ANNEX 57

FLEXIBILITY BY IMPLEMENTATION OF HEAT PUMPS IN MULTI_VECTOR ENERGY SYSTEMS AND THERMAL NETWORKS

IEA Heat Pumping Technologies Annex 57

FLEXIBILITY BY IMPLEMENTATION OF HEAT PUMPS IN MULTI_VECTOR ENERGY SYSTEMS AND THERMAL NETWORKS

Country report from Germany

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Introduction

The Federal Climate Change Act (KSG) of Germany has taken effect at 31st of August 2021. Thereby Germany declared its transition and certain targets over time to a green-house gas balanced system until 2045. The transition is essentially developed and accompanied by the long-term scenarios of DENA-Leitstudie [1], Agora - Klimaneutrales Deutschland 2045 [2], the german industry association (BDI) - Klimapfade 2.0 [3], “Langfristszenarien” of Federal Ministry for Economic Affairs and Climate Action (BMWK) [4] and the research within the „Ariadne framework“ [5]. The former Federal Ministry of Economics (BMWi) proposed in the “Dialog Klimaneutrale Wärme 2045” [6] the essential parts for the transition of the heating sector. The total sector emissions of green house gas equivalents (GHG) and its designated reduction path are shown for different sectors in figure 1 [7].

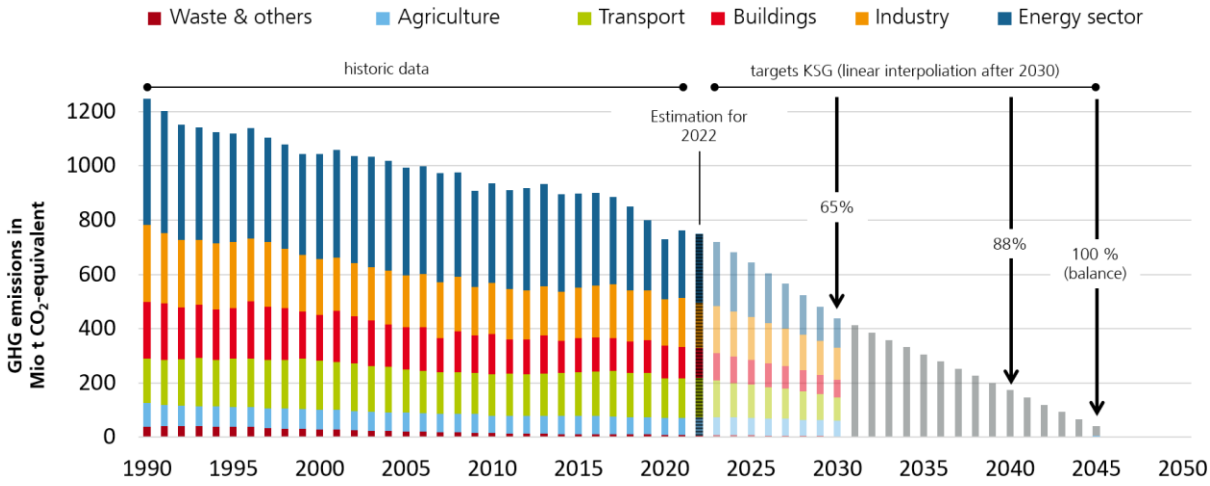

figure 1: Total green-house-gas (GHG) equivalent emissions since the year of 1990 for Germany and it´s reduction path until 2045

1: District heating demand now and in the future

The annual final energy demand supplied by district-heating (DH) systems is estimated based on [8] to 73 TWh/a for so called low-temperature heat. This is covering the residential as well as the trade and commerce sector and does include some 58 TWh/a for residential household supply. Additional 43 TWh/a need to be accounted for process heat in the industrial sector in 2021 [8]. Heat losses of distribution network are to be taken into account that might be estimated to additional 17 TWh, so that in 2021 134 TWh of heat accounting about 10% of total heat production in Germany might be allocated to have been generated in order to be supplied by DHN. The generation is thereby based on natural Gas (46%) and coal (20%) whereas renewables contributed 17% in terms of almost fully supplied by incineration of biomass.

Regarding to a model-based approach accounting a variety of resources more than 1.700 cities and communities where found incorporating DH systems by an annual demand of 67 TWh for space-heating and domestic hot water preparation in the residential as well as the industry sector by operating about 26.700 km of DH network [9]. It is furthermore shown that DH will annually supply 94 TWh in the residential sector in 2045 by means of an increase in quantities of 60% compared to 2020. This means additional quantities to be generated of annually about 1,6 TWh. Regarding energy efficient measures addressing the building physics and performance of its supply and distribution systems the specific heat demand is simultaneously decreasing, so that the number of buildings supplied by DH is to be increased by a factor of about 2 to 3 until 2045. To realize this annually about 130.000 to 150.000 new connection units and further 800 km of transmission line is to be constructed [9] that is about twice as much as currently being accomplished. Furthermore, the need for the industrial sector has to be taken into account as well. Although the infrastructural requirements might be larger considering on site constructions rather than long transportation lines. In another report an amount of about 200 TWh for DH is estimating in 2050 [10]. In this approach the capacity for DH

supply is divided in a fossil free system in about 30 GW to 40 GW of installed centralized large heat pumps and about 13 GW to 27 GW solar-thermal. Peak load is covered by gas based vessel and CHP in a range of 5 GW to 27 GW [11]. The quantities following this system analysis in the residential sector might be divided as shown in figure 2 for different future scenarios regarding social-economic behavior.

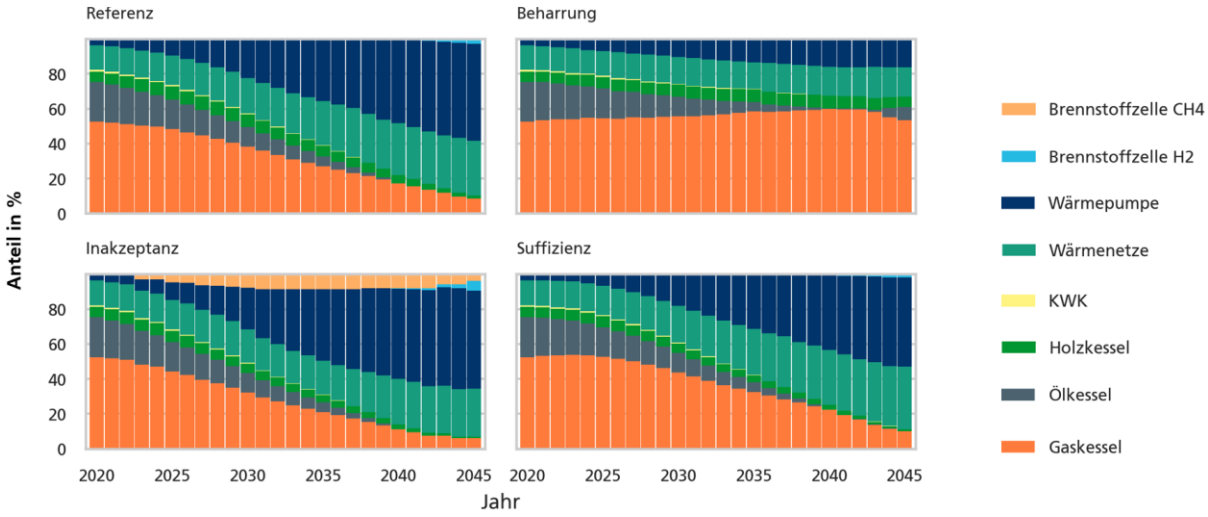

figure 2: Share of heat supply of different technologies in certain considered scenarios. DH is shown in green [11].

Regarding to [9] operation of large heat pumps will supply about 70% of DH related quantities in 2045 that has been developed more in detail in [12]. This means about annually 100 TWh supplied by large heat pumps and additional 10 TWh of electrode boiler connected to DHN in 2045.

2: Electricity demand now and then

The electricity production based on renewable energies is shown in figure 3 regarding [11]. It does align quite well the coalition contract [13] of the current government and the network transformation planning of the German Federal Network Agency [14].

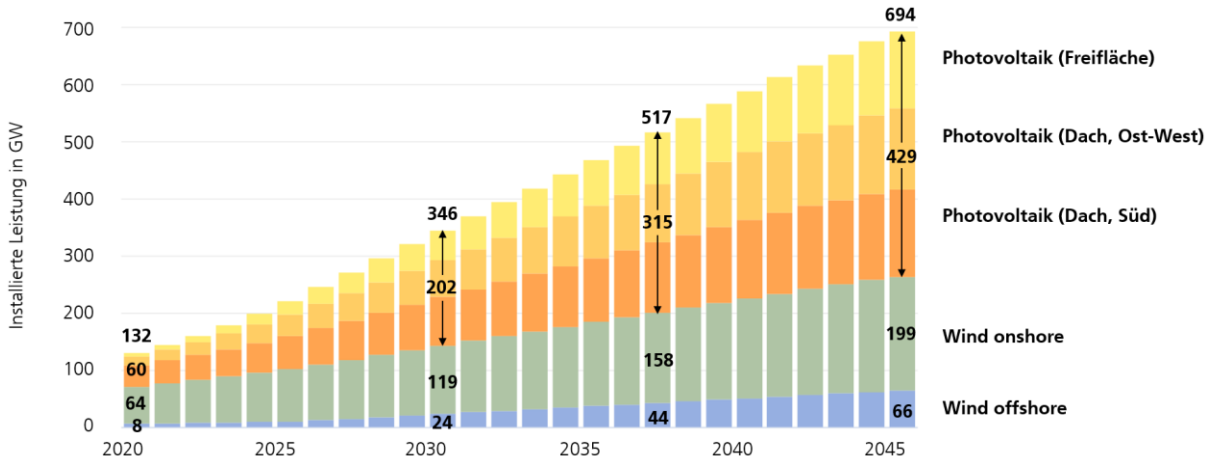

figure 3: Estimated electricity production until 2045 in Germany [11].

The consumption of electric energy is shown regarding to the estimation of different scenarios of [11] in the following figure 4.

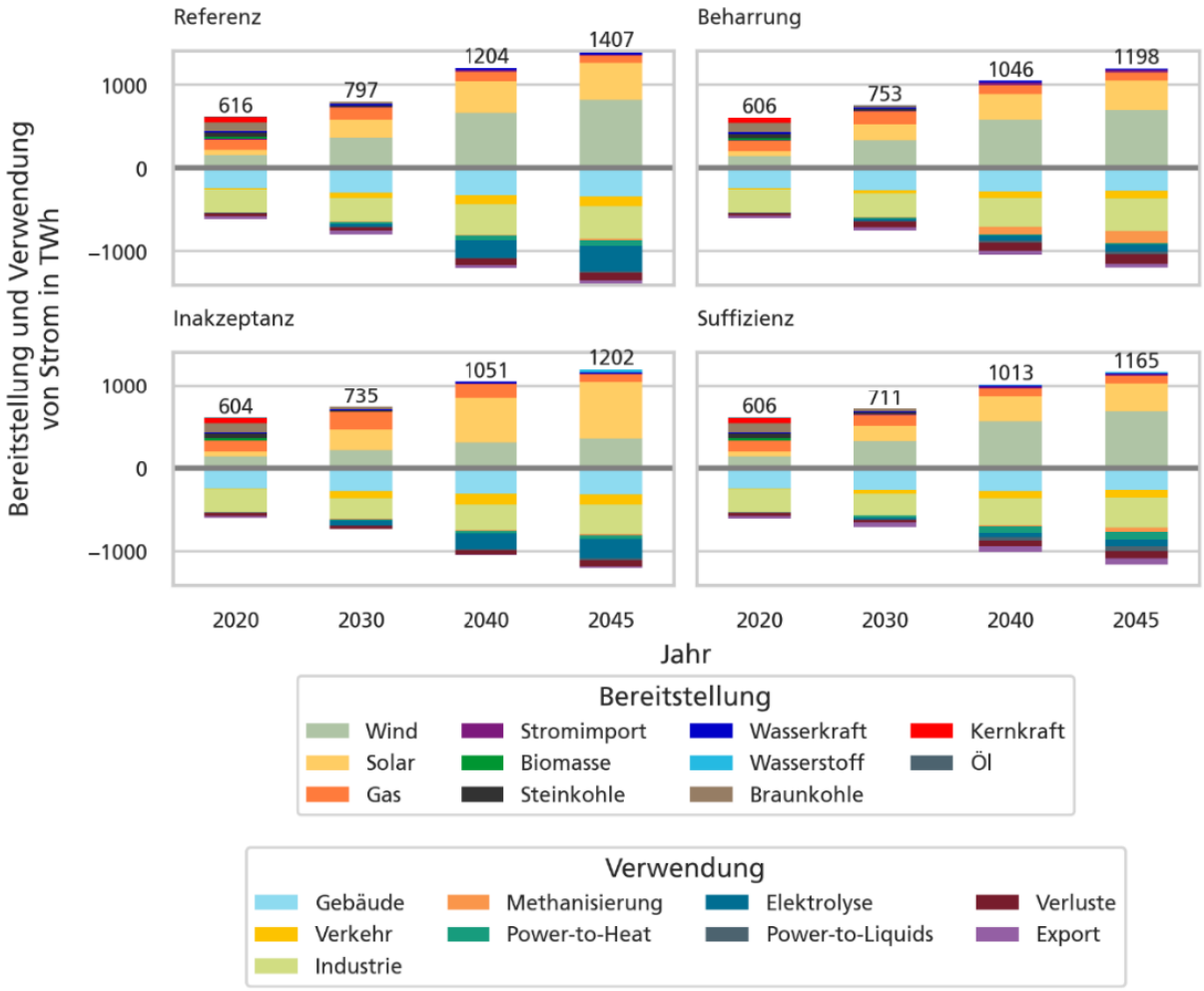

figure 4: Electricity generation and consumption in Germany regarding to [11] in 2045.

It becomes clear that the current electric quantities are approximately doubled to about 1.200 TWh annualy whereas hydrogen is by means of its quantities not supposed to play a significant role in supplying demand in the electricity sector.

3: Perspectives on the power grid

The capacity situation

Considering installed capacity the German Federal Network Agency [15] does take any system connected to the grid into account. A more detailed view regarding the current market development of home storage systems (HSS), large stationary storage systems (LSS), industrial storage systems (ISS) and battery electric vehicle is undertaken in [16]. The current development and its estimated increase is shown in figure 5 regarding to [11] where mobile battery systems are assigned to be used bidirectionally at a share of 10% of the total battery based vehicles. Further more a c-factor between power and capacity (GWh to GW) as assessed to 1.

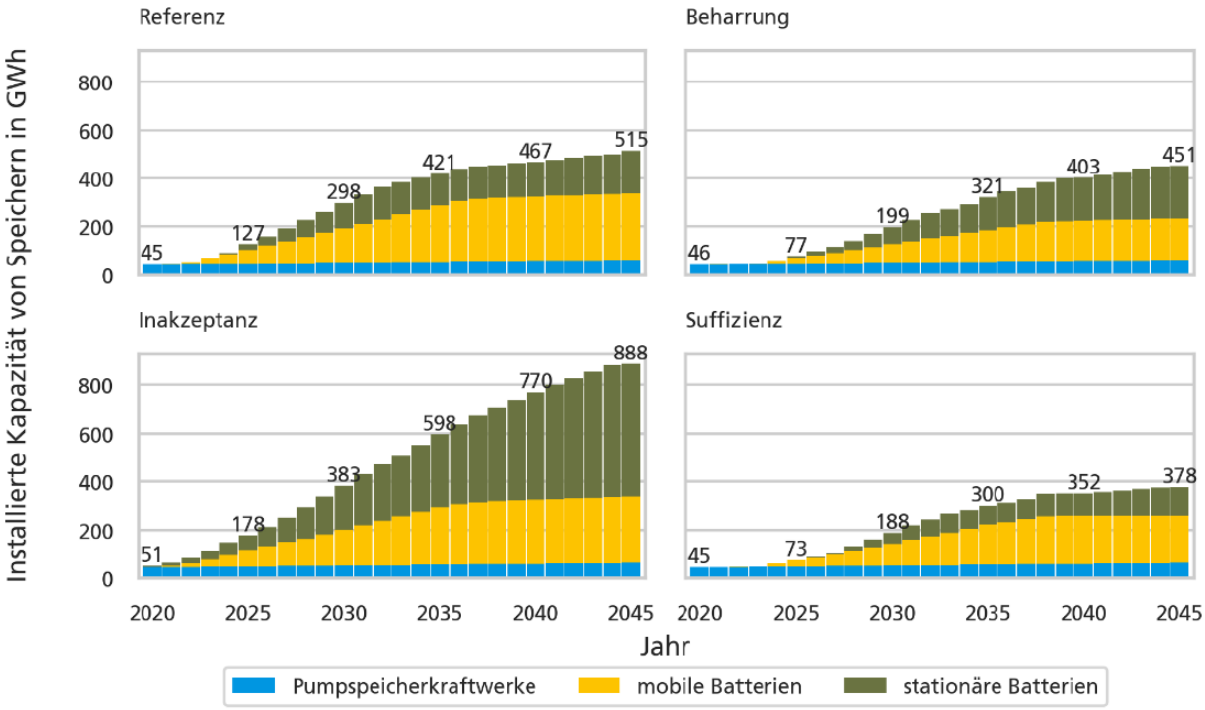

figure 5: Estimated increase of electricity storage capacity for pumped hydro, mobile vehicle and stationary systems for different scenarios [11]

Capacity markets

The current market design in Germany is basically divided into grid operation and power generation and is highly regulated by governmental law. It´s general sectors are shown by the following scheme:

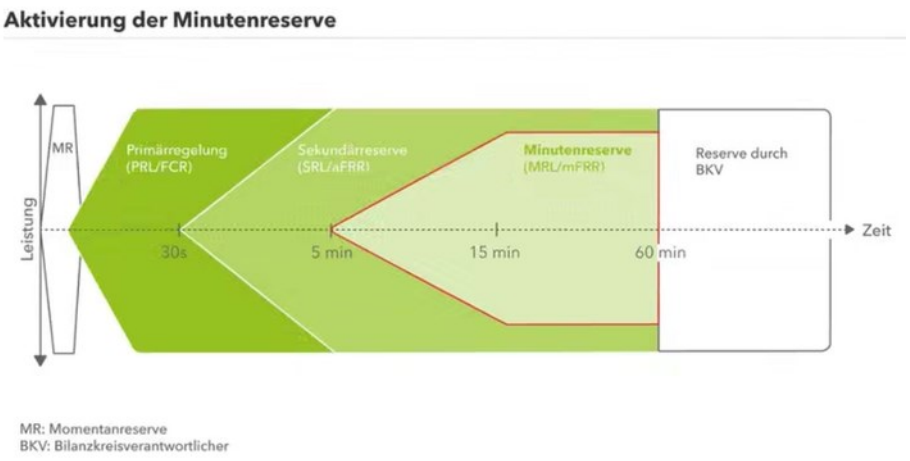

figure 6: Schematic of different regulated electricity grid measures for power supply and grid stability[1]

Some known obstacles to the introduction of new operation and business strategies from a regulatory point of view might be summarized as following:

Dodrer et. al. [17] mentioned and emphasized suggestions for a regulatory transformation with respect to sector coupling technologies. These are probably valid for several European countries, but as they were originally intended for Germany, they are summarized here again:

[1] https://www.next-kraftwerke.de/wissen/minutenreserve-tertiaerregelung

- Reduction of grid charges: Currently, batteries and Power-to-Gas plants connected to a grid do not have to pay grid charges. A suggestion is to include all kinds of coupling points, e.g. heat pumps.
- Reduction of EEG levy: A reduction of the EEG levy is proposed. This could be an incentive for new sector coupling technologies.
- Reduced costs for flexibility providing plants: If a coupling point is able to provide flexibility for the connected grid, costs, e.g. grid charges, could be reduced.
- Unified framework for electricity tax reduction: It is mentioned that some devices have the possibility to pay a reduced electricity tax. One example are batteries, which only have to pay taxes as long as they are discharged. It is suggested to unify these different regulations in order to provide fair conditions for all types of coupling points.

4: energy markets

Prices of energy

In the following charts the composition for the price of electricity is shown for a typically private household [18]. It becomes clear that taxes and cost allocation takes about 50%. Sales takes about 24% and grid charges including metering covers the other 25%. In the reference a specific price of 0.32 €/kWh is shown for an costumer of a private household with an annual consumption of 3.500 kWh.

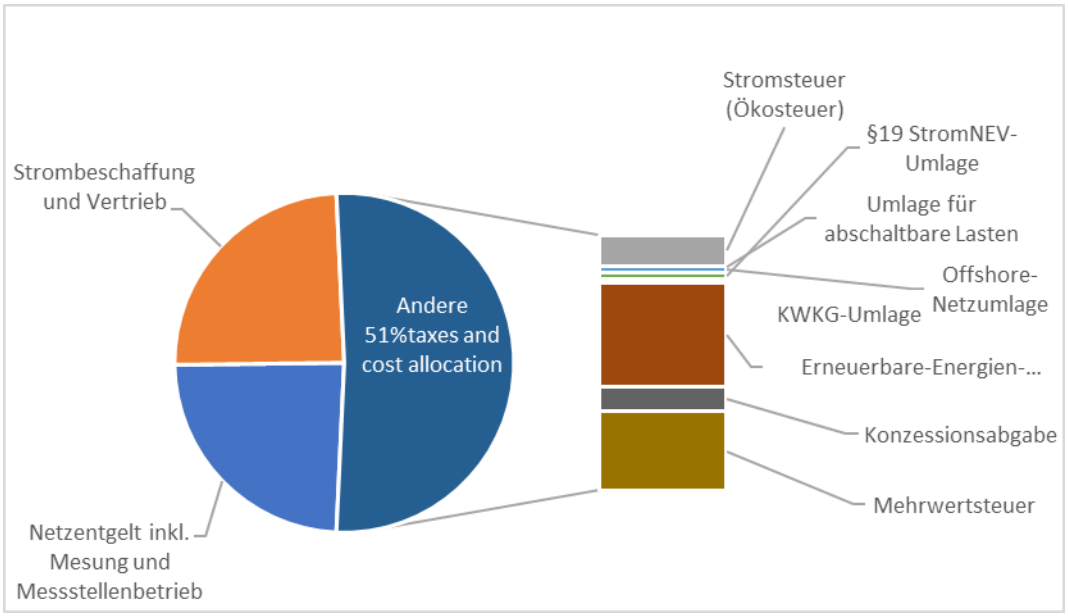

figure 7: Composition of price for electricity in private house holds in Germany in 2022

In contrary gas prices are composed as shown in the following chart regarding to [18] as well. The reference household with a consumption of annually 20 MWh is calculated to a specific fuel cost of 0.07 €/kWh.

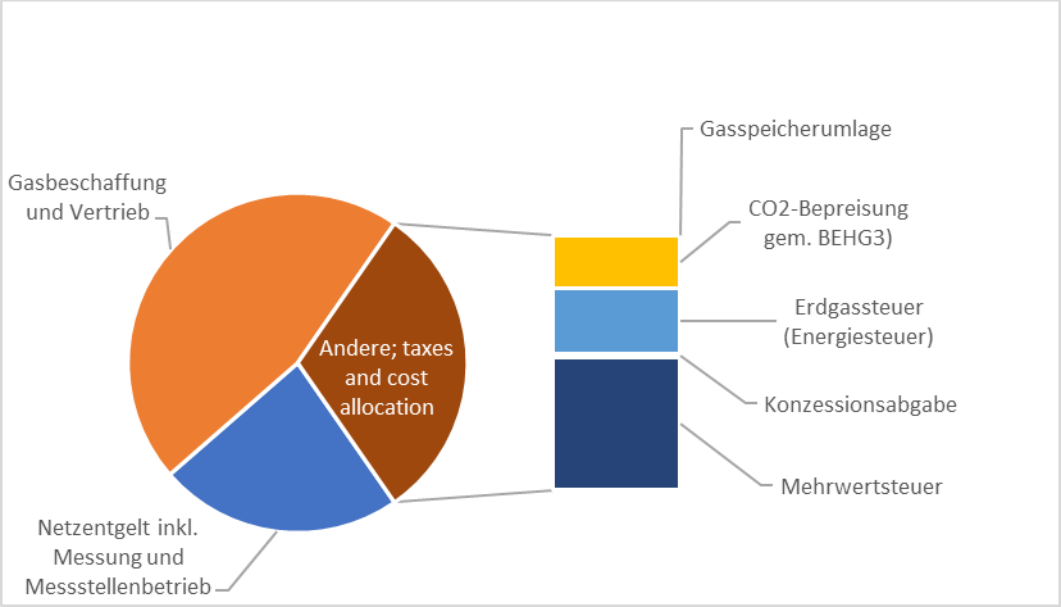

figure 8: Composition of fuel-price for natural gas in private house holds in Germany in 2022

In means of a comparison of gas and electricity fuel prices the following chart might result [19]. Taking into account the previous stated fuel prices in the private sector for single-family-buildings. A ratio of electricity to gas of about 4.5 does occur [18] that has been reduced to approximately 3 after the price shock in 2022 whereas robust reference is in the moment not possible. In the industry sector final consumer prices are rather difficult to examine. It might be expected to find a ratio of 2..2,5 for Germany depending on e.g. local infrastructural and further market criteria. Especially switching to LNG as natural gas source has a certain impact that might affect intensively future price scenarios. Indicating references might be found in recent publications on https://ariadneprojekt.de/ and [20]. For a robust scenario evaluation full cost as levelized-cost of heat (LCOH) taking e.g. CAPEX, OPEX and subsidies over a live-cycle into account are necessary when comparing both technologies for heat generation.

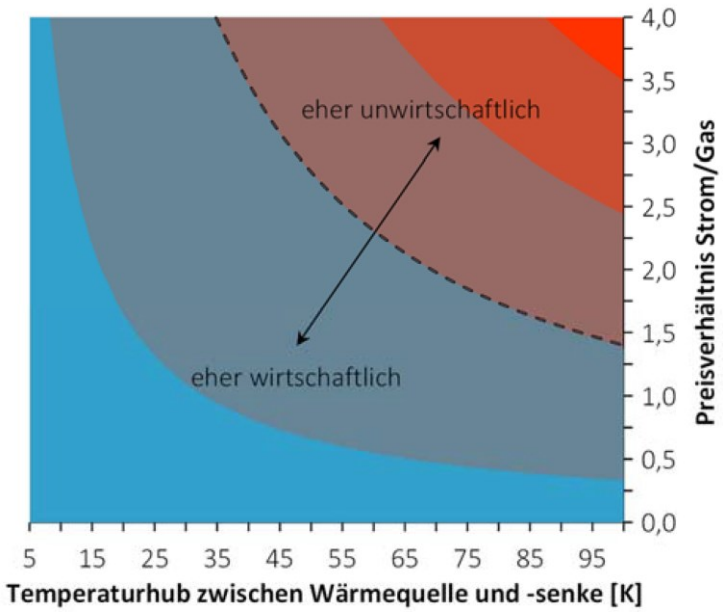

figure 9: Ratio of electricity to gas prices in an economically point of view for industrial consumer [19] in Switzerland

It becomes clear that implementation of heat pumps is very sensitive to the price ratio of electricity and gas. A ratio of about 2 is needed regarding to [19] to get a rather beneficial environment for heat pumps.

DH prices

The prices as total cost (LCOH) have been evaluated in comparison to typical heating technologies in [21] for a generic typically existing multi-familiy building.

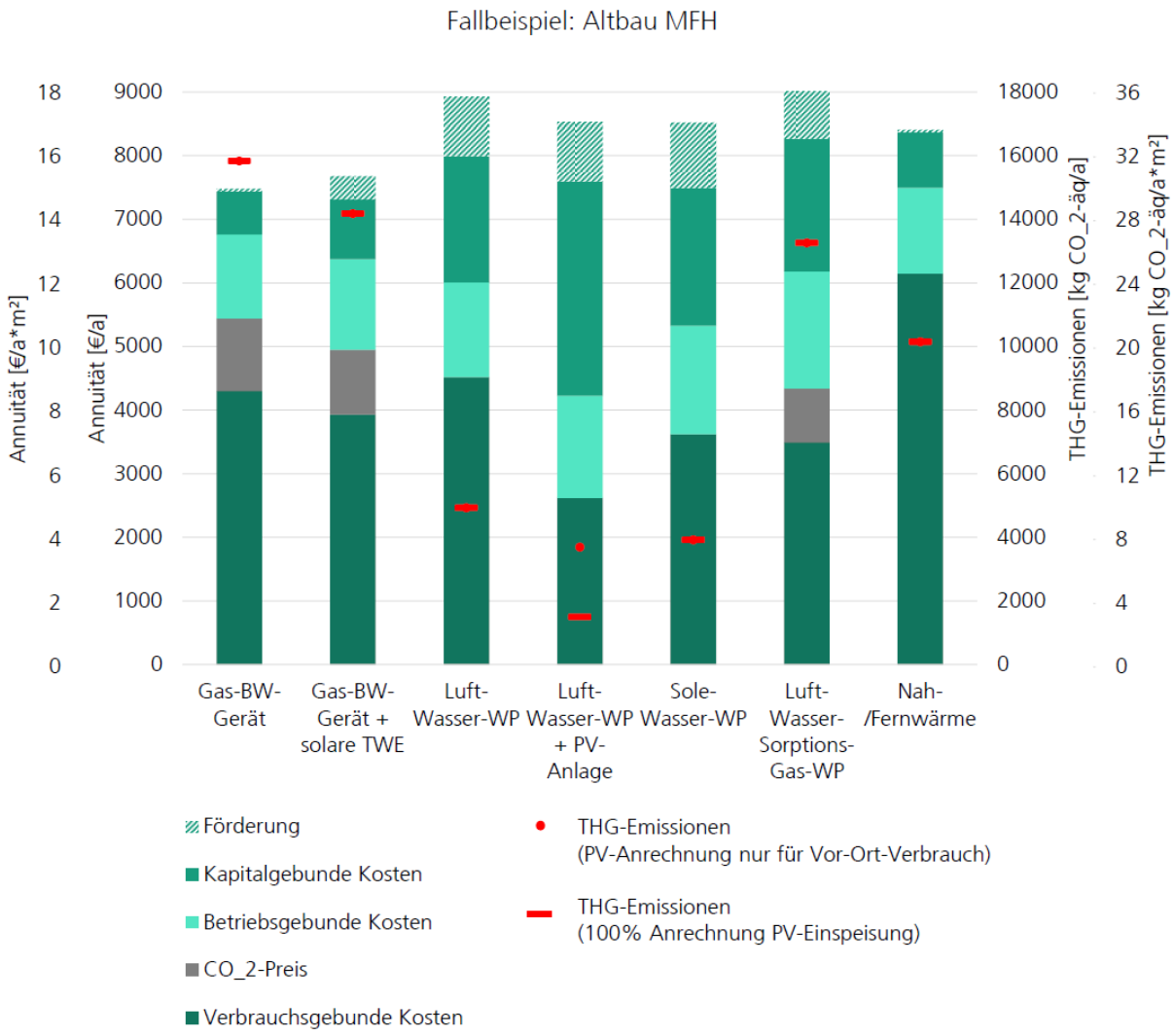

figure 10: levelized cost of heat (LCOH) for supplying heat in a typical multi-family building as specific cost per heated m² as well as the technology related CO_2 -equivalent emissions [21].

It can be observed that total cost does not vary that much as DH related supply does cost about 17 ct.€/kWh that is about the average of all considered supply technologies in a range of 15 ct€/kWh to 18 ct€/kWh.

5: policies

Until the BEW-directive came into force, funding for large heat pumps in Germany was essentially only possible as part of an innovative CHP system (iKWK) according to the KWKG. It basically means: The component for providing renewable heat must be dimensioned so that at least 30% of the reference heat (total heat provided by the iKWK system) can be generated as innovative renewable heat in a calendar year. Furthermore the use of waste heat is not covered [22].

The BEW-guideline came into force on September 15, 2022. It consists of four modules [23] considering:

1) Feasibility studies and transformation plans (max. 50% or 2 Mio. €)
2) Systemic promotion of heating and cooling networks – grid measures (max. 40% or 100 Mio. €; limited by economic efficiency gap to reference technology)
3) Individual measures – generating technology (max. 40% or 100 Mio. €; limited by economic efficiency gap to reference technology)
4) Operating cost support (depending on certain criteria for each technology e.g.: max. 9,2 ct€/kWh for heat pumps and further restrictions)

6: Aspects on the flexibility perspective

First some considerations of an optimal dispatch in ecological and economical relations are to be pointed out. Depending on the energy market design and cost relation between electricity and gas it has been investigated that the operation of large scale heat pumps depends a lot on ecological or economical aspects. Considering the operation of a district heating plant, consisting of CHP units and HP the following observations have been done: As [24] has shown, there are different methods for the allocation of CO_2 emissions in CHP systems for the produced heat and electricity. The most appropriate way is based on the Carnot-method, that is depending on temperature regime to be considered for each time of operation and not applied in regulatory schemes so far. Quite simple and robust rules are instead applied, that are based on constants like primary energy factor and a constant share of heat and power for instance. In the current energy system of Germany and its market restrictions such a consideration leads to rather different optimal dispatch of heat pumps that are coupled electrically to a CHP system on site. Considering most economical dispatch would lead to an operation at self-consuming electricity of the entire plant as it is favorable to consume the produced energy by the utility itself. In contrary most ecological dispatch would incorporate renewable based electricity that might be available through the grid but that is too expensive due to network charges. This issue is very sensitive to the considered source of the heat pump and therefore it´s assigned COP. On rather high source temperatures, resulting on high COP-values the issue might turn around.

The further flexibility contributions of different technologies are presented in this section based on [11]. Flexibility contributions are the amounts of energy that technologies can provide either when there is a shortage of electricity (electricity generation from renewables is less than the electricity load) or a certain surplus does occur (electricity generation from renewables exceeds electricity load). electricity load). In the following table some storage systems are listed that have to be taken into account. A special feature compared to the other technologies that can be used flexibly are the heat pumps and combined heat and power plants in combined operation in heating networks. If there is a surplus of electricity heat pumps are operated when there is a surplus of electricity and combined heat and power plants when there is a shortage of electricity, to both cover the heat demand and make a contribution to flexibility.

application	electricity	fuel	heat
technology	power plants, combined heat and power plants, batteries (stationary and in vehicles), pumped storage power plants	elektrolyse, methanisierung power-to-fuel	heat pumps, electric heating elements, combined heat and power systems

figure 11 and figure 12,show the monthly flexibility contributions in the scenario reference in the case of power surplus and power shortage are shown. In order to obtain a seasonal fluctuations, these values were averaged over the years 2041 to 2045. these values were averaged over the years 2041 to 2045. With an annual power consumption of of 244 TWh_{el}, the electrolysis plants take over 53% of the power surpluses. The heat pump is still clearly represented in combined operation with an annual power consumption of 45 TWh_{el}, followed by the electrical heating elements and stationary batteries. Seasonal fluctuations are particularly noticeable in storage technologies and heat pumps in combined operation.

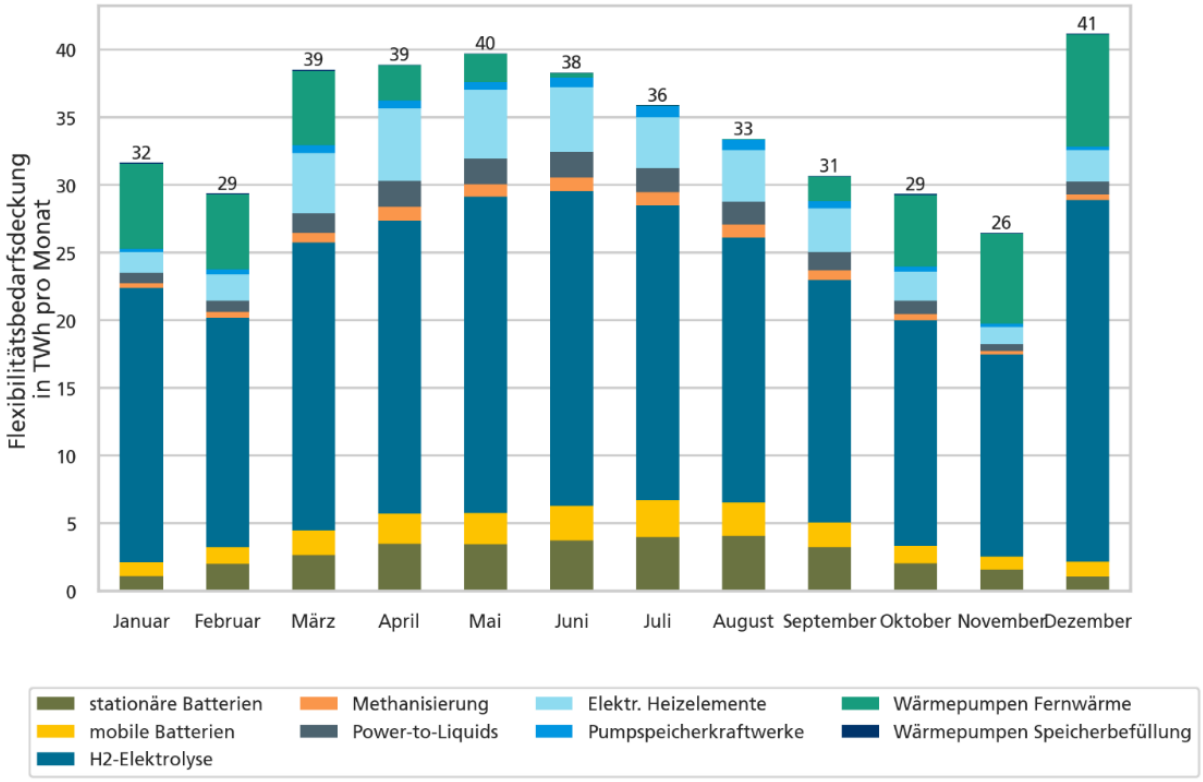

figure 11: Current consumption of the flexible technologies in the event of excess electricity in the reference scenario [11]

Comparing figure 11 and figure 12, it becomes clear that the flexible current consumption is significantly larger than the flexible current output. In addition, different technologies are used for these two processes different technologies are used. Stationary and mobile batteries and pumped-storage power plants feed the stored electricity (net of of efficiency losses) back into the grid during power shortages. In the building sector the filling of heat storage facilities (by electric heating elements and Heat pumps) achieves load shifting. This heat can be used during power shortages used when there is a shortage of electricity, in that heat pumps in particular do not have to be operated. In the case of synthetic energy sources, it is noticeable that although hydrogen is produced through H2 electrolysis, but is not used for reverse power generation (but rather in transport and industrial process heat, see chapter 2). Methane is used for seasonal especially in winter to cover the flexibility demand in the gas and steam power plants and the gas turbine. steam power plants and the gas turbine (CH4-GT) in the Reference scenario for a total of 42.1 TWhel (see figure 12). Methanation, on the other hand, is used, with annual flexible power consumption of 8.2 TWhel in the Reference scenario. operated1. The additional methane required is obtained from biomass or imported in a CO2- neutral imported.

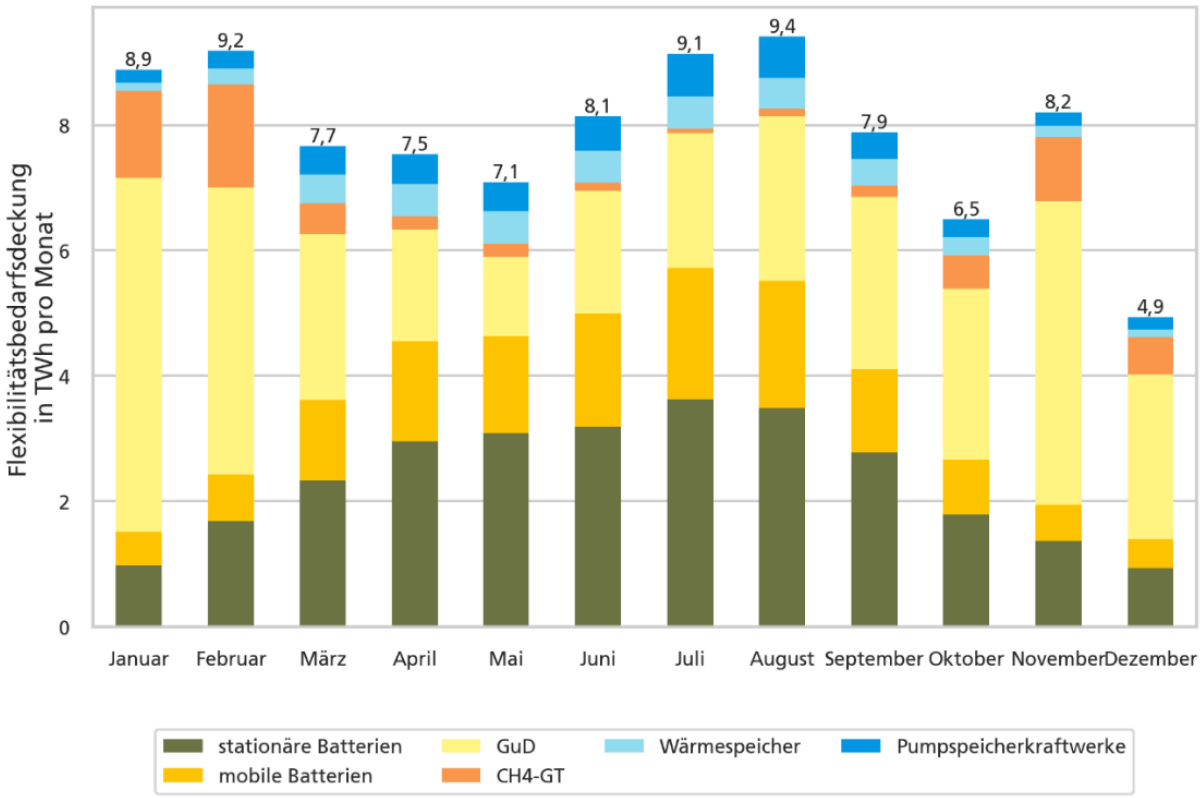

figure 12: Power output of the flexible technologies in the event of a power shortage in the reference scenario. (Values averaged over 2041-2045) [11]

If you compare the flexibility contributions of the scenarios with each other (see figure 13 and figure 14), the differences in installed services are clearly visible. These include the greatly expanded H2 electrolysis in the Reference and Unacceptance scenarios, the significantly higher flexibility contribution of stationary batteries in the Unacceptance scenario and the larger shares of power-to-gas and power-to-fuel in the Persistence and Sufficiency scenarios can also be seen. It is noteworthy that the H2 electrolysis plants in the Reference scenario absorb more electricity surpluses than in the Unacceptance scenario, even though the installed capacity is only about half (see Figure 15 in [11]). This is due to the more PV-heavy ratio of wind energy and photovoltaics in the Unacceptance scenario, meaning that the electrolysis systems are operated in significantly fewer hours. Due to less electrification of the energy system (see chapter 2 in [11]), the need for flexibility in the persistence

scenario (despite greater energy requirements) is lower than in the sufficiency scenario.

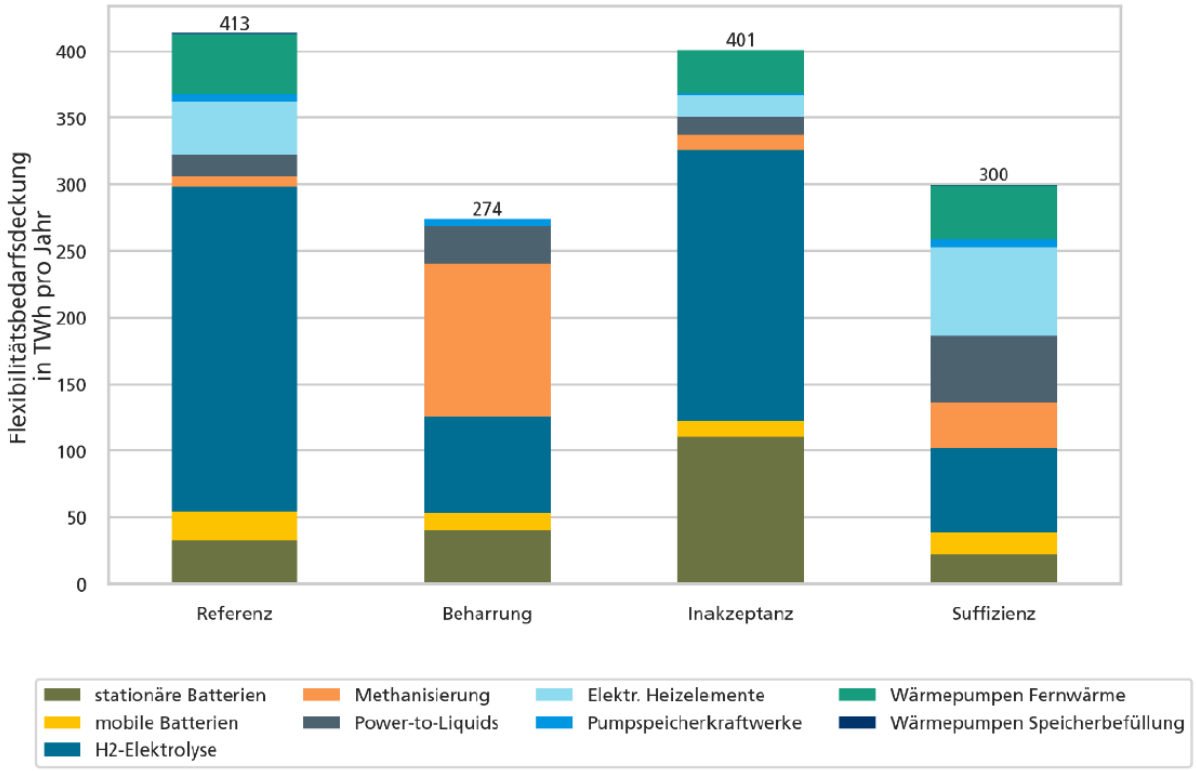

figure 13: Power consumption of the flexible technologies in the four scenarios. (Annual values averaged over 2041-2045) [11]

The above comparison of installed power and power consumption can also be carried out on the basis of on the basis of full cycles and full load hours, see table 1**.** The capacity utilization of a technology can be shown. To calculate the full cycles the respective battery capacity is compared with the total power consumption of a year, while in the example of electrolysis, the installed output is used to calculate the full load hours. the installed capacity is used. The significantly higher full load hours of H2 electrolysis are therefore not directly comparable with the full cycles of the batteries. The full cycles of the stationary batteries are around 200 per year in all scenarios. Overall the full cycles of the mobile batteries are significantly lower at 44 to 84, which This is due to the prioritized use of stationary batteries and the limited availability of mobile availability of mobile batteries. In the unacceptance scenario significantly lower utilization compared to the other scenarios, both for mobile batteries and mobile batteries and H-electrolysis electrolysis. Higher full load hours of H-2 electrolysis are achieved in the Persistence and Sufficiency scenarios, in which where lower shares of fluctuating renewable energies are installed and therefore a more more even electricity supply is available.

table 1: Full cycles and full load hours of stationary batteries, mobile batteries and H2 electrolysis. (Annual values averaged over 2041-2045)

		Referenz	*Beharrung*	*Inakzeptanz*	*Suffizienz*
stationäre Batterien	Vollzyklen	200,5	196,0	213,3	201,6
mobile Batterien	Vollzyklen	79,6	72,1	44,0	83,5
H_2-Elektrolyse	Volllast-stunden	3065,3	3917,8	1264,7	4100,8

Also in the electricity supply in case of electricity shortage in Figure 19, the larger contribution of stationary batteries in the Inacceptance scenario with 110 TWh_{el} (vs. 32 TWh_{el} in the Reference scenario) is evident. Since for the scenario Persistence

it was assumed that there would be a low level of willingness in society to to operate its own technologies flexibly, the flexibility contributions of electric heating heating elements and other heating technologies are eliminated in this scenario. Furthermore, the distribution of energy quantities is different, particularly in the case of electricity consumption different, as in the sufficiency scenario, heating technologies (first and foremost electric heating heating elements, followed by the district heating heat pump) make a significant contribution, while methanization is more strongly represented in the Persistence scenario.

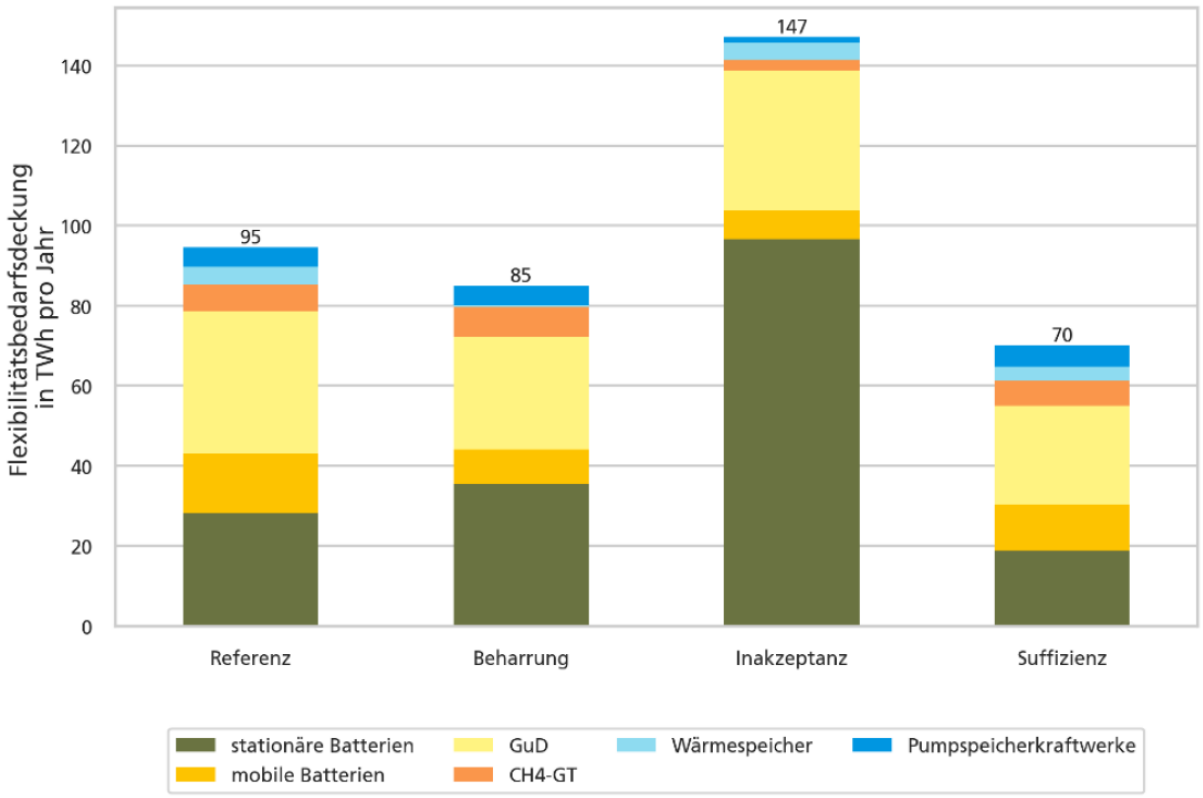

figure 14: Electricity provision of the flexible technologies in the four scenarios. (Annual values averaged over 2041-2045) [11]

The flexibilities in the system thus balance electricity provision and electricity requirements on both a daily and seasonal level. When using fluctuating renewable energies, the use of flexibility options is necessary in order to compensate for peak loads and to be able to use energy quantities at different times. In the previous analysis, the Unacceptability scenario is particularly noticeable due to the significantly greater installed output of the flexible technologies, which compensate for the shifted ratio of photovoltaics to wind energy (due to the exogenously very limited expansion of wind energy). This leads to greater flexibility contributions, but also to noticeably low utilization of mobile batteries and H2 electrolysis in particular. This low utilization of individual technologies makes the Inacceptance scenario less economical overall than the other scenarios. Electrolysis and stationary batteries, electric heating elements and district heating technologies, heat pumps and combined cycle power plants, which can be operated in combination, are the most important balancing technologies. However, this depends on the scenario, and other technologies (e.g. power-to-gas in the Persistence scenario) can also be of central importance given the appropriate boundary conditions.

7 Potential for demand response from HP (in buildings) / District heating grids

Flexibility capacity is considered by developing a generic method for building stock in Germany in [25]. It is shown that peak load in space heating and DHW supply might be reduced in a range of about 9% by demand-side management in typical districts of building stock in Germany. On a local level flexibility is evaluated in [26] where the operational parameters that influence the flexibility of heat pumps in buildings show a significant possibility in load shift at the electricity grid level. Regarding design on site for storage sizing the results from structural optimization showed that optimal storage size increased by factor 2.3 when time variable prices were added and factor 1.3 when on-site PV was added. It is furthermore shown that by planning individual heat pump operation ahead of time, e.g. using model predictive controls, the achievable shifting durations can be increased enabling to optimize operation in the presence of time variable electricity prices based on the day-ahead price at EPEX.

8 Conclusion

It can be stated that electricity is becoming the most important primary energy and flexibilization is becoming the new paradigm of grid operation. It might be put to the point that “yesterday supply follows demand” and for tomorrow “Flexibilization: continuous balancing between power generation from renewable energies (wind, sun), controllable power plants, flexible loads (including electrolysers) and storage”. Furthermore there is no need for base load power generation.

On-site energy supply solutions enable first a massive reduction in regulatory complexity for integrated energy supply concepts (buildings, districts) and secondly the creation of a simple legal framework with an interface to the higher-level network (system serving).

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