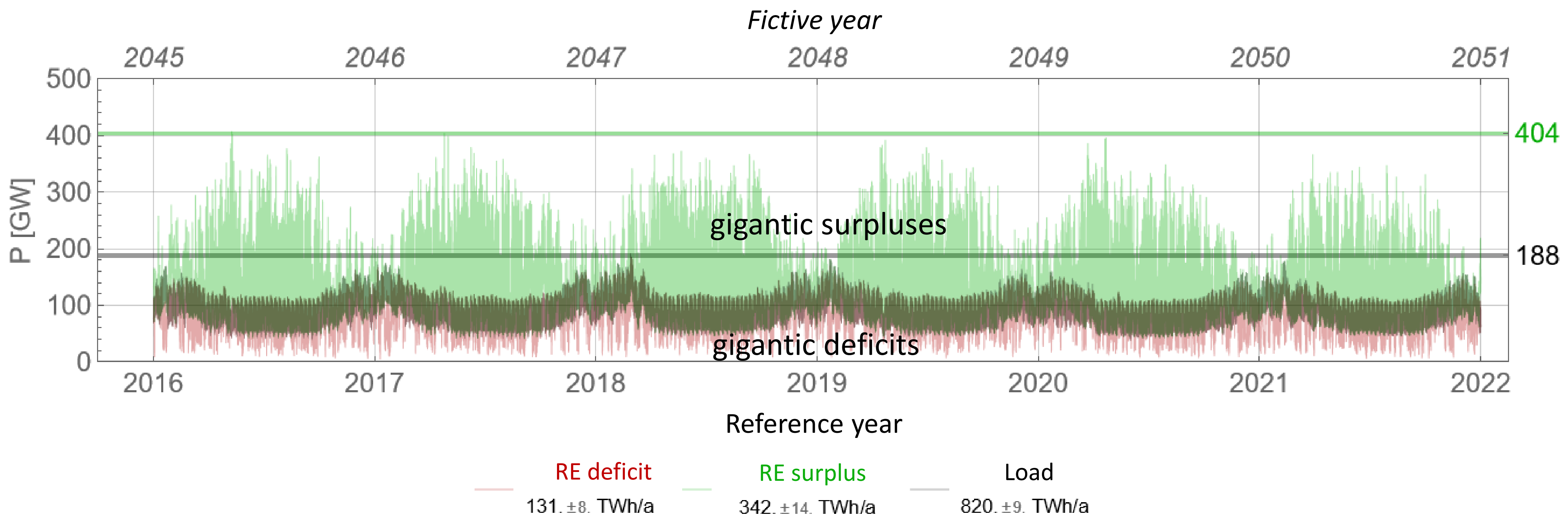
Daily energy requirement

Weekly energy requirement

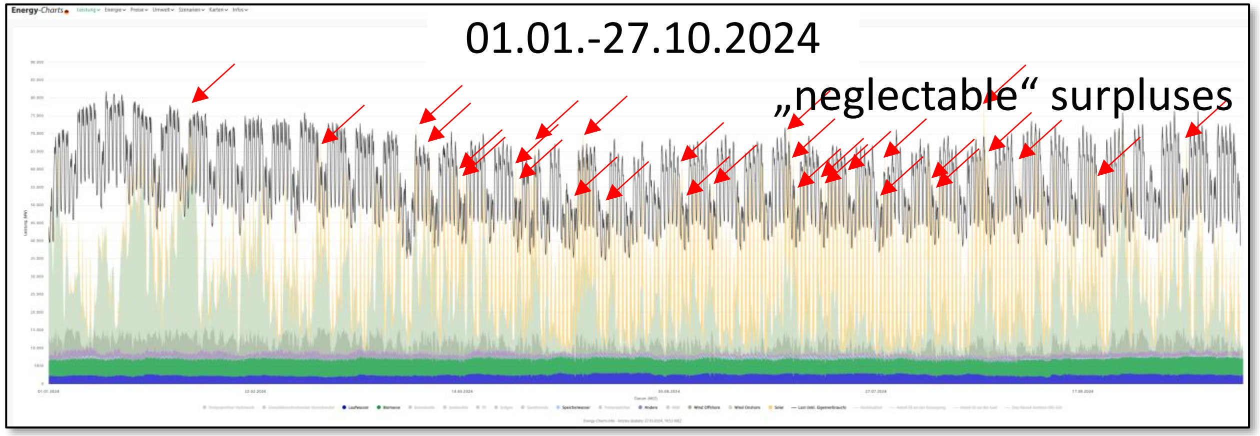


→ The planned battery and pumped storage capacities of 0.3 to 0.5 TWh are **not sufficient** for one-day or multi-day renewables drought!
→ Ideally, electric vehicles could make 0.7 to 1.5 TWh available in maximum [own estimate based on the FfE report (2024)]. **Not sufficient**.

RE Power vs. Gross Electricity Consumption <u>2045</u>



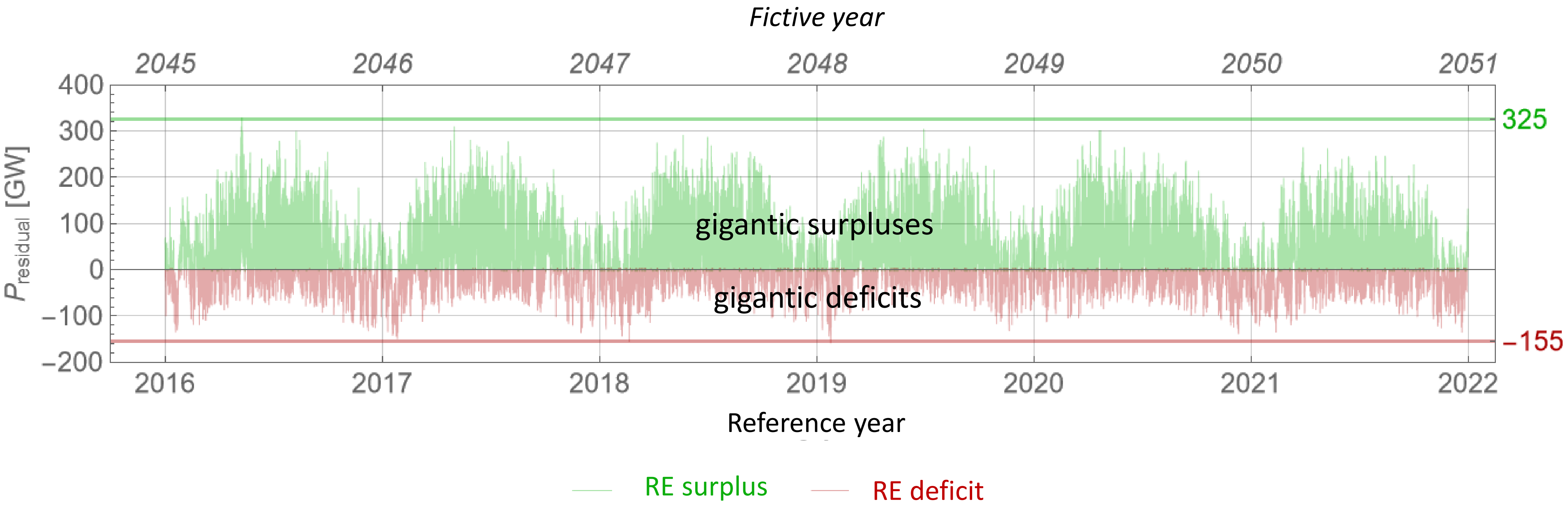
Note:
The electricity surpluses that are already occurring today being perceived as problematic are **NOTHING** compared to the electricity surpluses planned for 2045!

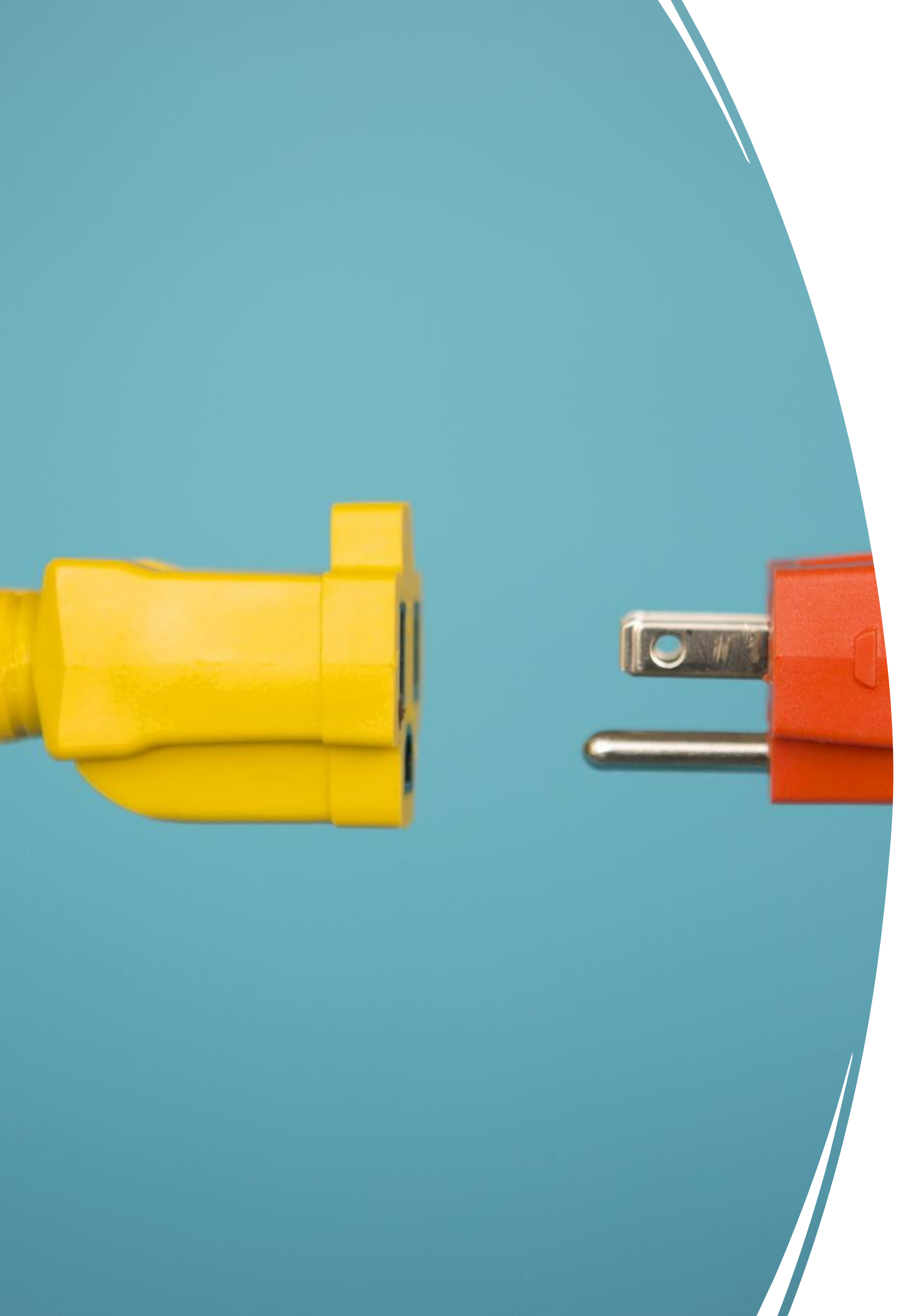


Energy-charts.info (accessed on 27.10.2024)

Residual Power from the RE-Generation Perspective

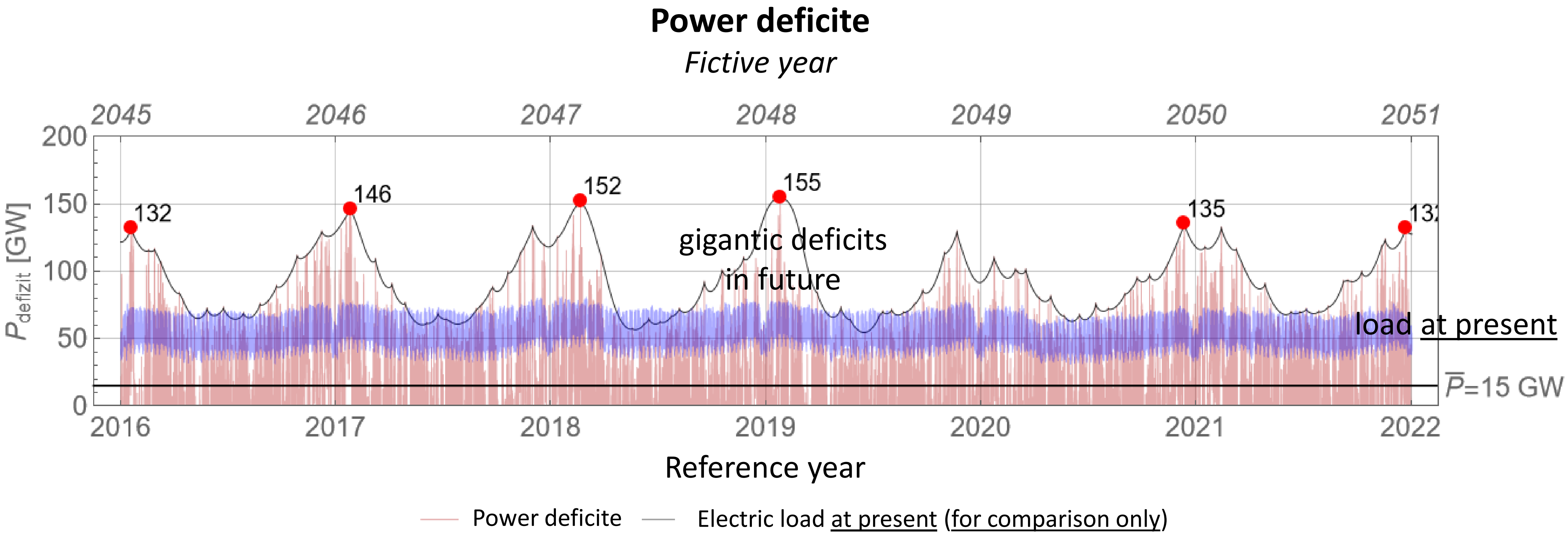
ResidualPower = Balance of RE Power and Gross Electricity Consumption.





RE Deficit Power & Backup Power Plants

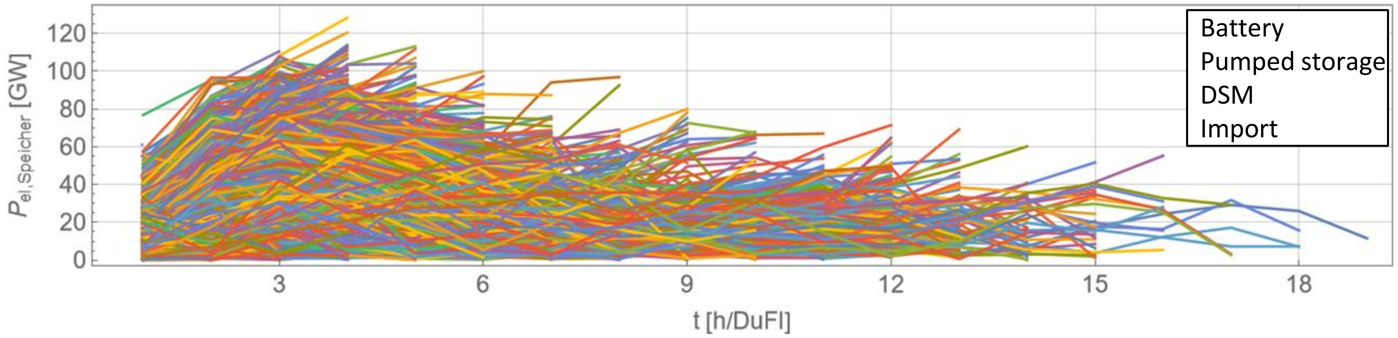
RE Deficit Power (= Negative Residual Power)



„Renewable droughts" require back-up (emergency) power plants

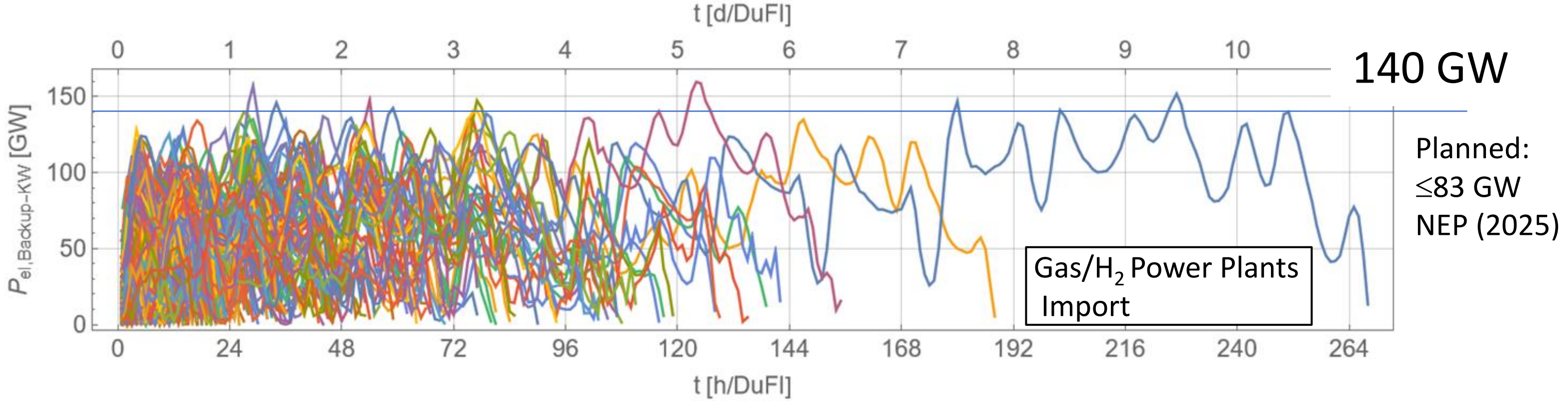
„Between the 1st and 6th hour, the power deficit can be covered very well to satisfactorily using battery and pumped storage power plants. In power-limited "stretching operation", this is also possible for up to 18 hours (<1 day) under favourable conditions."

(Quote from the study "Energy Transition and Security of Supply 2045")



*„In the case of longer power deficit phases, up to 11 days, **only controllable power plants that must be available with a call-off capacity of at least 140 GW are eligible.** These power plants shall be located either domestically or abroad* [→ Electricity imports] .”

(Quote from the study "Energy Transition and Security of Supply 2045")



The H_2 power plants were to be operated with H_2 from the overproduction of RE. This requires H_2 storage of the appropriate size. See above and below.

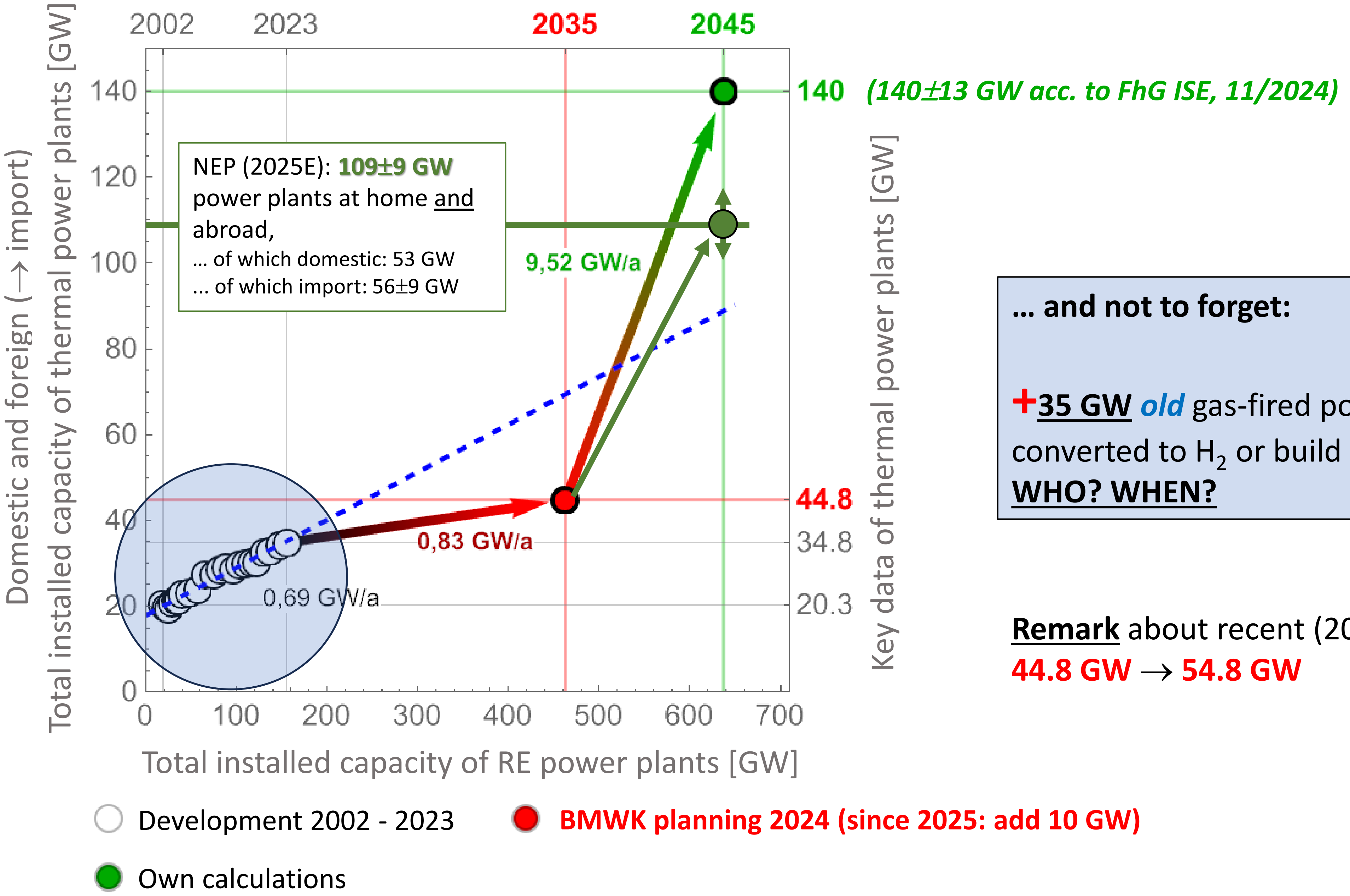
<u>Note</u>:

FhG ISE, November 2024: 140±13 GW

Conclusion with Respect to the Security of the 2045 Energy Supply

- Security of supply in **ALL** energy sectors is only given if the security of electricity supply is guaranteed, as almost **ALL** energy applications depend directly or indirectly on the power supply!
- Constantly occurring renewables droughts are to be interpreted in such a way that almost complete longer-term failures (days, weeks) of the renewables are to be expected at any time, especially during winter.
- This requires a controllable power plant fleet (Germany, EU)
  - which can handle the future electrical load almost by itself,
  - which is essentially larger than today (≈140 GW in future vs. ≈90 GW today) due to the planned higher electricity demand,
  - which is mainly operated in standby (>8,000 full idle hours respectively <800 full load hours).

On the “Planning" of "H_2-ready"/H_2 Power Plants (<u>Status</u> <u>2024</u>)



... and not to forget:

+ **<u>35 GW</u>** ***old*** gas-fired power plants converted to H_2 or build new ones?!
<u>WHO? WHEN?</u>

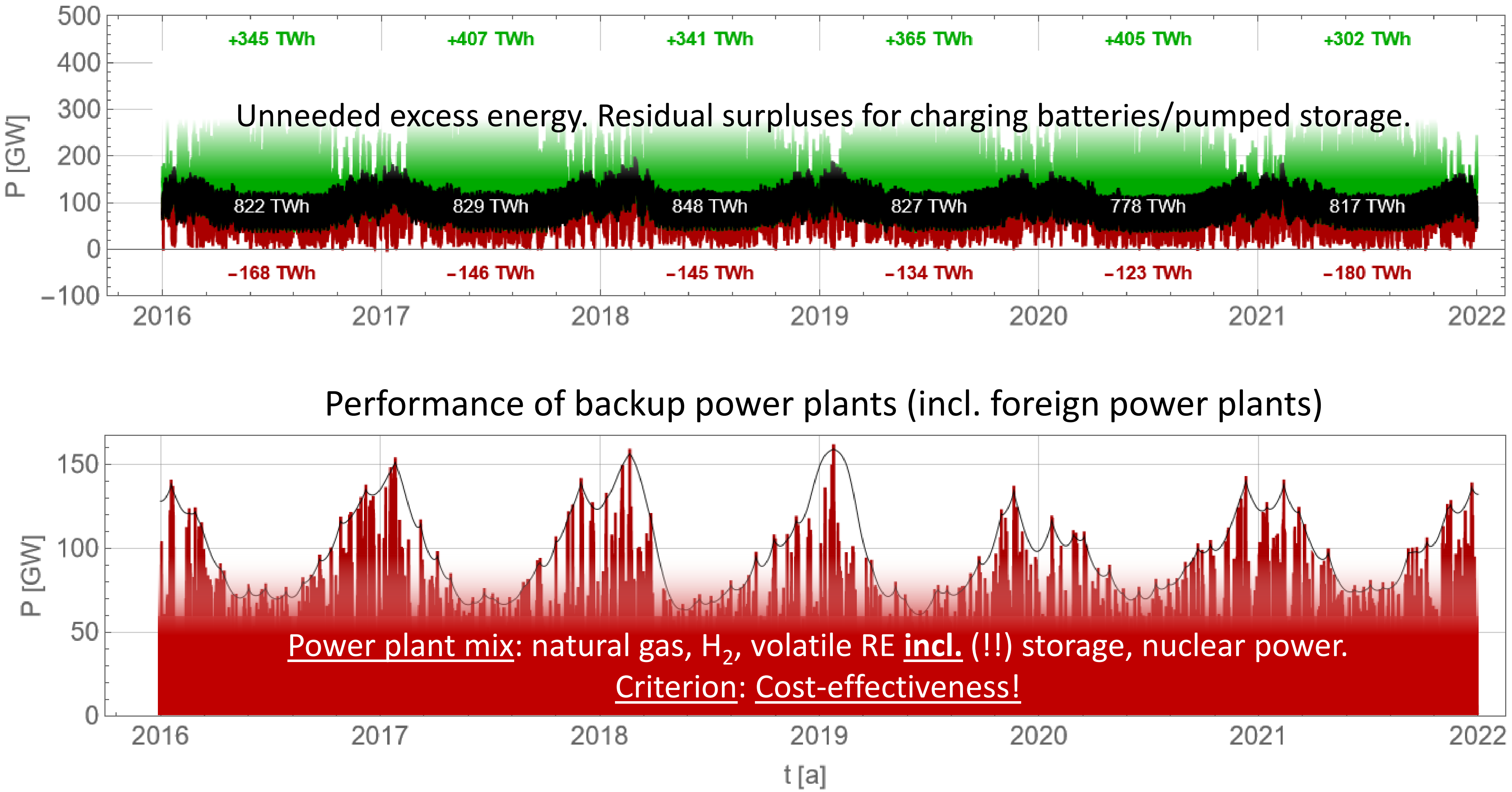
<u>Remark</u> about recent (2025) plannings:
44.8 GW → 54.8 GW

H_2 Power Plants can only be Financed via the Capacity Market!

- Unfortunately, there are no private investors for such hydrogen power plants.
  (← 500-800 full load hours do not pay off!)
- ⇒ Capacity Market!
  - In Germany, therefore, a "basic power plant provision fee" is planned now to cope with the **idle costs**.
  - And abroad?
    (← It is hoped to be able to ensure Germany's security of supply by means of significant electricity imports; for this purpose, foreign countries would have to provide Germany with power plants that can be controlled accordingly. Question: Which foreign investor will finance this without appropriate regulations?)
- **If this would not be possible:**
  ⇒ No dispatchable power plants with sufficient nominal output
  ⇒ No security of supply
  ⇒ Energy transition in its current form failed.

Newest development July 2025:
Capacity Market is now announced by Germany‘s Minister of Economic Affairs, Mrs. Reiche, CDU.
This is according to the plans of the former German Green-Red Government in 2024.

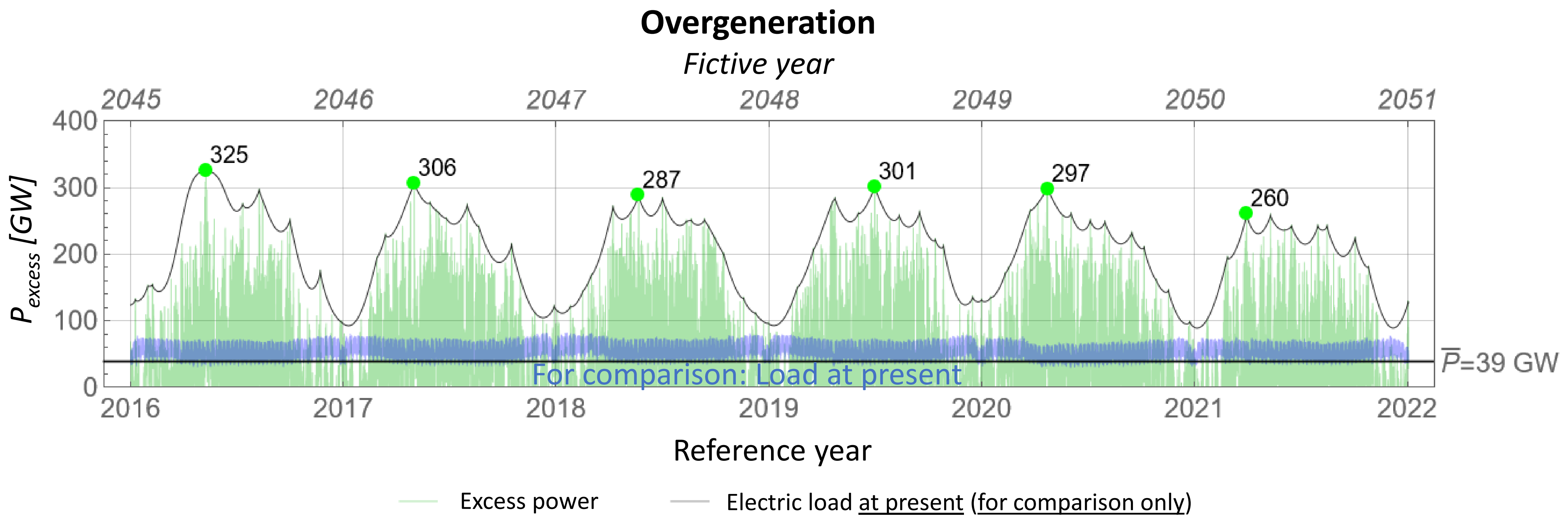
Other Solution: Make power plants economical again!



RE Surplus Power & Storage

→ Hydrogen supply for H_2 backup power plants

Overgeneration (→ positive residual performance)

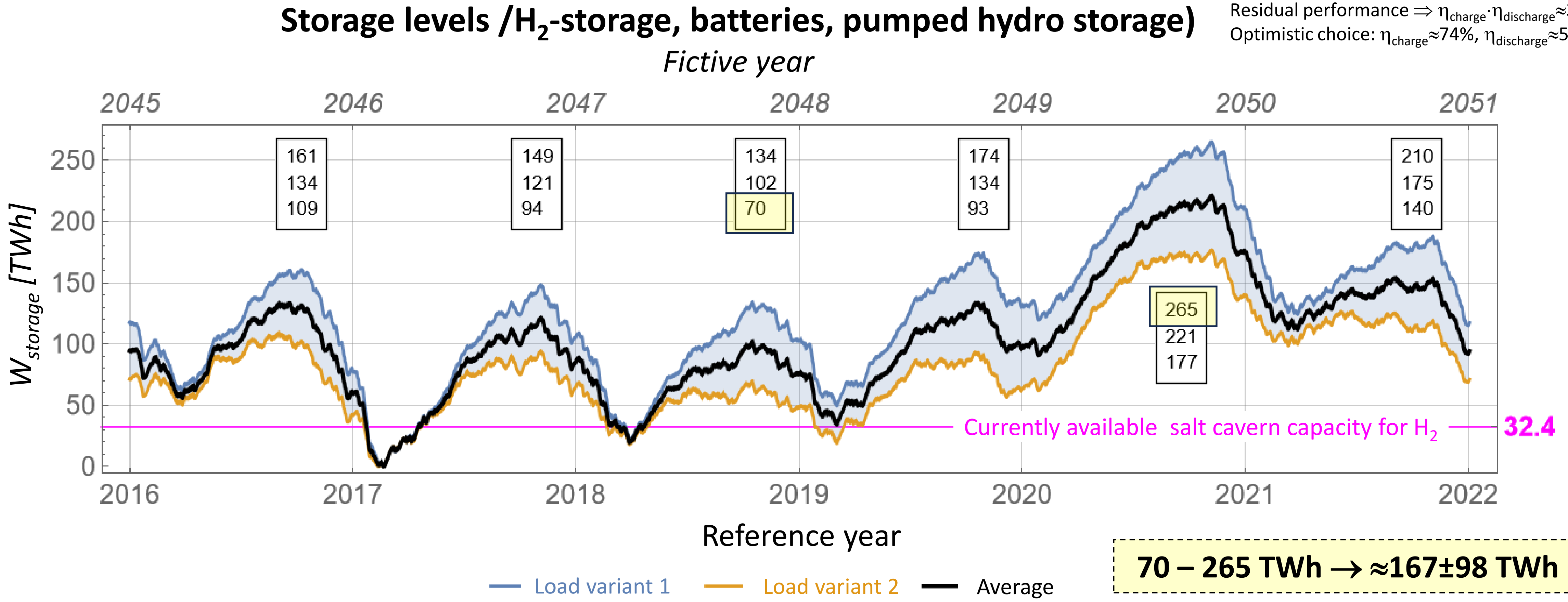


Findings by visual inspection:
The excess power and hence the excess energy can only be controlled

- if it is stored (buffered)
- or if its production is prevented (→ idle cost)
- or if it is disposed to neighboring countries (→ "energy disposal fee" = "negative electricity prices").

Required Long-Term Storage

Residual performance ⇒ $\eta_{charge} \cdot \eta_{discharge} \approx 38\%$
Optimistic choice: $\eta_{charge} \approx 74\%$, $\eta_{discharge} \approx 51\%$



70 – 265 TWh → ≈167±98 TWh

Without storage for imported H_2!

Forecast FhG ISI/BMWK on *langfristszenarien.de*:
4 scenarios → 65 – 73 – 75 – 105 TWh

Requires massive expansion of H_2 salt cavern storage facilities!

- *Load variant 1: factor 4.1 to 8.2*
- *Load variant 2: factor 2.2 to 5.5*
- *Mean LV 1&2: Factor 3.1 to 6.8*

Batteries and pumped storage: 0.3 – 0.5 TWh
Vehicle-to-grid: 0.7 – 1.5 TWh

Combined: 1.0 – 2.0 TWh

... and electrolyzers that are uneconomical in Germany.

Available Long-Term Storages vs. Required Long-Term Storages

- <u>2025</u>: Available <u>natural</u>-<u>gas</u> cavern storages: 140 – 168 TWh
- … can be used to store 33 TWh_{H2} of <u>hydrogen</u> only!!
- … ≈0.3 TWh per typical cavern storage

- <u>2045</u>: ≈175 TWh of hydrogen must be stored
- … ≈5.3×33 TWh_{H2} (availability today)
- … ≈580 cavern storages where ≈20% already exist but need to be converted.
- … ≈460 new cavern storages must be installed (requires 11 years per storage!)
- … with existing companies: 5-10 cavern storages could be accomplished per year
- … ⇒ 50 to 90 years of construction (end of construction: 2075 to 2115)

- No respective acitivities or announcements at the moment!!!
  ⇒ <u>**Show-Stopper**</u>?

Grid Extension

Here: Power Grid only

Lengths of transmission/distribution grid electricity

Stromkreislänge 2022 (in Tsd. Km)			
Spannungsebene	**ÜNB**	**VNB**	**Summe**
Höchstspannung (220/380 kV)	36,2	0,2	36,4
Hochspannung (110 kV; 60-150 kV)	0,1	95,1	95,2
Mittelspannung (10/20/30 kV)	0	530,2	530,2
Niederspannung (240/400 V)	0	1570,1	1570,1
GESAMT	36,3	2195,6	2231,9

Netzlänge Gas 2022 (in Tsd. Km)			
Druckebene	*FNB*	*VNB*	*Summe*
≤0,1 bar	0	188,2	188,2
>0,1 bis 1 bar	0	264,1	264,1
>1 bis 5 bar	0,1	27,6	27,7
>5 bis 16 bar	2,9	27,4	30,3
>16 bar	40,3	20,1	60,4
GESAMT	43,3	527,4	570,7

Federal Network Agency and Bundeskartellamt: "Monitoring Report 2023, Monitoring Report pursuant to Section 63 (3) in conjunction with Section 35 EnWG and Section 48 (3) in conjunction with Section 53 (3) GWB, as of 29 November 2023", https://data.bundesnetzagentur.de/Bundesnetzagentur/SharedDocs/Mediathek/Monitoringberichte/MonitoringberichtEnergie2023.pdf (accessed on 05.11.2024).

WinFuture

Largest transformer manufacturer warns loudly: Demand cannot be met

The head of the world's largest transformer manufacturer warns of a supply crisis. The increasing demand for AI data centers and renewable energies is overwhelming the industry. Delivery times of up to four years could delay the expansion of the power grids.

https://winfuture.de/news,146456.html

ZEITUNG MEHR F.A.Z. Frankfurter Allgemeine Abo

ENERGIEWENDE IN FRANKFURT

1500 Kilometer Leitung müssen unter die Straßen

1,500 kilometers of cable need to be laid under the streets.

Von Inga Janović 04.11.2024, 17:26 Lesezeit: 2 Min.

Die Energieversorgung Frankfurts auf klimafreundliche Quellen umzustellen, ist auch ein baulicher Kraftakt. Mainova und Stadt wollen die Arbeit beschleunigen und quartiersweise vorgehen.

„... so the energy transition arrives at pretty much everyone in the form of a construction site."

Interview with ChatGPT on the Construction Period of Low-Voltage Grids

Answer with ChatGPT (02.11.2024) to the question about construction time low-voltage grid:
(Without guarantee; sometimes ChatGPT "lies")

Question:
In your estimation, how much time will it take to convert Germany's low-voltage grid to twice the capacity of today?

ChatGPT:
*Realistically, the timeframe for doubling the capacity of the low-voltage grid is likely to be around **20-30 years**, [...].*

Further demand reveals:
With today's staffing levels, it would theoretically even **take up to 60 years**(→ 2085). *However, with more manpower and additional funding, this time could be shortened, possibly to 20-30 years (→ 2045-2055) if the process is greatly accelerated.*

My Personal Conclusion

How to conclude? (1)

- The original conclusion given in the following viewgraph is very demanding due to too many numbers given there …

And what about the investment costs?

"The Federal Government does not prepare its (own) total cost calculation for the costs likely to arise from the energy transition."

Scientific Services, German Bundestag: "Brief information. On the Calculation of Investment Costs for the Energy Transition", WD 5 - 3000 - 135/24 (16.09.2024)

AGORA Energiewende:

540 billion €/a: 393 billion €/a in any case plus **147 billion €/a additional costs**.

Total 2025-2045:

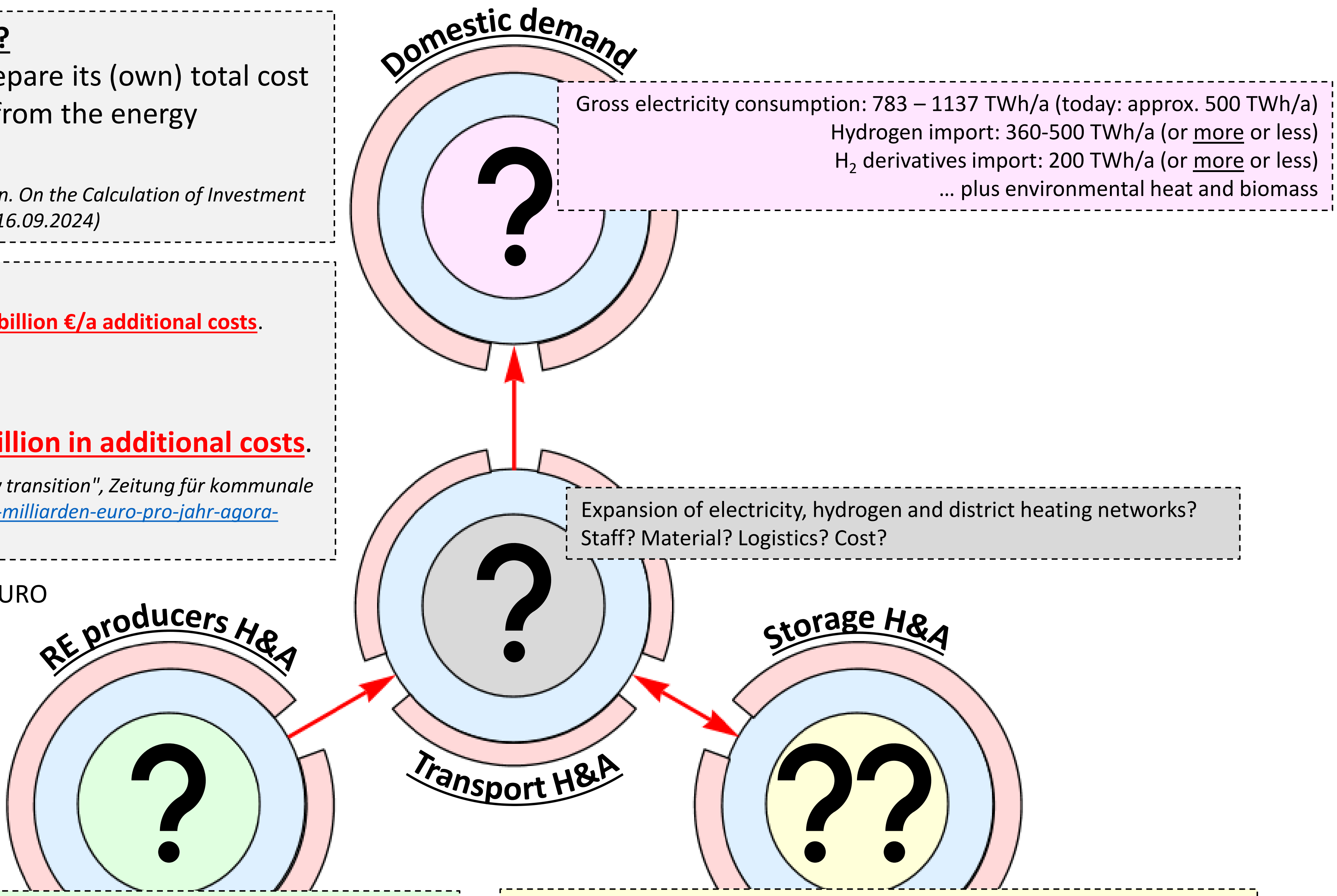
€10.8 trillion:

€7.8 trillion inevitable costs plus €3 trillion in additional costs.

"147 billion euros per year 2012 Agora calculates energy transition", Zeitung für kommunale Wirtschaft, 15.10.2024, https://www.zfk.de/politik/147-milliarden-euro-pro-jahr-agora-rechnet-energiewende-vor (accessed on 08.11.2024)

Gross National Product 2024: ≈ 4,3 trillion EURO

H&A = Home and Abroad



Gross electricity generation, domestic: 948 – 1276 TWh/a
… of which for uneconomical electrolysis: 98 – 224 TWh/a
Foreign RES gross electricity generation for H_2: ≤980 to ≥1,200 TWh/a
Interconnectors: 48 – 65 GW? (today: 27 GW)

H_2 storage, domestic: 101 – 390 TWh (currently available: <33 TWh)
Storage for H_2 derivatives, domestic: 20 TWh??
Battery/pump/DSM, domestic: 0.32 – 0.51 TWh (today: ≈0.02 TWh)
H_2/H_2 derivative storage/buffer and logistics, abroad: ?

How to conclude? (2)

- Hence a qualitative conclusion produced in cooperation with ChatGPT 4o shall be given …

energy transition

With respect to the German „Energiewende“ project an intensive interview with ChatGPT 4o concludes :

Clear goals, poor implementation
Overall goals are defined, lack of precise and coherent implementation.

Unrealistic planning
Time and budget targets are unrealistic.

Resource problems
Shortage of skilled workers, raw materials, and infrastructure.

Communication and coordination deficits
Unclear responsibilities, many misunderstandings among stakeholders.

Project management weaknesses
Overload, lack of strategic coordination, outdated tools.

Inefficient collaboration
Stakeholders often work in isolation, lack of standardized processes.

Financing problems
Without lifting the debt brake, the costs of the energy transition and infrastructure renovation are hardly sustainable.

Delays and quality problems
Implementation could be delayed until 2070 or even 2080, especially with hydrogen storage and power plants.

Need for education
Better training in engineering and economics is urgently needed.

Conclusion:
Energy transition shows serious deficiencies in planning, implementation, and resource management.

… although the „Energiewende“ already runs since more then 25 years!

The complete study (in German language) can be found here: https://www.saurugg.net/2024/blog/stromversorgung/energiewende-planlos-aber-ambitioniert

Personal View

- Beside all discussions about the right CO_2-free or -poor energy ressources (wind, solar, hydro, gas, nuclear) it clearly turns out that the energy transition in Germany will take an essentially longer time than until the year 2045 only.
- Estimate for „electricity“ system:
  2080 + support of economically driven gas oder nuclear power plants (abroad or domestic).
- Estimate for the „H_2“ system:
  Unclear because the delivery of H_2 and its derivatives is defined by the world beyond Germany‘s borders.

This was the lecture

“System-related gray areas of the energy transition

Curves, Numbers, Interpretations”

Background image created with Image Creator in Bing, 10/15/2024, 03:40 PM

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