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CAN AN ENERGY AUTARKY PRIVATE HOUSE BE ECONOMICAL? AN ANALYSIS BASED ON GERMANY†

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Abstract

The energy self-sufficiency of private households is a very interesting topic against the background of the current developments in the world, such as power failures as a result of weather catastrophes and new infrastructure challenges as a result of transport electrification. There are various options available for achieving this goal. In the context of this work, a newly built single-family house in Germany with a photovoltaic system with a power storage system and a heat pump with surface heat collectors will be used to investigate whether energy autarky (for electricity and heat) can be economically designed - in comparison to a classic energy supply with electricity from the grid, and a gas condensing boiler heating system. The results show that, through the high gas and electricity prices, scenarios in Germany allow such an economical operation compared to the classic energy supply. However, a condition for this is always that there is a connection to the grid in order to be able to compensate for the differences between electricity supply and demand.

Keywords: Energy Autarky, Renewable Energy, Photovoltaics, Geothermal Energy, Profitability Analysis, Visualization of Financial Implications

JEL Classifications: G50, G51, Q41, Q42

1. Introduction

The ambitious energy policy goals of the European Union (EU) and their implementation at the national level have led to a situation where renewable energies, such as solar and wind power, have experienced an enormous upswing in Germany in the last two decades. The problem here, however, is the strongly fluctuating and sometimes difficult-to-predict yield from wind power and photovoltaic systems (PV systems), which makes it difficult to accurately forecast energy production and the associated supply. The topic is also of great relevance against the background of power failures as a result of weather catastrophes, new infrastructure challenges as a result of transport electrification, and the consequences of the Ukraine war on electricity and gas prices.

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Therefore, discussions arose throughout Europe as to whether private households would be able to shoulder the price increases for electricity and gas at all. For some households, the question even arose as to whether they should heat or eat, which could cause considerable social issues. The resulting problems could be counteracted in private households with a self-sufficient way of life (Walker *et al*. 2021; Hassan *et al*. 2022a, Hassan *et al*. 2022b). This self-sufficiency can basically extend to the areas of electricity, heating, water, and, if necessary, waste (Rae and Bradley, 2012), where self-sufficiency is fundamentally defined as independence from external goods, services, or resources (Glastetter, 1998).

The advantages of autarky can be seen in the independence from the public supply or from rising purchase prices for energy sources (Müller *et al*. 2011; Rae and Bradley, 2012). Further, there are no transport costs for the resources needed in energy generation, and efficiency losses when transporting energy are reduced - since the energy is generated directly at the point of use. In addition to the desire to make a contribution to climate protection when using renewable energies, the motivation to achieve energy autarky can also be of a financial nature (Müller *et al*. 2011). The aim is to examine the extent to which the installation and operation of systems that contribute to the creation of energy self-sufficiency, with regard to electricity and heat in the private sector, is economical when building a new single-family house in Germany. The aim here is not to achieve an off-grid solution - there is no connection of the considered system to the environment - but to retain the connection to the public grid in order to be able to maintain a corresponding degree of flexibility (Netzow *et al*. 2019) in the investigation of the various possible scenarios.

The paper is structured as follows. The second section explains the basics of self-sufficient energy supply in the private sector, followed by the actual economic analysis in the third section. The paper ends with a conclusion in the fourth section. The status of the work is October 1st, 2022. It is thus based on the Renewable Energy Sources Act (EEG) 2021.

2. Basics of autarky energy supply in the private sector

2.1. The concept of autarky

Autarky is derived from the Greek philosophical term *autarkeia* and means something related to independence or autonomy (Büchi, 1996). With regard to the energy supply, self-sufficiency has long been discussed against the background of joint projects in renewable energies or decentralized energy systems.

The existing literature deals with the potential of a self-sufficient energy supply from individual buildings to regions and even entire countries (Müller *et al*. 2011). Müller *et al*. (2011, p.5802) define energy autarky in general as “a situation in which a region does not import substantial amounts of energy resources from other regions, but rather relies on its own resources to satisfy its need for energy services”. However, they point out that such a strict definition can probably not be achieved since trade with other regions usually leads to a certain energy import. A similar definition comes from Rae and Bradley (2012, p.6499) who describe energy autonomy as “the ability of an energy system to function (or have the ability to function) fully, without the need of external support in the form of energy imports through its own local energy generation, storage, and distribution systems”. In contrast to Müller *et al*. (2011), however, Rae and Bradley (2012) deal explicitly with the extent and degree of autonomy. The extent of energy autarky refers to the question of how many inhabitants and buildings in an area should be integrated into the system that is to become self-sufficient. The degree of autonomy then serves as a measure to quantitatively capture the term self-sufficiency (Rae and Bradley, 2012; McKenna *et al*. 2014). Building on this, Rae and Bradly (2012) deal with the various possibilities of changing the degree of autonomy.

McKenna *et al*. (2014) distinguish between tendential, on-grid, and hard (off-grid) autarky against the background of municipalities, although these considerations can also be applied to private households. Tendential autarky means that development takes place in the direction of a decentralized energy supply that covers more than half of the annual energy demand without explicitly defining self-sufficiency as a goal (McKenna *et al*. 2014). In the case of on-grid or soft autarky, the municipality or region is self-sufficient in terms of energy over the period of a year.

The existing supra-regional grid infrastructure is used to compensate for discrepancies between supply and demand. In the case of an off-grid solution, this import and export of energy are dispensed with, and the required energy is provided independently at all times. There is, therefore, no connection to an energy grid (McKenna *et al*. 2014).

Deutschle *et al*. (2015), on the other hand, only distinguish between on-grid and load-based energy autarky. By on-grid autarky, they mean that energy is generated in the same amount as it is consumed within the system over the period under consideration. An exchange between the system and the environment to balance energy flow is explicitly allowed. By load-based energy autarky, the authors mean that the self-generated energy at least covers the required energy within the system at all times. An import of missing energy across the system boundary is not allowed, but an export is possible. According to Deutschle *et al*. (2015), this energy export does not contradict that of autarky as an ideal concept. Their study, however, does not pursue an off-grid solution.

2.2. Key figures of energy autarky

In this paper, we study a detached house with a garden (system boundary) in Germany in the base scenario. The energy considered is limited to heat and electricity. This means that enough electricity and heat must be generated and stored within this system to ensure sufficient energy is always available. Surplus energy from power generation is fed into the public power grid. Various key figures are introduced to measure the level of energy autarky. The self-consumption rate *s*, shown in Equation (1), describes the ratio between the generated solar energy (E_{PV}) that is consumed by the user (E_{DU}) or used for charging the battery (E_{BC}) (Weniger *et al*. 2014; McKenna *et al*. 2015; Mertens, 2020):

$$s = \frac{E_{DU} + E_{BC}}{E_{PV}} \tag{1}$$

The degree of on-grid autarky *d*, shown in Equation (2), measures how high the share of self-generated energy is in total energy consumption (E_L). The self-generated energy is divided into energy consumed by the user and energy discharged from the battery (E_{BD}) (Weniger *et al*. 2014; Quaschning, 2021).

$$d = \frac{E_{DU} + E_{BD}}{E_L} \tag{2}$$

The degree of load-based autarky *l,* shown in Equation (3), indicates how much of the total energy consumed in a system is self-generated (Mertens, 2020).

$$l = \frac{E_{PV}}{E_L} \tag{3}$$

In order to achieve on-grid autarky *d* or load-based autarky *l*, the degree of energy self-sufficiency must be (at least) 100%. In order to achieve hard autarky (off-grid), the self-consumption rate would also have to be 100%. The achievement of hard autarky excludes the feeding of excess electricity from a PV system into the public grid (McKenna *et al*. 2015).

2.3. Selection of the technical systems

In order to achieve a high degree of energy self-sufficiency, with regard to electricity and heat use in a detached house, it makes sense to combine several technologies. In addition to a photovoltaic system, currently the simplest form of electricity generation for private households, there are various options for heat supply that are not dependent on external fuels. These include various types of heat pump systems and, in a broader sense, fuel cell systems, which produce electricity as well as heat (Badenhop, 2017; Quaschning, 2021).

With fuel cell systems, however, it must be taken into account that autarky can only be achieved if the private household itself can produce the fuel used. This could be done using electrolysis. During electrolysis, the splitting of water produces hydrogen, which is then used as fuel in the fuel cell (Quaschning, 2021). Fuel cell systems with electrolyzers will not be considered further since the corresponding market in Germany is in its infancy at the moment.

Another possibility to increase energy autarky is the use of electricity storage systems, which store the self-generated electricity (here by a PV system) and make it available when there is no sufficient power supply. This way, differences between electricity supply and demand can be balanced out (Sterner and Bauer, 2017). In this work, electricity generation and storage are to be upheld with the help of a PV system and an electricity storage unit in the form of a lithium-ion accumulator (Mertens, 2020; Quaschning, 2021).

Heat generation and storage are maintained with the help of a geothermal probe and a heat pump with a heat storage unit. This is due to the fact that the technical installations for electricity and heat generation must not conflict in terms of space requirements. Such a conflict would cause the simultaneous use of solar thermal energy and PV systems because both require the installation of collectors on the roof. There are various forms of heat pumps to choose from, which can be differentiated in terms of heat sources (Becker, 2016; Quaschning, 2021). Heat sources differ in terms of temperature level and fluctuations.

Using the ground as a heat source has the advantage that temperature fluctuations are relatively small (Wesselak and Voswinckel, 2016), although these are greater at the surface than in deeper layers of the ground since the upper layer is still influenced by air temperature, whereas this is no longer the case in deeper layers of the ground (Günther, 2015; Kürten, 2015). Thus, the deeper one goes, the more independent the heat supply in the ground becomes from climatic influences (Kurzrock and Gauer, 2018). In turn, the efficiency becomes increasingly constant throughout the year, based on the deeper layers of the earth one reaches. In terms of efficiency, borehole heat exchangers have an advantage over surface collectors, which are installed at a depth of about one to two meters and require about 1.5 to 2 times the living area (Günther, 2015; Kurzrock and Gauer, 2018). This increased space requirement can be a factor not to be underestimated in the case of high land prices - and may have to be taken into account in an investment calculation via an increase in the acquisition payout. The advantage of surface collectors is that they are easier to install than geothermal probes. At the same time, geothermal probes can be subject to various legal regulations that can prevent their use.

When using air-source heat pumps, depending on the design, the outside air, exhaust air, and air from waste heat are used as heat sources (Becker, 2016). In contrast to the ground as a heat source, the air has much higher temperature fluctuations, which makes the planning and use of an air-source heat pump as the sole (monovalent) building heating system much more complicated. For example, in winter, when the building's heating load is highest, the efficiency of the air-source heat pump decreases as the temperature drops because the difference between the outdoor temperature and the supply temperature becomes greater (Günther, 2015; Quaschning, 2021). These considerations show that all types of heat pumps have certain advantages and disadvantages.

The profitability of a self-sufficient energy supply for a detached house, in terms of electricity and heat, is to be considered on the basis of a scenario-based example. For this purpose, a PV system with a lithium-ion accumulator for electricity generation/storage and a geothermal heat pump with surface collectors[1] for heating are used for the analysis (investment alternative 1 or IA-1). The system consists of the following components (for more information, see Watter, 2022; Quaschning, 2021).

- Geothermal heat pump with surface collectors
- Heat accumulator
- Grid-connected PV system
- Power storage
- Other (e.g., cabling, pipe connections, etc.)

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[1] Further calculations can, in principle, also be transferred to other types of heat pumps.

In order to be able to assess the quality of the results, investment alternative 2 (IA-2) is used as a comparison, in which electricity is drawn from the public grid and the heat is generated using a classic gas condensing boiler, which is the most widely used in Germany (BDEW, 2022). The analysis was carried out using the so-called Visualization of Financial Implications (VoFI) method, i.e., calculating full financial plans (Götze *et al*. 2008; Trost and Fox, 2017; Oesterreich and Teuteberg, 2020).

3. Profitability analysis with the Visualization of Financial Implications (VoFI)

3.1. Database scenario

3.1.1. General Information

The analysis is carried out in the context of a new construction of a detached house, which is occupied by four people. The living area of the house is set at 150 m^2, which is divided into one and a half floors. This roughly corresponds to the average living space of detached houses completed in Germany in 2019, which is 157 m^2 (Destatis, 2021). The roof shape chosen is a gable roof without dormers, skylights, or similar with an inclination of 45° and 0° south in orientation. According to the assumed size of the detached house, the usable roof area is approximately 165.52 m^2. For the size of the property, it is assumed that there is enough space for the required surface collectors and that no increase in the purchase payment is necessary. The location of the building is the city of Bischofsheim in Bavaria, Germany. For simplification reasons, the new building meets the standards of a German KfW Efficiency House 40, so the obligation to use renewable energies in accordance with the German Renewable Energy Sources Act does not apply to the investment alternative with the gas condensing boiler.

The period of consideration for the investment calculation is 20 years, which corresponds to the remuneration period of the German Renewable Energy Sources Act that establishes a payment claim for the electricity generated from renewable energies. All cash flows are in arrears. Corresponding offers were obtained from various companies for the work, taking into account reasonable market prices. Unless otherwise stated, this section references gross prices, which are based on market prices at the beginning of 2022.

3.1.2. Determination of the degree of autarky

The degree of autarky of the building for the investment project was determined with the help of a simulation model (degree of autarky calculator), in which the most important parameters influencing the overall system were taken into account. In addition to the size of the PV system and the battery storage, this also includes the diurnal and seasonal course of the electricity and heat demand, which depends on user behavior and the household's appliance equipment (Weniger *et al*. 2015).

The power output of the PV system depends on the location of the system and the solar radiation, as well as on the orientation of the solar modules (Mertens, 2020). For a realistic calculation, it is necessary to represent the energy supply and demand in high temporal resolution. For this purpose, these variables were simulated and recorded over the course of the day and the year.

The guidelines of the Association of German Engineers (Verein Deutscher Ingenieure, VDI) served as the database for these so-called load or generation profiles of the residential building under consideration. Accordingly, data for a detached house with the simultaneous category of a low-energy house was used (Verein Deutscher Ingenieure, 2021). For the location determination, categorization according to so-called type days was carried out in accordance with the Association of German Engineers, which are subdivided according to season, day of the week, and degree of cloudiness (Association of German Engineers, 2021), where the test reference year (TRY) 2017 serves as the basis. This is divided into summer, winter, and transition and differentiated between weekdays and Sundays, cloudy and clear days (Verein Deutscher Ingenieure, 2021). For detached houses, ten typical, standardized reference load profiles (nRLP) of the electricity and heating demand in 2-second, 1-minute, or 15-minute resolution are deposited in the guideline (Verein Deutscher Ingenieure, 2021). The TRY 2017 of climate zone 10 and the 15-minute resolution were used for the study (Verein Deutscher Ingenieure, 2021). Using the type day distribution, a simulation year was created by comparing the respective nRLP for a single-family/low-energy house with the normalized generation load profiles (nEP) for PV systems for each type day. Then, the difference between the generation profile (EP) of the PV system and the reference load profile (RLP) for electricity and heat was taken as the resulting electricity demand of the house.

Here, the energy demand for heating and domestic hot water must be converted into electricity demand since the provision of the heating demand is realized with an electric heat pump. Based on this data, the respective daily energy requirements per type day were calculated, and a daily load profile was derived from it. The respective daily load profiles were strung together according to the type day distribution of the TRY, from which the total energy demand of the whole year can be simulated (Verein Deutscher Ingenieure, 2021).

The electricity production of the PV system was also simulated for a whole year, according to the guidelines of the Association of German Engineers (Verein Deutscher Ingenieure, 2021). Now, it can be determined at any time whether there is an energy demand (the value of the reference load profile exceeds the value of the PV system generation profile) or an energy surplus (the value of the PV system generation profile exceeds the value of the reference load profile). Energy requirements must then either be drawn from the battery storage (battery discharge), if sufficient energy is stored here, or from the grid (grid purchase). Energy surpluses can be consumed directly (direct consumption), or if sufficient usable storage capacity is available, they can be fed into battery storage (battery charging) or the public grid (grid feeding).

The technology chosen is a lithium-ion accumulator (see section 2.3.), where energy efficiency is neglected due to its low relevance (Stadler *et al*. 2017). The battery inverter has an efficiency of 95% (Mertens, 2020). It is assumed that the same percentage of energy is lost during the charging and discharging of the storage tank. In addition, the usable storage capacity is reduced by 1% per annum for the simulation calculation, assuming a service life of 20 years (Mertens, 2020). In addition, the usable storage capacity already takes into account the maximum depth of discharge. The solar generator's inverter efficiency is already considered in the generation profile used. It is also assumed that the PV inverter is always dimensioned so that it can process the maximum PV power. For the degradation of the PV generator, it is assumed that the PV system has a power loss of 2% in the first year and 0.55% in the following years (Trinasolar, 2021).

3.1.3. Annual energy demand

The annual energy requirements for electricity and heat of the household must be determined to determine the degree of autarky. The annual energy demand for electricity for a house occupied by four people is up to 4,000 kWh/year for average consumer behavior in Germany (Stromspiegel, 2021) and is taken as the value for the base scenario. The energy demand for heat is calculated according to standards applicable in Germany DIN V 18599: 2018-09 or DIN V 18599, and it varies depending on the preferences of the builder regarding the insulation of the house. The heat demand for heating and hot water preparation for a new detached house that meets the requirements of a KfW Efficiency House 40 is approximately 65 kWh/m^2 per year (Mahler *et al*. 2019). This results in a total heat energy demand of 9,750 kWh/year for a living area of 150 m^2. Because heating, and domestic hot water heating, are realized by the ground source heat pump, it is assumed that approximately 83.5% of the total heat energy demand is accounted for by the heating - and an approximated 16.5% by the domestic hot water heating (Statistisches Bundesamt, 2021).

This results in a demand of 8,141 kWh/year for space heating and 1,609 kWh/year for domestic hot water. Assuming the heat pump's seasonal performance factor (SPF) is 4, the electricity demand for space heating is approximately 2,035 kWh/year, and it is 402 kWh/year for domestic hot water heating. The SPF is the ratio between the heat produced by the heat pump and the electricity consumed by the heat pump (Fraga *et al*. 2017). From these annual energy requirements, the energy requirements per type day can be determined (Verein Deutscher Ingenieure, 2021).

3.1.4. Size of the PV system

It is easy to understand that with a larger nominal power of the PV system, a larger on-grid autarky level can also be achieved. Therefore, the entire roof area of the detached house is used for the PV system. Of these, one-half faces south (ideal conditions), and the other half faces north. The PV modules used are Trina Vertex S TSM-400 DE09.08 from Trina Solar (Trinasolar, 2021). According to the dimensions and performance data of the modules, the nominal power of the entire PV system is 28 kWp (14 kWp per side of the roof). However, the north-facing solar modules can generate less power than the south-facing modules due to the lower solar irradiance, so it is assumed here that this side only achieves about 51% of the power generation of optimally oriented solar modules (see also Mertens, 2020). This results in a calculated nominal power of the PV system of approximately 21 kWp.

3.1.5. Degree of autarky and storage size

A battery storage system with a usable capacity of 16 kWh is used as the starting point for the investigations, since here, with a system size of 21 kWp, the increase in the degree of on-grid autarky to the next largest storage capacity just falls below a value of 0.50% (Appendix). The BYD Battery-Box Premium HVM 16.6 with a usable storage capacity of 16.56 kWh (BYD, no date) is selected as the storage unit, resulting in a load-based degree of autarky of 83.9%, an on-grid degree of autarky of 310.1%, and a self-consumption rate of 27% (Tables A1 and A2 in the Appendix). Further analysis of the input data is provided in section 3.3.

3.1.6. Acquisition costs

The PV system was created using the solar planning tool Solar Planit from BayWa r.e. Solar Energy Systems GmbH[2]. The values for solar modules, transports, and others were taken from various offers and adjusted to the plant size where necessary. The individual components and the corresponding costs are in Tables A3 and A4 in the Appendix. The total investment costs for the PV plant with storage system amount to €41,861.70 (net). The individual components and the corresponding costs for the geothermal system can be found in Table A5 in the Appendix, which results in an investment amount of €26,733.95. Accordingly, the total cost for the acquisition of IA-1 is €68,595.64. Further, it is assumed that an energy efficiency expert will be consulted for the project, for which the costs have been estimated at €600.00. The acquisition costs for the gas condensing heating system amount to €14,900.00. For the base scenario, it is assumed that the household can be connected to the gas supply network of the local gas supplier Bayerische Rhöngas GmbH.

3.1.7. Funding

For the PV system, the feed-in tariff obtained from the grid operator is set at the value from 01.10.2022 at 5.80 ct/kWh for the next 20 years (Bundesnetzagentur, 2022). This remuneration is derived from the Renewable Energy Sources Act (EEG) regulations mentioned in section 3.1.1. In order for the loan subsidy for the geothermal system to be possible based on the Building Energy Act, it is assumed that the Effizienzhaus 40 energy efficiency class is achieved. This allows a loan repayment subsidy of 22.50% for the geothermal system and 50% for specialist planning and construction support (BAFA, 2021a; BAFA, 2021b; KfW, 2022a). For the base scenario, this results in an absolute subsidy amount of €6,150.14 for the geothermal system. The commissioning of an energy efficiency expert is subsidized with a repayment subsidy of 50% (here €300.00). The repayment subsidy for the geothermal system and energy consulting is credited after the completion of the project. It thus reduces the loan amount to be repaid and

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[2] See https://www.solar-planit.de/solarplanit.

shortens the term (KfW, 2022a). There is no subsidy for IA-2 since the sole operation of a gas condensing boiler with the insulation standard of an Efficiency House 40 just about meets the legal requirements in Germany.

3.1.8. Financing and capital investment

The PV system with battery storage is financed via the KfW loan 270 (KfW, 2022b), where all requirements for the promotion should be fulfilled, and the debit interest rate is set, taking into account the economic circumstances of the borrower. The following conditions (as of 13.10.2022) are selected for the base scenario.

- Term and duration of the fixed interest rate: 120 months
- Repayment-free start-up period: 24 months
- Debit interest rate: 4.20% per annum (price class A: credit rating excellent)
- Repayment: quarterly in equal installments
- Interest payment: quarterly

The heat pump with surface heat collectors is financed via KfW loan 261 as a monthly annuity loan (KfW, 2022c), where all requirements for the promotion should be fulfilled. The following conditions apply to the base scenario (as of 13.10.2022).

- Term and duration of the fixed interest rate: 120 months
- Repayment-free start-up period: 24 months
- Debit interest rate: 0.64% per annum

Any period surpluses can be invested at a constant 0.0% per annum based on the average interest rate for overnight money in Germany in September 2022 (Deutsche Bundesbank, 2022)[3] although an increase in the interest rate level due to the ECB's key interest rate increases is very likely. However, this is not relevant for the base scenario due to a lack of surpluses. For the sake of simplicity, a possible interest credit would take place on a calendar year basis on December 31. The gas condensing boiler cannot be purchased with a KfW loan at a reduced rate. Therefore, a building loan is used, the conditions of which, like those for KfW loans, can change regularly. For the basic scenario, a loan broker (Dr. Klein, 2022) is used to obtain the corresponding conditions (as of 18.10.2022).

- Term and duration of the fixed interest rate: 120 months
- Debit interest rate: 0.64% per annum
- Repayment: monthly (annuity loan)

All costs incurred over the period under consideration could be covered by equity. However, opportunity costs would then have to be considered, which are difficult to determine for private individuals. Therefore, the other costs incurred for both investment alternatives in the base scenario are covered as a starting point by a loan in current account from Sparkasse Bad Neustadt, in whose catchment area the planned investment property is also located, at a debit interest rate of 11.22% per annum (as of 18.10.2022). It is also assumed that there is an unrestricted credit line and that free financial resources are used primarily to repay the loan in the current account. At the end of the term, the loan is repaid with own funds.

3.1.9. Useful life and residual value

The individual components of the investment alternatives have different lifetimes, which cannot always be estimated precisely. For this work, it is assumed that only the inverter, with a service life of 15 years, is below the observation period of 20 years (Kaltschmitt *et al*. 2020; Mertens, 2020; Wittlinger, 2020; Quaschning, 2021) and must therefore be replaced once. In principle, all components can still have a residual value after the period under consideration, which has a

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[3] Newer data are not yet available.

positive effect on the result. For reasons of simplification, a residual value of 0 is used in the base scenario, although adjustments can be integrated into the calculation at any time.

3.1.10. Operating payments

Electricity and gas prices are subject to strong fluctuations due to the current political and economic environment, which are likely to persist in the coming years. In 2021, for example, the average electricity price for a German household was 32.16 ct/kWh. In 2000, this price was still 13.94 ct/kWh (BDEW, 2022). In October 2022, the German comparison portal Verivox already indicated the average price at 41.00 ct/kWh. This shows the dynamic development in Germany, which makes it very difficult to forecast electricity prices (Verivox, 2022a). The figures represent a price increase of 194.1% over 22 years, which corresponds to an average increase per year of 5.03%. For the base scenario, the price of 41.00 ct/kWh is assumed, and this rate of increase is extrapolated.

The gas prices in Germany in 2021 averaged 7.06 ct/kWh, the same level as in 2009 (BDEW, 2022). Such low gas prices seem rather unlikely for the next few years, as presumably, higher gas prices are realistic due to the framework conditions (CO_2 tax, war in Ukraine). According to the German comparison portal Verivox, the average gas price in Germany in October 2022 was around 22 ct/kWh (Verivox, 2022b). In the base scenario, the average gas price in October 2022 is taken as the most current value. A price increase rate is omitted in the base scenario due to a lack of indications. The effects of corresponding changes in gas prices will be discussed in more detail later. The basic price is taken over by the public gas supplier Bayerische Rhöngas GmbH at 13,09 €/month (Bayerische Rhöngas GmbH, 2022).

No maintenance costs are taken into account for the PV system in the base scenario, as PV systems are considered to require relatively little maintenance in practice (Sandner, 2013), and there is currently no legal obligation to do so in the private sector in Germany. Thus, the modules can be operated without maintenance for 20 to 30 years (Quaschning, 2021). At the same time, however, it can make sense to carry out maintenance at certain intervals, especially if the system is exposed to problematic environmental influences or in order to regularly monitor the yield situation of the system so that any problems can be identified at an early stage (Sandner, 2013). The inverter and storage do lose power over time, but this cannot be prevented by maintenance. The only thing to consider is that in the 16th year of operation, the inverters are replaced (see section 3.1.9).

For reasons of simplification, the original price for the initial installation of the system is used (Table A3 in the Appendix). In addition, there is an installation fee of €500.00 gross (€420.17 net) per inverter, which is also based on the price of the original installation. The cost of maintenance of the geothermal system is €577.15 per annum. In the case of gas condensing heating, approximately €100.00 per annum are due for a flat-rate maintenance contract and approximately €50.00 every two years for the exhaust gas path inspection, which is carried out by the chimney sweep. Price increases are not taken into account in the base scenario due to a lack of empirical values. For the PV system, costs for insurance in the amount of €224.00 per annum (net) are taken into account. The heating systems are not insured.

In a profitability analysis, tax payments that occur must also be taken into account, where a distinction must be made between sales tax and income tax. Within the scope of the tax consideration, the standard taxation is initially selected for the PV system with the sales tax liability according to German law. This means that there is an input tax deduction entitlement, which is why the acquisition payment for the PV system is set at the net price for simplification purposes. After six years, a change to small business status is made in order to reduce the amount of work involved in the tax return. However, the operator of the PV system is then no longer entitled to deduct input tax. The sales tax liability exists for the sold as well as the self-consumed electricity. For any profits from operating the PV system, the top tax rate of 42% applicable in Germany is assumed.

The profit is determined from the difference between operating income and operating expenses. The operating income includes the income from the net feed-in tariff, the sales tax collected on this, the withdrawal of own consumption (value transfer, which is recognized with the feed-in tariff), the sales tax collected on this, and the VAT refund from the tax office. The operating expenses include depreciation, which is recognized for the PV system over a period of 20 years and for the storage system over a period of 10 years in accordance with the AfA table in Germany, interest payments, input tax amounts paid, insurance, maintenance and the VAT payment to the tax office (Bundesministerium der Finanzen, 2000). The feed-in compensation from the grid operator is used as the operating payments. From 1 October 2022, this amounts to 5.80 ct/kWh net for the electricity fed into the grid in Germany.

3.2. Calculation and evaluation of the base scenario

After defining all input parameters for the base scenario, the future values of the two alternatives are now determined. Table 1 shows the VoFI for the PV and geothermal system, and Table 2 shows the VoFI for the investment alternative 2. All values, except for the degree of load-based autarky, are given in euros. Periods 1, 4, 7, 10, and 20 are shown as examples. The complete VoFI can be seen in Tables A6 and A7 in the Appendix. The future value of the investment alternative 1 can be found in the line "net balance" in the last period and amounts to -€401,260.31. The net balance is not positive in any period and steadily decreases over the period under consideration due to the fact that the payment sequence of the investment is not greater than the financing costs in any period.

The future value of alternative 2, at -€441,342.30, is even smaller than alternative 1. Thus, the advantage of the PV and geothermal system, compared to the gas condensing heating system with power supply from the public grid, is €40,081.99. The main reason for this is the current high prices of gas in Germany. The rising price of electricity is also having a negative impact on alternative 2. Another strong effect on the result is the way in which the costs are financed over the period under consideration if we were to assume that the private individual does not take out an overdraft for financing but does not unrealistically fall back on it. For example, his savings in a call money account, which according to the base scenario, bears interest at 0%, then the future value of alternative 1 would be -€96,974.84 and that of alternative 2 would be -€129,200.06. However, the relative advantage of alternative 1 over alternative 2 would remain. In the following, we will focus on the main factors influencing energy autarky.

Table 1. VoFI of investment alternative 1 - PV and geothermal system

Year		**2022**	**2025**	**2028**	**2031**	**2032**	**2037**	**2041**
Period	**t = 0**	**t = 1**	**t = 4**	**t = 7**	**t = 10**	**t = 11**	**t = 16**	**t = 20**
Acquisition costs: PV system (net)	-31,537.41							
Acquisition costs: storage system (net)	-10,324.29							
Maintenance costs: PV system		0.00	0.00	0.00	0.00	0.00	-8,748.80	0.00
Insurance PV system		-224.00	-224.00	-224.00	-224.00	-224.00	-224.00	-224.00
Feed-in compensation (net)		940.18	921.99	903.83	885.67	879.61	849.35	825.14
Acquisition costs: geothermal system	-26,733.95							
Energy efficiency expert	-600.00							
Maintenance costs: geothermal system		-577.15	-577.15	-577.15	-577.15	-577.15	-577.15	-577.15
Electricity costs		-289.56	-363.88	-454.77	-565.33	-607.22	-862.18	-1,133.04
Series of net cash flows	-69,195.64	-150.53	-243.05	-352.09	-480.81	-528.76	-9,562.77	-1,109.04
Tax payment/refund		-396.34	-454.68	0.00	0.00	0.00	0.00	0.00
KfW-loan 270								
+ Credit intake	41,861.70							
- Debitor interest		-1,758.19	-1,456.00	-796.68	-137.36	0.00	0.00	0.00
- Redemption		0.00	-5,232.71	-5,232.71	-5,232.71	0.00	0.00	0.00
KfW-loan 261								
+ Credit intake	27,333.95							
- Debitor interest		-174.94	-144.87	-79.27	0.00	0.00	0.00	0.00
- Redemption		0.00	-3,416.74	-3,416.74	0.00	0.00	0.00	0.00

Table 1. Continued

Loan in current account								
+ Credit intake		2,480.00	12,857.24	16,553.55	18,334.34	15,069.33	34,746.65	
- Debitor interest			-1,909.19	-6,676.05	-12,483.46	-14,540.57	-25,183.88	-40,367.71
- Redemption			0.00	0.00	0.00	0.00	0.00	-359,783.55
Own funds (overnight money account)								
- Reinvestment		0.00	0.00	0.00	0.00	0.00	0.00	0.00
+ Financial return			0.00	0.00	0.00	0.00	0.00	0.00
+ Disinvestment			0.00	0.00	0.00	0.00	0.00	401,260.31
Net funding		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Balances								
on KfW-loan 270	-41,861.70	-41,861.70	-31,396.27	-15,698.14	0.00	0.00	0.00	0.00
on KfW-loan 261	-27,333.95	-27,333.95	-20,500.46	-10,250.23	0.00	0.00	0.00	0.00
on loan in current account	0.00	-2,480.00	-29,873.20	-76,054.90	-129,595.11	-144,664.43	-259,201.87	0.00
on own funds (overnight money account)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-401,260.31
Net balance	-69,195.64	-71,675.64	-81,769.93	-102,003.27	-129,595.11	-144,664.43	-259,201.87	-401,260.31
Load-based degree of autarky		89.55%	88.67%	87.78%	86.89%	86.59%	85.10%	83.91%

Table 2. VoFI of investment alternative 2 - electricity public grid and gas condensing boiler

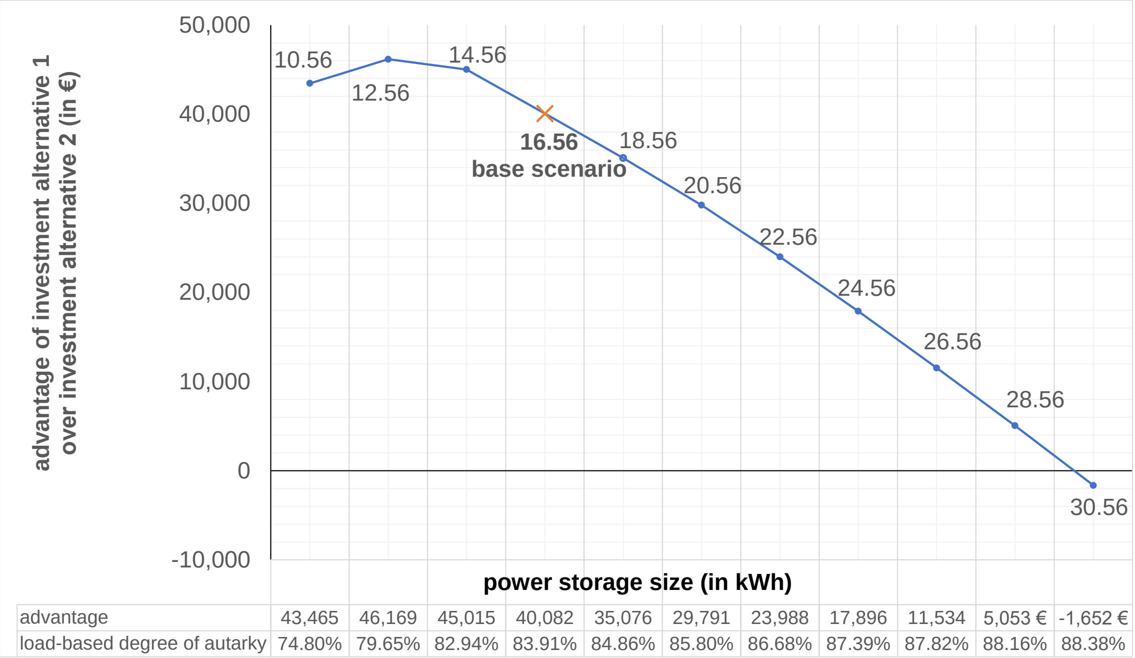
Year		**2022**	**2025**	**2028**	**2031**	**2032**	**2037**	**2041**
Period	**t = 0**	**t = 1**	**t = 4**	**t = 7**	**t = 10**	**t = 11**	**t = 16**	**t = 20**
Acquisition costs	-14,900.00							
Maintenance costs		-100.00	-150.00	-100.00	-150.00	-100.00	-150.00	-150.00
Electricity costs		-1,722.49	-1,995.71	-2,312.26	-2,679.03	-2,813.78	-3,596.31	-4,376.34
Gas costs		-2,302.08	-2,302.08	-2,302.08	-2,302.08	-2,302.08	-2,302.08	-2,302.08
Series of net cash flows	-14,900.00	-4,124.57	-4,447.79	-4,714.34	-5,131.11	-5,215.86	-6,048.39	-6,828.42
Mortgage loan								
+ Credit intake	14,900.00							
- Debitor interest		-1,644.64	-1,122.99	-601.35	-79.70	0	0	0
- Redemption		-1,490.00	-1.490,00	-1.490,00	-1.490,00	0	0	0
Loan in current account								
+ Credit Intake		7,259.22	9,764.91	13,147.92	17,970.55	18,501.90	32,519.74	
- Debitor interest			-2,704.13	-6,342.23	-11,269.74	-13,286.03	-26,471.35	-43,834.25
- Redemption								-390,679.62
Own funds (overnight money account)								
- Reinvestment		0	0	0	0	0	0	0
+ Financial return		0	0	0	0	0	0	0
+ Disinvestment		0	0	0	0	0	0	441,342.30
Net funding	0	0	0	0	0	0	0	0
Balances								
on mortgage loan	-14,900.00	-13,410.00	-8,940.00	-4,470.00	0	0	0	0
on loan in current account	0	-7,259.22	-33,865.85	-69,674.08	-118,413.86	-136,915.76	-268,449.77	0
on own funds (overnight money account)	0	0	0	0	0	0	0	-441,342.30
Net balance	-14,900.00	-20,669.22	-42,805.85	-74,144.08	-118,413.86	-136,915.76	-268,449.77	-441,342.30

3.3. Analysis and optimization of the base scenario with regard to the degree of autarky

3.3.1. The storage size as a critical variable

As described, the result of the base scenario does not yet represent the situation of 100% load-based autarky. This means that the supply of electricity to the house cannot be guaranteed all the time by the PV system. Therefore, this study investigated how large the storage system would have to be in order to achieve load-based autarky with the given maximum possible number of PV modules on the roof and the extent to which this would make economic sense.

Notably, more than three times the electricity needed for the home is produced (on-grid degree of autarky: 310.1%). Figure 1 shows the evolution of the degree of load-based autarky for different storage sizes, taking into account economic efficiency. This shows that from a storage size of approximately 30 kWh, the investment considered is no longer economically worthwhile compared to a gas condensing boiler using the public power grid, and at the same time, the load-based degree of autarky is still only approximately 88%. Even in the extreme case of a storage size of 100 kWh, the load-based degree of autarky would only be 91.07%, and there would be a deterioration of the result by about €302,000 compared to the baseline scenario. This clearly shows that 100% load-based autarky is far from being economically worthwhile. At the same time, it becomes apparent that the basic scenario with a storage of 16.56 kWh does not represent the economic optimum. This lies at approximately 12.56 kWh and an advantage of €46,169.



advantage	43,465	46,169	45,015	40,082	35,076	29,791	23,988	17,896	11,534	5,053 €	-1,652 €
load-based degree of autarky	74.80%	79.65%	82.94%	83.91%	84.86%	85.80%	86.68%	87.39%	87.82%	88.16%	88.38%

Figure 1. The advantage of a PV depending on the size of the power storage

Note: The figure shows the advantage of a PV with geothermal system compared to a gas condensing heating system using electricity from the public grid depending on the size of the power storage.

3.3.2. The system size as a critical variable

Another influence on autarky and the corresponding economic efficiency is the size of the system. In the base scenario, the entire roof area was covered with modules, although half of the roof area had a non-optimal north orientation. At the same time, this system size represents the technical maximum in terms of the load-oriented degree of self-sufficiency unless there were other areas available for development (e.g., garage), which would enable a higher electricity yield. If, on the other hand, the number of modules was to be reduced, the degree of self-sufficiency, in terms of load and balance sheet, would also be reduced since less electricity would be produced to cover the energy demand (see Tables A1 and A2 in the Appendix).

3.3.3. On-grid autarky

For the goal of on-grid autarky, alternative 1 must have as much energy output as it consumes after 20 years. This means that the PV system must still generate at least 6,437 kWh (from the base scenario) of electricity after 20 years. The optimal storage size is selected analogously to the procedure from section 3.3.1. Based on these assumptions, the PV plant is set with the following parameters.

- Nominal power: 6.8 kWp
- Electricity yield in t = 20: 6,463.64 kWh
- Storage size: 5.12 kWh
- PV system orientation: south
- Acquisition costs of new PV system: €9,274.07 (net)
- Acquisition costs of new PV storage system: €4,868.32 (net)
- New PV insurance: €54.40 per annum

The remaining data is taken from the base scenario. The future value of alternative 1 in the "on-grid autarky" scenario is €357,279.54, with an on-grid degree of autarky of 100.41. The load-based degree of autarky is 47.14%. This corresponds to an improvement in the future value of €43,980.77 in contrast to the baseline scenario; the advantage of the system with PV and geothermal system over the gas condensing heating system with power supply from the public grid is now €84,062.75. Here, above all, the much lower installation costs of the PV system have a disproportionately positive effect on the result.

3.3.4. Load-based autarky

The load-based autarky scenario investigates how a system must be designed if it is to be completely autarkic in terms of energy without aiming for an off-grid solution so that the excess energy produced by the PV system can be fed into the public grid. The total PV system size, including storage, is selected in such a way that it will have a load-based degree of autarky of 100% after 20 years. This results in the following parameters for the PV plant:

- Nominal power: 30 kWp
- Electricity yield in t = 20: 28,516.04 kWh
- Storage Size: 44.16 kWh
- PV system orientation: south
- Acquisition costs of new PV system: €33,257.14 (net)
- Acquisition costs of new PV storage system: €23,982.02 (net)
- Funding amount for the new PV storage system: €3,200.00
- New PV insurance: €54.40 per annum

In contrast to the base scenario, it is now assumed that the plant has a complete southern orientation, which is made possible by additional areas (such as a garage, etc.). This is, of course, a very idealized assumption and will probably only rarely be encountered in practice. The remaining data are taken from the base scenario. Alternative 1 now has a future value of €-24,454.64, which is a deterioration compared to the baseline scenario of €23,194.33. At the same time, however, it is still better than alternative 2 by €16,887.66. Not surprisingly, the improved orientation of the PV system has a major impact on the amount of electricity fed into the grid, in contrast to the base scenario. Thus, the revenue from the feed-in tariff exceeds the operating costs in every period considered except the 16th (replacement inverter). However, these surpluses are not sufficient to justify the higher acquisition payout in contrast to the baseline scenario, which is why the future value is lower.

3.4. Gas and electricity prices as critical variables

Gas and electricity prices do not have a direct impact on the degree of self-sufficiency, but they do have an impact on the profitability of a self-sufficient system. The current situation in the context of the Ukraine war led to an enormous increase in gas and electricity prices in 2022 in Germany and many other parts of the world. Figure 2 shows the course of the advantageousness depending on the gas price.

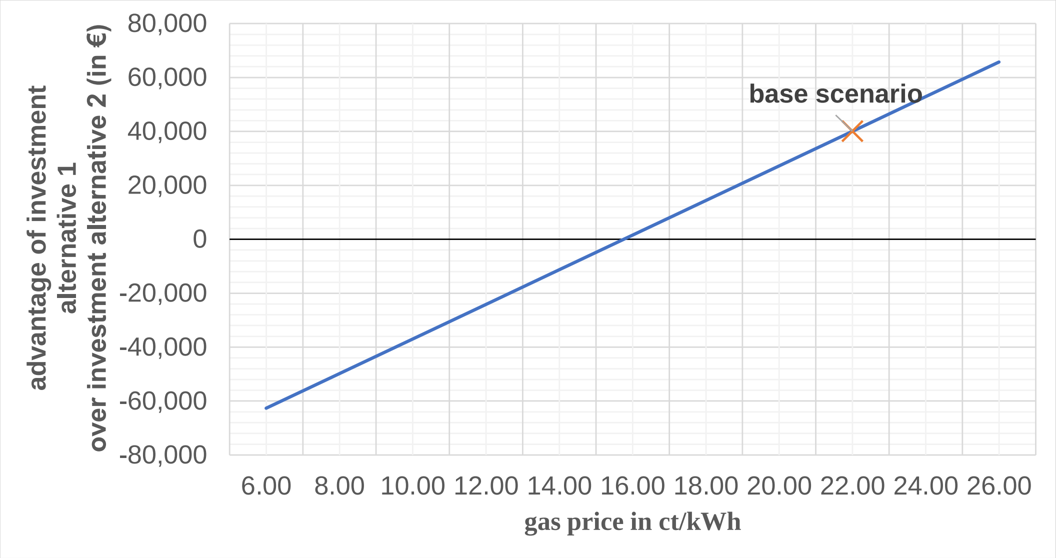


Figure 2. Advantage of a PV depending on the gas price

Note: The figure shows the advantage of a PV with geothermal system compared to a gas condensing heating system with electricity from the public grid depending on the gas price.

It becomes clear that with an average gas price in Germany, from the year 2021, the amount of 7.06 ct/kWh, the considered PV with geothermal system, is far from economical compared to conventional heating with gas (€-55,833.46). Only the present high gas prices in Germany lead to the fact that one can pursue an economical operation. Thus, the gas price development and/or the price development of all classical fuels have a crucial influence on the acceptance of alternative energies with the current and heat supply. The planned gas price cap in Germany, at 12 ct/kWh for 80% of the purchased electricity in 2023 (Reuters, 2022), could mean that alternative 1 would no longer be worthwhile since the critical value of the gas price is just under 15 ct/kWh. Figure 3 shows the course of the advantageousness depending on the electricity price.

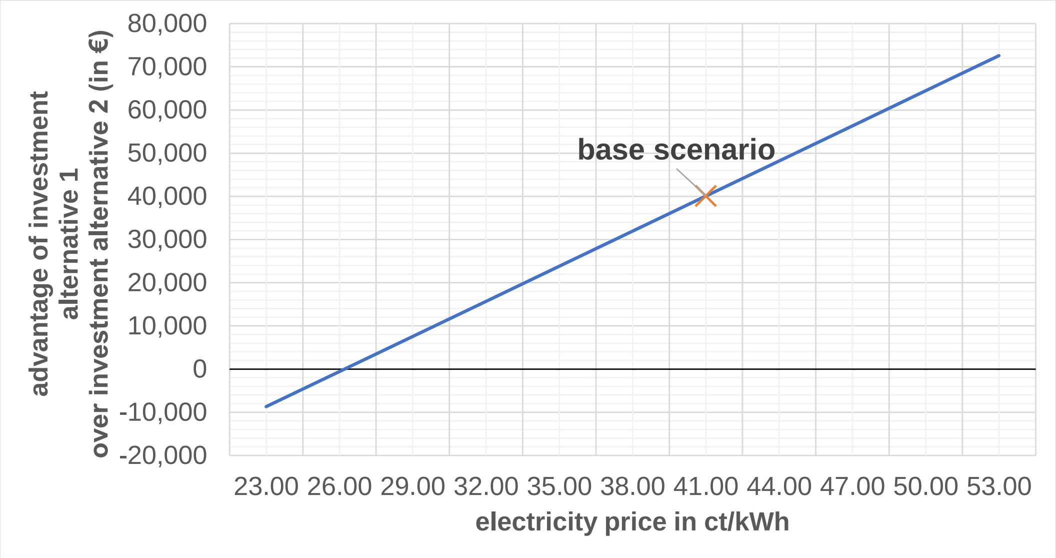


Figure 3. Advantage of a PV depending on the electricity price

Note: The figure shows the advantage of a PV with geothermal system compared to the electricity condensing heating system with electricity from the public grid depending on the electricity price.

As with gas prices, the development of the electricity price has a major influence on the economic efficiency of the systems. As with the gas price, the current high electricity prices mean that the PV with geothermal system under consideration can be operated economically compared to conventional heating with gas. In contrast to the gas price, however, this economic operation would also have been possible with the average electricity price in Germany from 2021 of 32.16 ct/kWh, although the effects of the planned electricity price cap in Germany in 2023 (Reuters, 2022) on the result must also be examined.

4. Conclusion

The results show that the goal of energy autarky in the private sector need not be uneconomical per se. However, due to a large number of factors, only specific situations can be depicted. Under the assumptions made for a detached house in Germany, it is shown that both on-grid and load-based autarky can be economical compared to a conventional energy supply system.

Thus, the difference in the acquisition costs is offset by subsidies (financing relief, feed-in tariff) and the high energy costs). Other important factors that affect economic efficiency and the degree of self-sufficiency are the size and orientation of the PV system. Additionally, it is important to adapt the storage size to the energy demand and to match it optimally to the PV system size. The many individual constellations and the rapidly changing framework conditions (energy costs, subsidies) mean that decisions have to be reviewed regularly, and no blanket statements can be made. Thus, in the base scenario, the advantage of the system with PV and geothermal system over the gas condensing heating system with power supply from the public grid was €40,081.99. A calculated PV output of 21 kWp and a usable storage capacity of 16.56 kWh was used, and a load-based degree of autarky of approximately 83.91% was achieved after 20 years. A planned gas price cap in Germany, at 12 ct/kWh for 80% of consumption, would result in alternative 1 no longer being worthwhile compared to alternative 2 in the base scenario.

With regard to the autarky figures, it could be shown that at 100% on-grid autarky, the system with PV and geothermal system is advantageous compared to the gas condensing heating system using power supply from the public grid. In this case, a smaller, optimally aligned system achieves a significantly better future value than in the base scenario. Although the load-based degree of self-sufficiency then drops to about half in the load-based autarky scenario, it can be seen that complete load-based autarky is theoretically possible. Such a larger plant would generate higher revenues due to the higher electricity sales in the summer months, but this cannot justify the higher acquisition costs compared to a smaller plant. It should be noted, however, that the technical assumptions made for load-based autarky of 100% are rather unrealistic, such that the implementation of such a system is only possible in the least cases.

Other framework conditions, such as the assumed interest rates, seem to be variables that need to be regularly scrutinized against the background of current developments in the financial markets. Regarding weather conditions, it seems plausible that sunnier weather makes it easier to achieve a self-sufficient energy supply and makes it economical. This means that sunny regions, in particular, should have the opportunity to successfully implement such a concept. Finally, the increasingly scarce fossil fuels and the associated rising costs, as well as the global quest for "green energy", could make the realization of autarky increasingly attractive for private individuals in the coming years. Legal regulations that significantly restrict the use of non-renewable energy could be another building block to encourage households to meet their energy needs via renewable energy systems.

Future research could, on the one hand, investigate further investment alternatives since, for example, the gas supply is not feasible in all cases. On the other hand, such investigations could be extended to the corporate sector, which faces similar challenges as private individuals.

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Appendix

Table A1. Autarky indicators in the base scenario

Storage size (in kWh)	Degree of on-grid autarky	Self-consumption rate	Delta
0	36.00%	11.61%	0.00%
1	40.42%	13.03%	4.42%
2	44.73%	14.42%	4.31%
3	49.04%	15.81%	4.31%
4	53.35%	17.20%	4.31%
5	57.66%	18.59%	4.31%
6	61.73%	19.91%	4.07%
7	64.79%	20.89%	3.06%
8	67.78%	21.86%	3.00%
9	70.59%	22.76%	2.80%
10	73.30%	23.64%	2.72%
11	75.92%	24.48%	2.62%
12	78.39%	25.28%	2.47%
13	80.57%	25.98%	2.18%
14	82.50%	26.60%	1.93%
15	83.16%	26.82%	0.66%
16	83.64%	26.97%	0.48%
17	84.12%	27.13%	0.48%
18	84.59%	27.28%	0.47%
19	85.06%	27.43%	0.47%
20	85.54%	27.58%	0.47%
21	86.00%	27.73%	0.47%
22	86.44%	27.88%	0.44%
23	86.87%	28.01%	0.42%
24	87.26%	28.14%	0.40%
25	87.49%	28.21%	0.22%
26	87.71%	28.29%	0.22%
27	87.90%	28.34%	0.18%
28	88.06%	28.40%	0.17%
29	88.21%	28.45%	0.15%
30	88.32 %	28.48%	0.11%

Note: The table shows the degree of on-grid autarky and the self-consumption rate for a 21 kWp PV system depending on the storage size in the base scenario.

Table A2. Degree of load-based autarky for different system sizes

System size (in kWp)	Degree of load-based autarky
5	78.47 %
10	156.94 %
15	235.42 %
21	310.10 %
25	392.36 %
30	470.83 %

Table A3. Acquisition costs - PV system 28 kWp (net)

System part	Name	Quantity	Single price	Total price
Solar panel	Trina Vertex S TSM-400DE09.08 - 400 Wp	70	€188.83	€13,218.10
PV inverter	SMA Sunny Tripower STP 15000TL-30	2	€2,035.21	€4,070.42
Mounting systems	Solar Planit Tool	1	€4,105.13	€4.105.13
Generator junction box	GAK mit Überspannungsschutz 2 MPPT	1	€348.76	€348.76
Radio ripple control receiver	-	1	€1,500.00	€1,500.00
Delivery	-	1	€250.00	€250.00
Installation	-	1	€6,825.00	€6,825.00
Connection to the power grid	-	1	€1,220.00	€1,220.00
	Total price			**€31,537.41**

Table A4. Acquisition costs - storage system 16.56 kWh (net)

System part	Name	Quantity	Single price
Battery inverter	Kostal PLENTICORE Bi 10/26	1	€2,021.01
Battery storage	BYD B-Box Premium HVM 16.6	1	€7,803.28
Delivery	-	1	€150.00
Installation	-	1	€350.00
	Total price		**€10,324.29**

Table A5. Acquisition costs geothermal system (gross)

System part	Name	Quantity	Single price	Total price
Geothermal heat pump	OCHSNER TERRA DX 11 HCUA	1	€10,994.41	€10,994.41
Heat source system	Cu-Erdkollektor O-Tube-Pro 12x0,8mm 75m	7	€490.28	€3,431.96
Heat source system	Warmbandrolle 250m	3	€28.56	€85.68
Heat utilization system	Trennspeicher PU 500 inkl. Isolierung	1	€904.40	€904.40
Heat utilization system	Tauchhülse 210mm, 1/2"	2	€16.66	€33.32
Hot water system	3-Wege-Umschaltmodul intern für M2-2 (TERRA DX)	1	€285.60	€285.60
Hot water system	Warmwasserspeicher SP350 emailliert und isoliert 4,5 qm Register	1	€2,327.64	€2,327.64
Hot water system	Tauchhülse für SP350/550, UNI 500/1000 1 Fühler, 100 mm, 1/2", 7 mm Durchmesser	1	€16.66	€16.66
Installation	-	1	€1,329.23	€1,329.23
Miscellaneous	Anbindeleitung-Set TERRA DX 11 (5 m)	1	€301.07	€301.07
Miscellaneous	Electricity meter	1	€411.74	€411.74
Surface heat collectors	Earthworks	1	€6,612.24	€6,612.24
	Total price			**€26,733.95**

Table A6. Complete VoFI of investment alternative 1 (Years 2022 to 2031)

Year		**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
Period	**t = 0**	**t = 1**	**t = 2**	**t = 3**	**t = 4**	**t = 5**	**t = 6**	**t = 7**	**t = 8**	**t = 9**	**t = 10**
Acquisition costs: PV system (net)	-31,537										
Acquisition costs: storage system (net)	-10,324										
Maintenance costs: PV system		0	0	0	0	0	0	0	0	0	0
Insurance PV system		-224	-224	-224	-224	-224	-224	-224	-224	-224	-224
Feed-in compensation (net)		940	934	928	922	916	910	904	898	892	886
Acquisition costs: geothermal system	-26,734										
Energy efficiency expert	-600										
Maintenance costs: geothermal system		-577	-577	-577	-577	-577	-577	-577	-577	-577	-577
Electricity costs		-290	-313	-337	-364	-392	-422	-455	-489	-526	-565
Series of net cash flows	-69,196	-151	-180	-211	-243	-277	-314	-352	-393	-435	-481
Tax payment/refund		-396	-415	-434	-455	-476	-498	0	0	0	0
KfW-loan 270											
+ Credit intake	41,862										
- Debitor interest		-1,758	-1,758	-1,676	-1,456	-1,236	-1,016	-797	-577	-357	-137
- Redemption		0	0	-5,233	-5,233	-5,233	-5,233	-5,233	-5,233	-5,233	-5,233
KfW-loan 261											
+ Credit Intake	27,334										
- Debitor interest		-175	-175	-167	-145	-123	-101	-79	-57	-11	0
- Redemption		0	0	-3,417	-3,417	-3,417	-3,417	-3,417	-3,417	-383	0
Loan in current account											
+ Credit Intake		2,480	2,806	11,730	12,857	14,114	15,514	16,554	18,210	16,996	18,334
- Debitor interest			-278	-593	-1,909	-3,352	-4,935	-6,676	-8,533	-10,576	-12,483
- Redemption			0	0	0	0	0	0	0	0	0
Own funds (overnight money account)											
- Reinvestment		0	0	0	0	0	0	0	0	0	0
+ Financial return			0	0	0	0	0	0	0	0	0
+ Disinvestment			0	0	0	0	0	0	0	0	0
Net funding		0	0	0	0	0	0	0	0	0	0
Balances											
on KfW-loan 270	-41,862	-41,862	-41,862	-36,629	-31,396	-26,164	-20,931	-15,698	-10,465	-5,233	0
on KfW-loant 261	-27,334	-27,334	-27,334	-23,917	-20,500	-17,084	-13,667	-10,250	-6,833	0	0
on loan in current account	0	-2,480	-5,286	-17,016	-29,873	-43,987	-59,501	-76,055	-94,265	-111,261	-129,595
on own funds (overnight money account)	0	0	0	0	0	0	0	0	0	0	0
Net balance	-69,196	-71,676	-74,482	-77,562	-81,770	-87,234	-94,099	-102,003	-111,564	-116,493	-129,595
Load-based degree of autarky		89.6%	89.3%	89.0%	88.7%	88.4%	88.1%	87.8%	87.5%	87.2%	86.9%

Note: The table shows the future value of the investment alternative 1 (PV and geothermal system) using a VOFI for the years 2022 to 2031.

Table A6. Complete VoFI of investment alternative 1 (Years 2032 to 2041)

Year	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**
Period	t = 11	t = 12	t = 13	t = 14	t = 15	t = 16	t = 17	t = 18	t = 19	t = 20
Acquisition costs: PV system (net)										
Acquisition costs: storage system (net)										
Maintenance costs: PV system	0	0	0	0	0	-8,749	0	0	0	0
Insurance PV system	-224	-224	-224	-224	-224	-224	-224	-224	-224	-224
Feed-in compensation (net)	880	874	868	861	855	849	843	837	831	825
Acquisition costs: geothermal system										
Energy efficiency expert										
Maintenance costs: geothermal system	-577	-577	-577	-577	-577	-577	-577	-577	-577	-577
Electricity costs	-607	-652	-700	-750	-804	-862	-924	-989	-1,059	-1,133
Series of net cash flows	-529	-579	-633	-690	-750	-9,563	-881	-953	-1,029	-1,109
Tax payment/refund	0	0	0	0	0	0	0	0	0	0
KfW-loan 270										
+ Credit intake										
- Debitor interest	0	0	0	0	0	0	0	0	0	0
- Redemption	0	0	0	0	0	0	0	0	0	0
KfW-loan 261										
+ Credit intake										
- Debitor interest	0	0	0	0	0	0	0	0	0	0
- Redemption	0	0	0	0	0	0	0	0	0	0
Loan in current account										
+ Credit intake	15,069	16,811	18,751	20,911	23,318	34,747	29,964	33,397	37,220	
- Debitor interest	-14,541	-16,231	-18,118	-20,221	-22,568	-25,184	-29,082	-32,444	-36,192	-40,368
- Redemption	0	0	0	0	0	0	0	0	0	-359,784
Own funds (overnight money account)										
- Reinvestment	0	0	0	0	0	0	0	0	0	0
+ Financial return	0	0	0	0	0	0	0	0	0	0
+ Disinvestment	0	0	0	0	0	0	0	0	0	401,260
Net funding	0	0	0	0	0	0	0	0	0	0
Balances										
on KfW-loan 270	0	0	0	0	0	0	0	0	0	0
on KfW-loant 261	0	0	0	0	0	0	0	0	0	0
on loan in current account	-144,664	-161,475	-180,226	-201,137	-224,455	-259,202	-289,166	-322,563	-359,784	0
on own funds (overnight money account)	0	0	0	0	0	0	0	0	0	-401,260
Net balance	-144,664	-161,475	-180,226	-201,137	-224,455	-259,202	-289,166	-322,563	-359,784	-401,260
Load-based degree of autarky	86.6%	86.3%	86.0%	85.7%	85.4%	85.1%	84.8%	84.5%	84.2%	83.9%

Note: The table shows the future value of the investment alternative 1 (PV and geothermal system) using a VOFI for the years 2032 to 2041.

Table A7. Complete VoFI of investment alternative 2

Year		**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**
Period	**t = 0**	**t = 1**	**t = 2**	**t = 3**	**t = 4**	**t = 5**	**t = 6**	**t = 7**	**t = 8**	**t = 9**	**t = 10**
Acquisition costs	-14,900										
Maintenance costs		-100	-150	-100	-150	-100	-150	-100	-150	-100	-150
Electricity costs		-1,722	-1,809	-1,900	-1,996	-2,096	-2,202	-2,312	-2,429	-2,551	-2,679
Gas costs		-2,302	-2,302	-2,302	-2,302	-2,302	-2,302	-2,302	-2,302	-2,302	-2,302
Series of net cash flows	-14,900	-4,125	-4,261	-4,302	-4,448	-4,498	-4,654	-4,714	-4,881	-4,953	-5,131
Mortgage loan											
+ Credit intake	14,900										
- Debitor interest		-1,490	-1,490	-1,490	-1,490	-1,490	-1,490	-1,490	-1,490	-1,490	-1,490
- Redemption		-1,645	-1,471	-1,297	-1,123	-949	-775	-601	-427	-254	-80
Loan in current account											
+ Credit intake		7,259	8,036	8,805	9,765	10,737	11,923	13,148	14,616	16,154	17,971
- Debitor interest			-814	-1,716	-2,704	-3,800	-5,004	-6,342	-7,817	-9,457	-11,270
- Redemption											
Own funds (overnight money account)											
- Reinvestment		0	0	0	0	0	0	0	0	0	0
+ Financial return		0	0	0	0	0	0	0	0	0	0
+ Disinvestment		0	0	0	0	0	0	0	0	0	0
Net funding	0	0	0	0	0	0	0	0	0	0	0
Balances											
on mortgage loan	-14,900	-13,410	-11,920	-10,430	-8,940	-7,450	-5,960	-4,470	-2,980	-1,490	0
on loan in current account	0	-7,259	-15,296	-24,101	-33,866	-44,603	-56,526	-69,674	-84,290	-100,443	-118,414
on own funds (overnight money account)	0	0	0	0	0	0	0	0	0	0	0
Net balance	-14,900	-20,669	-27,216	-34,531	-42,806	-52,053	-62,486	-74,144	-87,270	-101,933	-118,414
Year	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	
Period	*t* = 11	*t* = 12	*t* = 13	*t* = 14	*t* = 15	*t* = 16	*t* = 17	*t* = 18	*t* = 19	*t* = 20	
Acquisition costs											
Maintenance costs	-100	-150	-100	-150	-100	-150	-100	-150	-100	-150	
Electricity costs	-2,814	-2,955	-3,104	-3,260	-3,424	-3,596	-3,777	-3,967	-4,167	-4,376	
Gas costs	-2,302	-2,302	-2,302	-2,302	-2,302	-2,302	-2,302	-2,302	-2,302	-2,302	
Series of net cash flows	-5,216	-5,407	-5,506	-5,712	-5,826	-6,048	-6,179	-6,419	-6,569	-6,828	
Mortgage loan											
+ Credit intake											
- Debitor interest	0	0	0	0	0	0	0	0	0	0	
- Redemption	0	0	0	0	0	0	0	0	0	0	
Loan in current account											
+ Credit intake	18,502	20,769	23,198	26,007	29,039	32,520	36,299	40,612	45,318		
- Debitor interest	-13,286	-15,362	-17,692	-20,295	-23,213	-26,471	-30,120	-34,193	-38,750	-43,834	
- Redemption										-390,680	
Own funds (overnight money account)											
- Reinvestment	0	0	0	0	0	0	0	0	0	0	
+ Financial return	0	0	0	0	0	0	0	0	0	0	
+ Disinvestment	0	0	0	0	0	0	0	0	0	441,342	
Net funding	0	0	0	0	0	0	0	0	0	0	
Balances											
on mortgage loan	0	0	0	0	0	0	0	0	0	0	
on loan in current account	-136,916	-157,685	-180,883	-206,891	-235,930	-268,450	-304,749	-345,361	-390,680	0	
on own funds (overnight money account)	0	0	0	0	0	0	0	0	0	-441,342	
Net balance	-136,916	-157,685	-180,883	-206,891	-235,930	-268,450	-304,749	-345,361	-390,680	-441,342	

Note: The table shows the future value of the investment alternative 2 (electricity public grid and gas condensing boiler) using a VOFI for the years 2022 to 2041.