MODELLING THE ADOPTION AND DIFFUSION[1] OF HEAT AND ELECTRICITY SELF-SUPPLY FOR VARIOUS REPRESENTATIVE CONSUMERS AND ITS EFFECTS ON THE ELECTRICITY MARKET

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1.1 Overview

Remark: this paper is based on findings of the project "Zukunftswerkstatt Erneuerbare Energien - Eigenversorgung mit Strom" (BMWi 2017)*.*

In the scientific as well as in the political context, the field of "self-supply" is becoming increasingly important in Germany. Over the recent decades, new technologies like PV-, battery storage and CHP-systems have emerged, allowing consumers to generate electricity and heat independently for themselves. By becoming more and more affordable during the last few years, these technologies now represent reasonable alternatives to the prevailing supply from public grids. While at first the main motivation for consumers to supply electricity and heat independently was of ideological nature, the introduction of EEG funding in Germany in 2000 increasingly brought economic reasons of self-supply to the fore and lead to a widespread adoption of PV systems.

Since investments were mostly only economically feasible due to these funding, the coming reduction (or even expiry) of this subsidies now reveals self-supply in a new light. In addition, the decline of the cost of these new technologies, for PV and storage systems in particular, which is sure to continue for the next years, leads to further dynamics.

A number of publications suggest that with low public support via feed-in tariffs or other instruments, the profitability of self-supply technologies requires a high share of self-consumption (Dusonchet und Telaretti 2015; Chiaroni u. a. 2014; Diermann 2015). As regular electricity usage enables only a relatively low degree of flexibility, many publications suggest the use of self-produced energy for heating (e.g. applying heat pumps or electric heaters) or for charging electric vehicles (Weniger, Quaschning, und Tjaden 2014). Yet, only few publications elaborate on this and quantify it by including further technologies in their models (for example (Bardt u. a. 2014)).

To determine the full economic potential of self-supply technologies in a post-FIT scenario, it is important to identify further possibilities to increase the share of self-consumption. This can be done by taking into account all relevant technologies like heat pumps, CHP, and the like. Hence, this implies a self-supply model that couples the consumer's electricity and heating sector.

Moreover, in order to determine of the economic potential of self-supply technologies and to understand their impact on the energy system as a whole, it is not sufficient to examine the situation only for household consumers, as most publications do. A look on the German electricity consumption by sectors reveals that the tertiary sector claims about the same share as the household sector (BDEW 2017) (see Figure 1, meaning small-scale industries/trade/service, public organizations and agriculture) . Hence, a determination of the full economic potential of self-supply technologies must not only include all relevant technologies, but also all relevant kinds of consumers from these sectors.

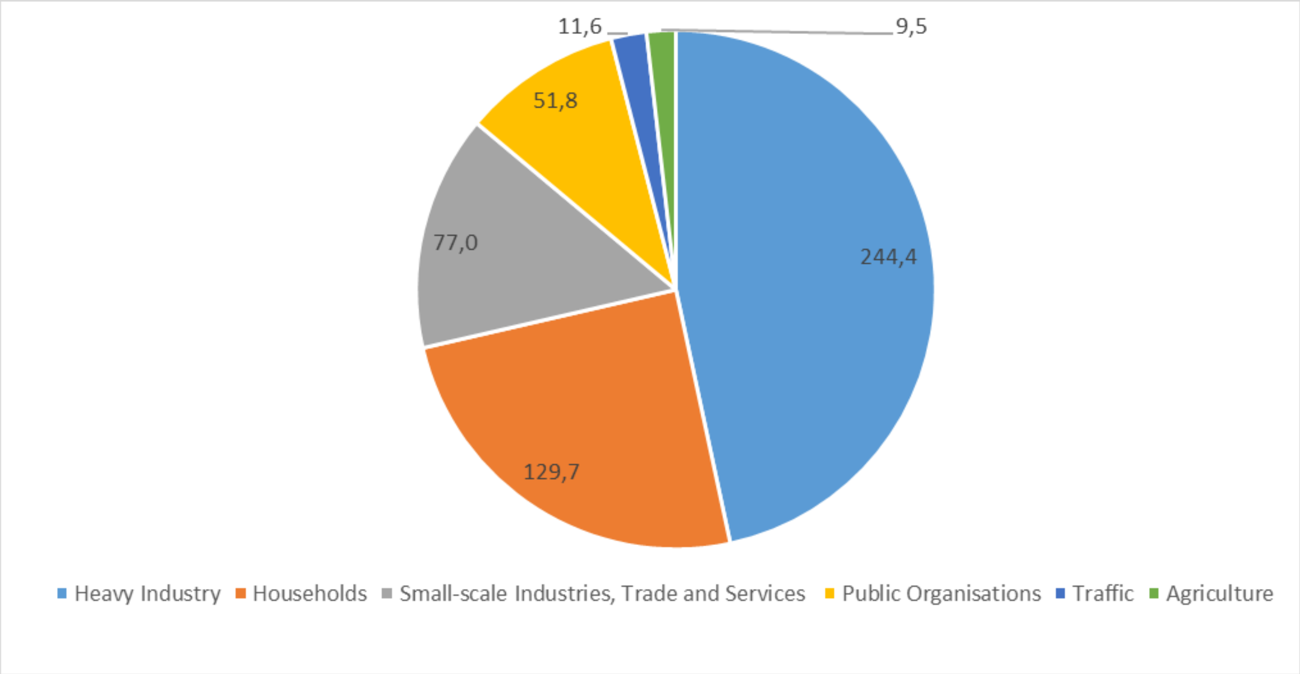

Figure 1: 2017 German electricity demand in TWh in sectors.

Besides the issues on the consumer side, a widespread adoption of self-supply technologies is likely to have an impact on the energy system. Still it is unclear whether these dynamics will solely lead to marginal effects, and whether they will only slightly affect the expansion targets set within the scope of the German Energiewende, or whether they will lead to an explosive expansion of PV, storage and other technologies. Especially the latter case could lead to considerable regulatory problems, and political instruments to steer these developments are yet to evaluate (Horst 2016) (as of before this project). Those effects include the development of grid fees and other quantities, which also have an impact on welfare distribution (see (Bost, Hirschl, und Aretz 2011; Podewils und Rutschmann 2010), as well as on grid stability (see (Moshövel u. a. 2015) for a comprehensive study).

However, the impact and intensity of these effects depend especially on the actual adoption of self-supply technologies and not merely their economic potential. In order to quantify these impacts, it is necessary to model the diffusion and adoption of self-supply technologies. While a number of publications deal with drivers and barriers of the adoption of self-supply technologies (mostly PV), none of them quantifies the effects (Lund 2015; Guidolin und Mortarino 2010; Rode 2014).

1.2 Methods

In order to fully understand and investigate the interplay of these dynamics, we need a model that covers all technical and legal aspects of self-supply. Such a model is required to distinguish between individual types of consumers; In addition, due to the close interactions that are possible between electricity and heat generation technologies, only a combined examination of these sectors will yield meaningful conclusions. A model that fulfills all these specifications at the required level of detail is not available up to now.

Furthermore, even if self-supply is an increasingly favorable alternative to grid supply, it is also unclear how quickly consumers will adopt the new technologies. Several factors, such as cost-effectiveness versus conventional supply methods, or the grade of market penetration, could affect the market in opposing ways. To this date, there is no comprehensive concept for the market diffusion of self-supply technologies.

To address these questions, we developed a multi-stage model for self-supply. Consisting of three parts, it primarily combines a private-sector decentralized optimization of the energy-supply of a set of representative consumers with a model for market diffusion and an estimation of the development of certain parameter. Figure 2 depicts an overview of the model structure.

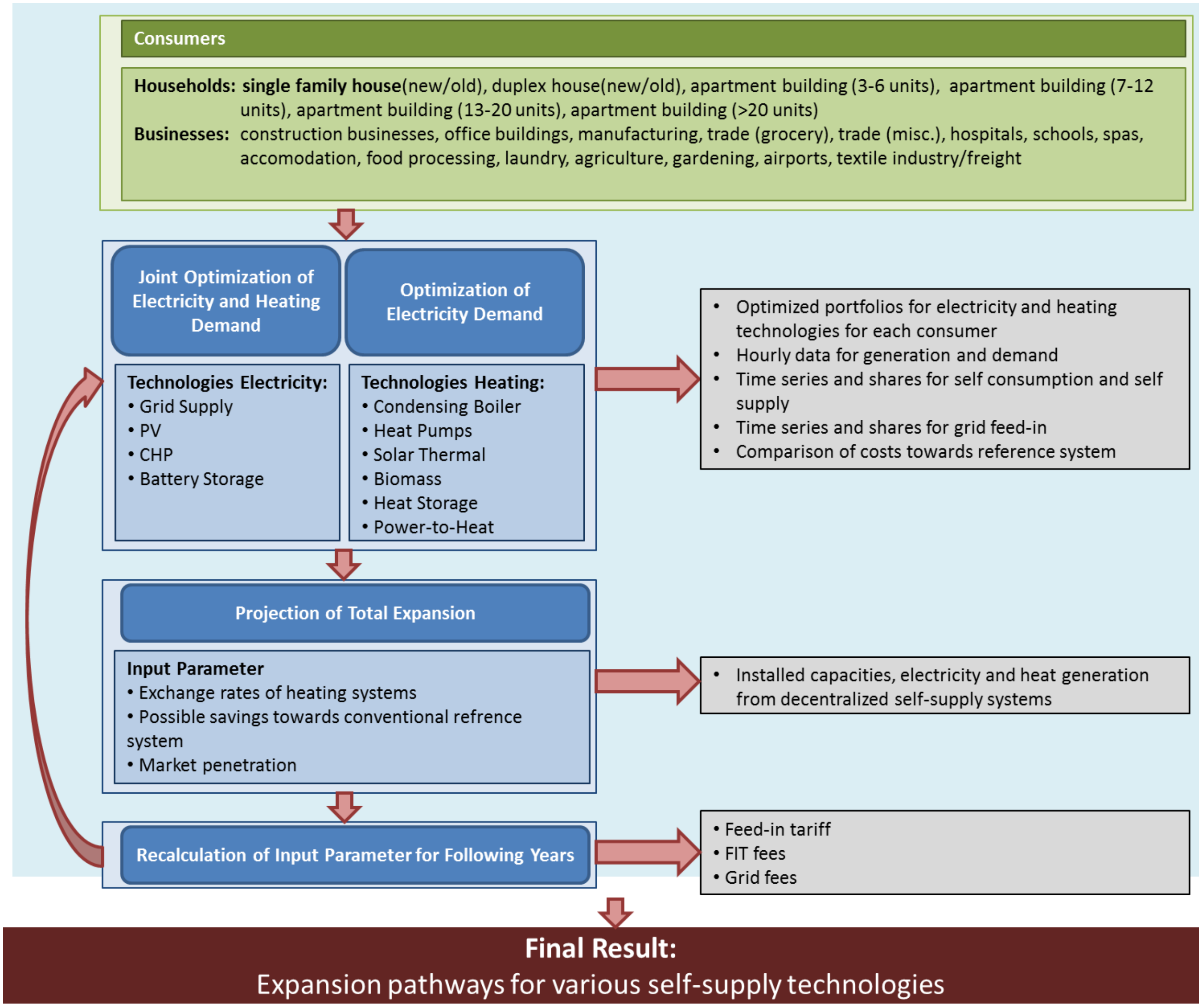

Figure 2: Model Structure

In its first stage, the model optimizes the electricity and heat supply for each representative consumer individually for one model year. This takes into account various highly detailed technology options as well as grid supply, and results in a technology portfolio that is economically optimal for each type of consumer.

The second model stage consists of a market diffusion model, which estimates how many consumers from the first stage will invest in the optimized technology portfolio for the considered model year. This model stage yields the total expansion figures for each particular self-supply technology.

In addition, a third stage will examine the effects of this newly added capacities on the overall energy system, in particular their impact on network charges and on the EEG levy. The resulting changes are fed back into the optimization of the next model year. Through this feedback, the three stages of the model are interlinked and so repeated over and again for consecutive model years, starting 2016 up to 2030.

This model is used to evaluate a couple of scenarios, which were designed to address the problems mentioned above. This includes

- a **Business-as-usual Scenario** (BAU-Scenario), in which the regulatory and economic framework is kept as is,
- a pair of **Minimum and Maximum Scenarios**, in which the regulatory and economic framework is altered once in favor and once to the disadvantage of the adoption of self-supply, to determine upper and lower boundaries on the impact and expansion of self-supply, and
- a **Measures Scenario**, in which some previously discussed political instruments are implemented and evaluated.

Additionally, as the model and the scenarios are subject to assumptions and methodical side effects, a sensitivity analysis of the BAU-Scenario is conducted.

1.3 Results

In this paper, the focus on the results shall lay on the BAU-Scenario. For further results and a more detailed look, the reader might consider to consult the main projects final report (BMWi 2017).

We first look on the development of the feed-in tariffs (see Figure 3), which start to decline by 2019, until they are suspended after reaching the 52 GW PV barrier in 2021, which is implemented by the EEG law. This has a significant impact on the overall PV expansion, which is displayed in Figure 4 - while the expansion reaches its height in 2020 with nearly 2,5 GW added, it drops drastically after the FIT is suspended. This shows that despite a number of flexibility options, feed-in tariffs are still a major driver of self-supply systems.

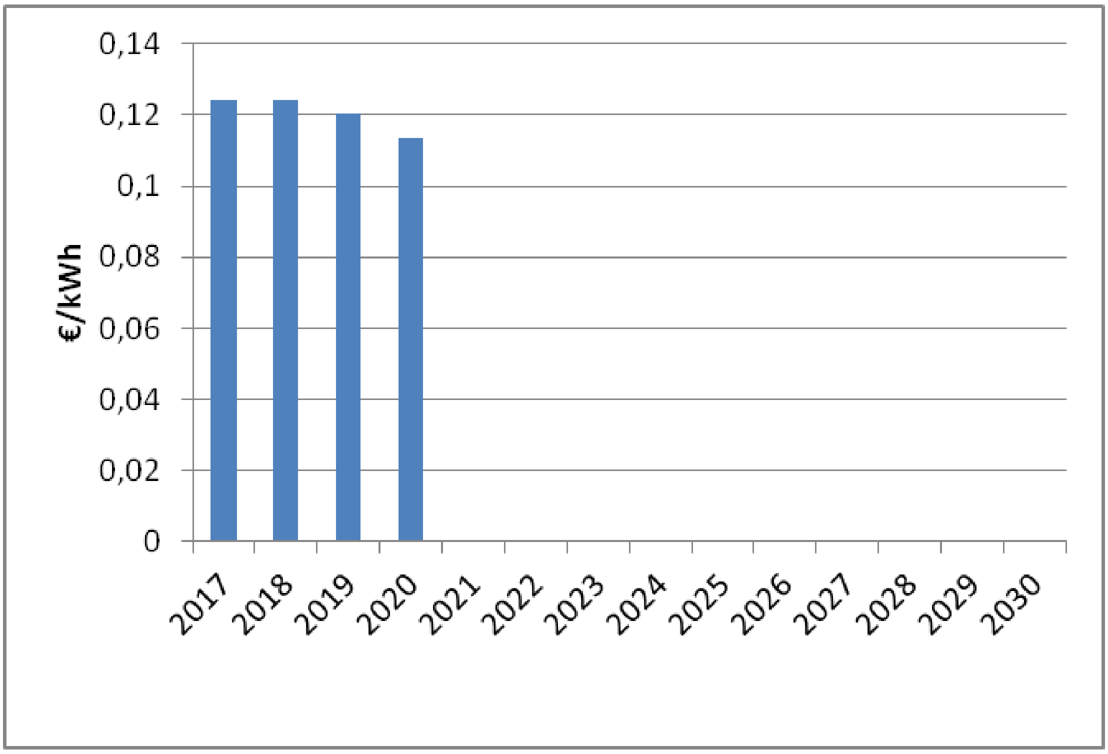

Figure 3: EEG Feed-in Tariffs.

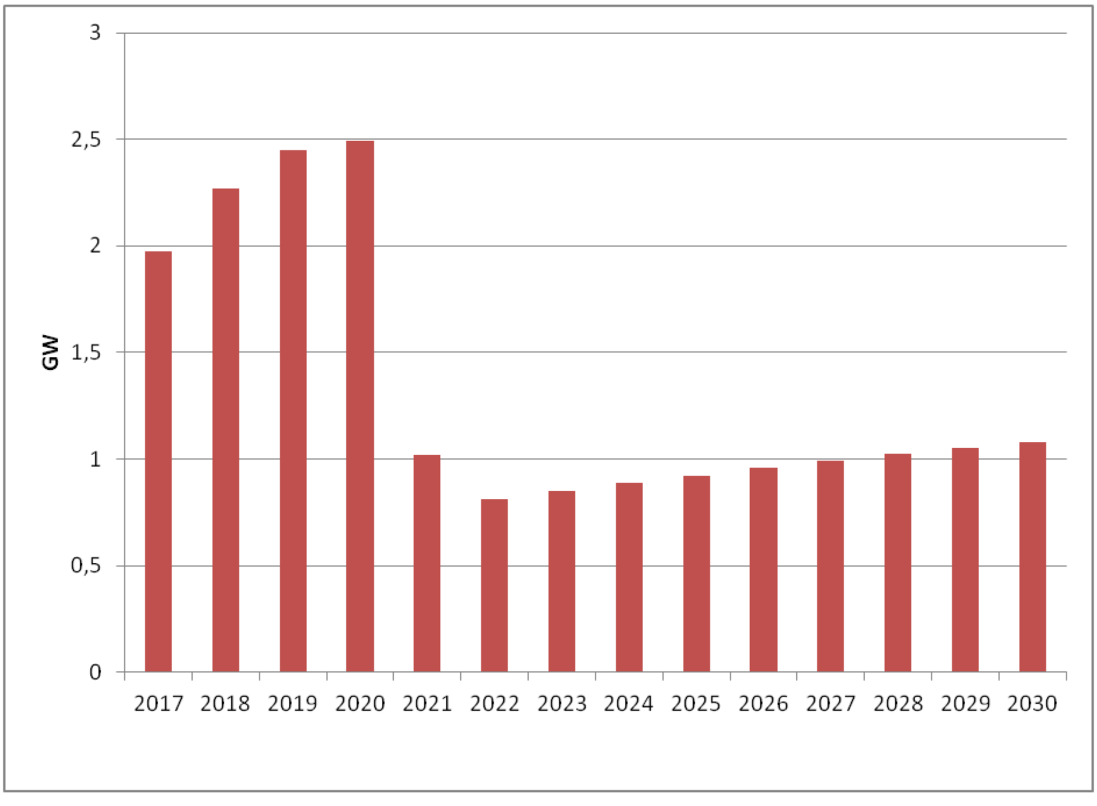

Figure 4: Additionally installed capacity of PV.

Since the largest group of the model's consumers are the single-family households, a more detailed look on this consumer serves as a showcase for all other consumers. Figure 5 shows the optimized portfolio for electricity supply technologies (including grid supply (purple) as the maximum capacity drawn from the grid). The fluctuation of PV during first years are the result of interactions of falling technology costs, declining feed-in tariffs and rising electricity costs. Figure 6 shows the equivalent data for the households heating demand, which reveals that condensing boilers are receding, while with declining costs heat pumps play a more and more important role.

It is due to the models optimization nature that the results show a combination of heating technologies like CHP and heat pumps, although this does not necessarily make sense in real world applications. Effects like this have to be kept at the back of one's mind and must be interpreted properly before any generalizations. In reality, a consumer would propably decide to invest in a CHP *or* a heat pump system, but very unlikely in a combination of both. Nonetheless, the model results reveal an insight and an estimation of the most economical way of self-supply.

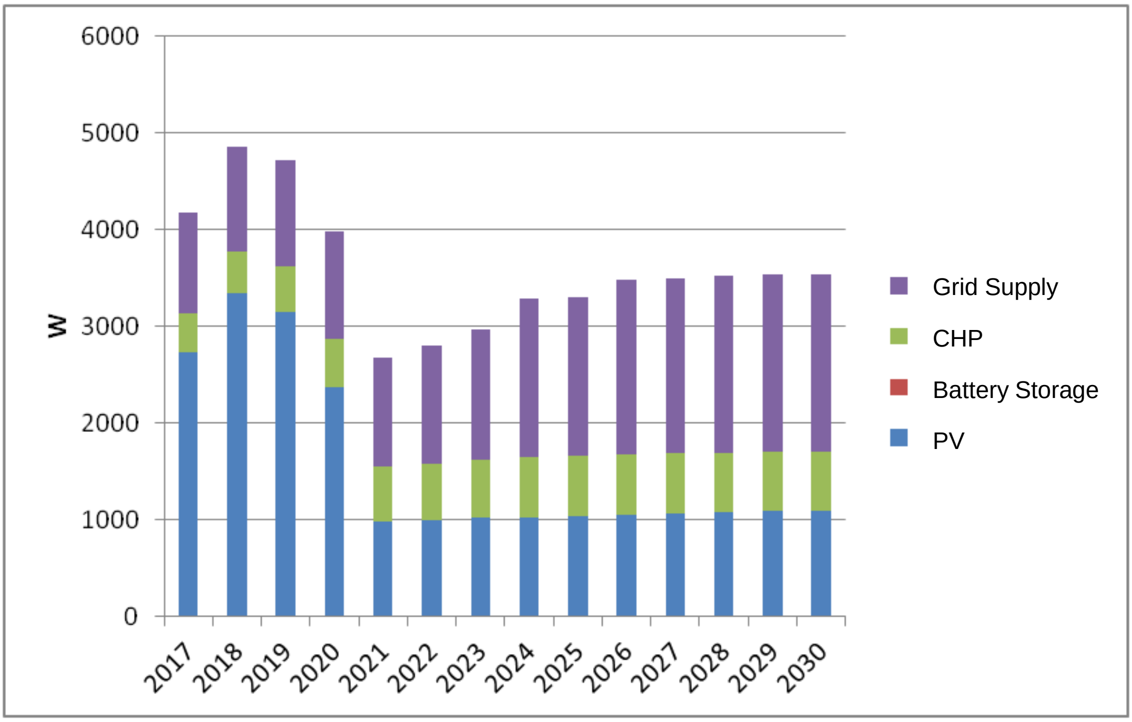

Figure 5: Optimized share of capacities of electricity technologies for single-family households

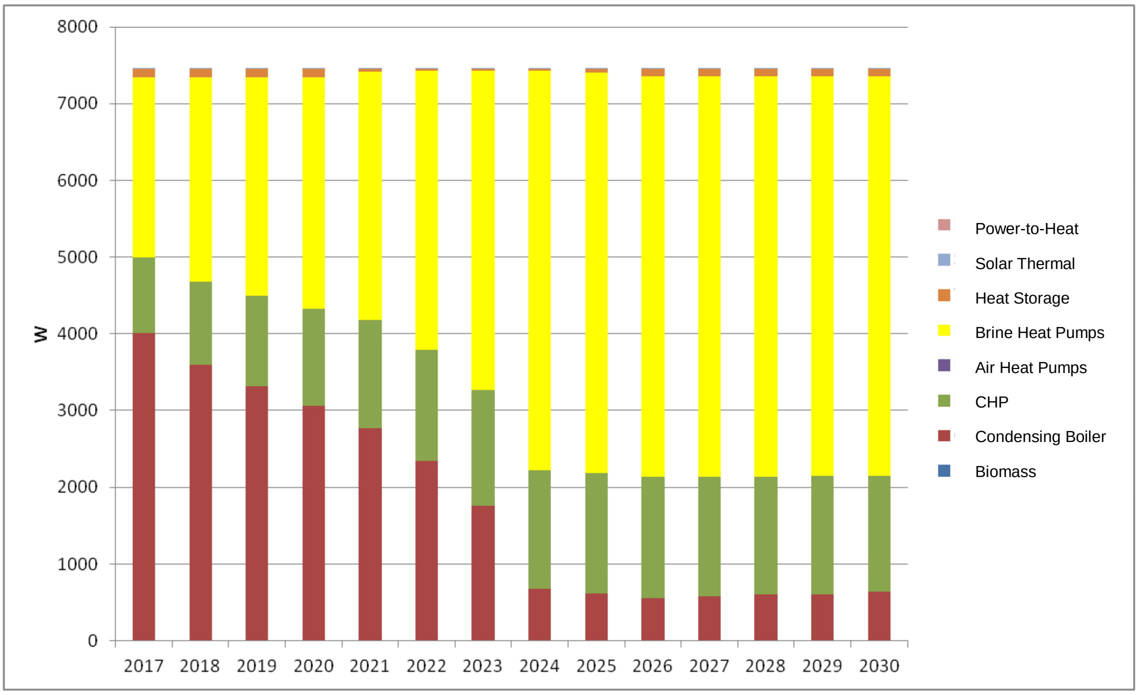

Figure 6: Optimized share of capacities of heating technologies for single-family households

With the other scenarios and the most important sensitivities of the BAU-scenario, a general pathway of the expansion of self-supply and its effects can be fathomed. Figure 7 shows the PV expansion in those scenarios. The Maximum (orange) and the Minimum scenario (light blue) confine all other scenarios pathways, while the BAU-scenario reaches more than 70 GW (dark blue). This shows that even for very favorable circumstances, self-supply technologies and especially PV will not get out of hand, and that even with very diverting assumptions the expansion will at most differ by around 30 GW.

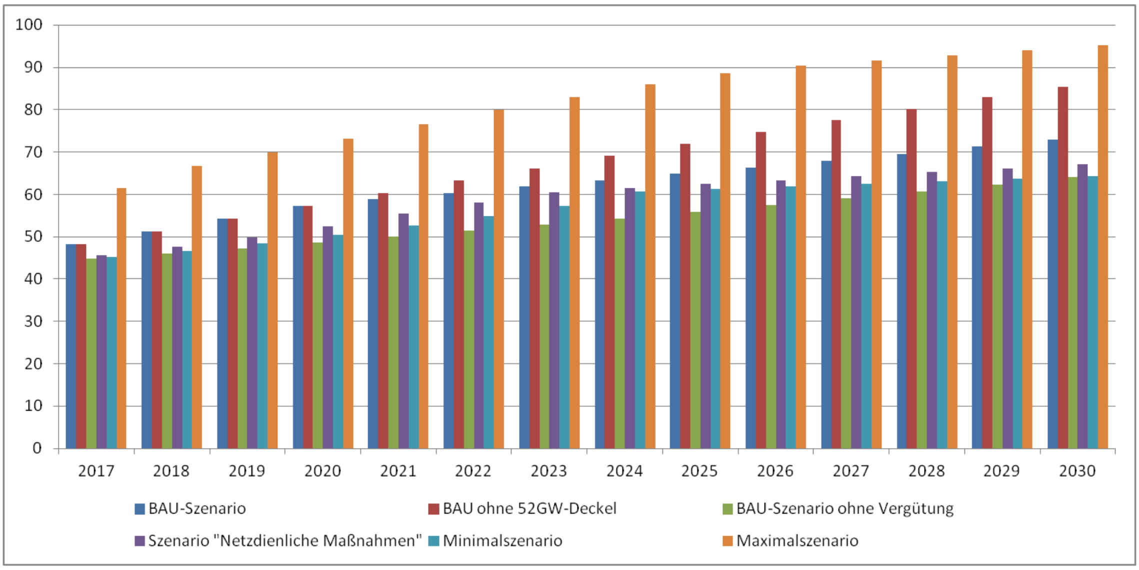

Figure 7: Total PV expansion in different scenarios.

Additionally, the measures taken in the Measurement scenario (purple) to regulate the expansion of self-supply actually have a dampening effect, with a PV expansion merely above the Minimum scenario. These measures include a two-part grid fee tariff consisting of a capacity- and a lower-than-usual demand-based part, and the application of these grid fees on self-consumed electricity, too.

Figure 8 shows the development of the demand-based part of the grid fees in the scenario selection. While this share is artificially lower for the Measures scenario (purple) as described, again the Minimum and Maximum scenario confine all remaining scenarios as expected. Yet, although of the widely different assumptions, the fee only varies by about one cent in 2030.

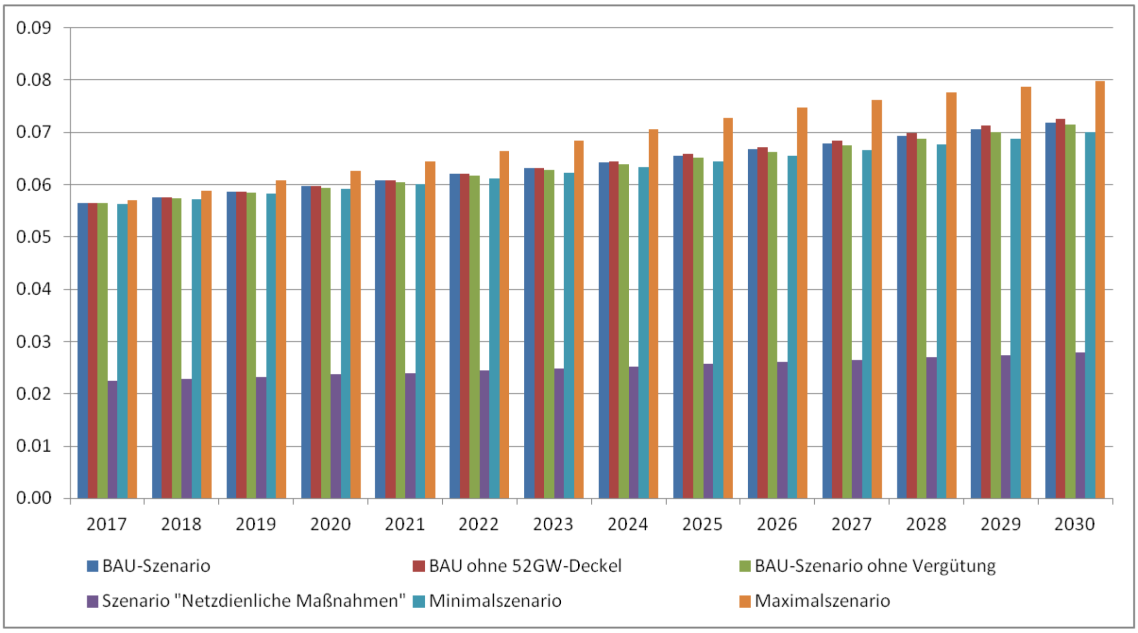

Figure 8: Grid fees in different scenarios (demand-based part).

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1.4 Conclusions

The different stages of the model allow to both draw conclusions for technology diffusion as well as for the technology adoption by single representative consumers. Regarding single consumers, we focused on the "single-family household" representative consumer, which is by far the most common type of consumer in Germany. For them, some of the findings are:

- PV systems are economical for almost all consumers, even without funding.
- With their current costs, battery systems are almost never part of an optimized technology portfolio, unless their costs drop dramatically. However, this does not mean they're not economical, since second- or third-best solutions are ignored due to the optimization nature of the model.
- Heat pumps are suitable to increase the self-supply quota.

Regarding technology diffusion and its impact on the system, we conclude the following aspects (among others):

- Under the assumed circumstances, a quick diffusion and market adoption of self-supply technologies will not occur in the next decades.
- The influence of self-supply on network charges is rather small.

- The EEG funding is a very effective control mechanism, since PV diffusion and adoption react extremely sensitive to changes and especially to an expiration of this subsidy. Its current implementation will act as a driver of self-supply until it expires.

1.5 Literature

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