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ELECTRICITY - THE RENEWABLE ENERGY SOURCE FOR INDUSTRY

GRID CHARGES AS THE KEY TO THE ECONOMIC USE OF ELECTRICITY-BASED PROCESS HEAT AND THERMAL STORAGE IN INDUSTRY AND COMMERCE

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BVES - Energy Storage Systems Association
Oranienburger Straße 15, 10178 Berlin
030 - 54 610 630
E-Mail: info@bves.de
Internet:
Contact person: Simon Steffgen ( ) s.steffgen@bves.de

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DESIGN AND PRODUCTION

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1. ELECTRICITY – THE RENEWABLE FUEL

ELECTRICITY IS THE CENTRAL ENERGY SOURCE OF THE ENERGY TRANSITION IN ALL SECTORS

Electricity is the main energy source in a renewable energy system. In order to also electrify mobility, heating and process heat requirements, efficient coupling of the sectors is required. The conversion of electricity into heat, so-called power-to-heat (PtH) applications, are therefore a central component of the transformation. Many industrial applications that are currently powered by fossil fuels will be covered by electricity in the future. Electricity is the renewable fuel for industry. This means that the electricity grids will become the backbone of the energy infrastructure. In principle, this means simplification, as many infrastructures for gas, oil and coal will no longer be needed. However, the path to this is complex.

STORAGE AS THE KEY TO THE INDUSTRIAL USE OF ELECTRICITY FOR PROCESS HEAT

Storage systems are the key building block for using electricity as a fuel for industry in a renewable energy system. Electricity generation from PV and wind systems is volatile. That is why storage is needed. Storage is needed at all levels of the energy system: in generation, in the grid and in consumption.

THE VOLATILITY OF ELECTRICITY PRICES BECOMES AN OPPORTUNITY FOR COMPANIES WITH STORAGE SYSTEMS

However, it is not only generation that is volatile, but also the price of electricity. Companies can use energy storage systems to take advantage of and benefit from favorable electricity prices. The economic potential of energy procurement through flexibility with storage should also be exploited by the companies themselves and thus contribute to resilience and cost reduction for the industry.

GRID FEES ARE THE HURDLE FOR THE MARKET ENTRY OF POWER-TO-HEAT

The decisive factor for the industrial use of electricity to generate process heat is the cost. In the case of electricity, it is not the generation costs that are the problem today, but the costs for transportation – the grid fees: grid fees for electricity procurement are currently the decisive obstacle to the broad market entry of power-to-heat technologies in Germany.

"GRID CHARGES FOR ELECTRICITY PROCUREMENT ARE CURRENTLY THE KEY OBSTACLE TO THE BROAD MARKET ENTRY OF POWER-TO-HEAT TECHNOLOGIES IN GERMANY."

NEED FOR ACTION FOR A SUCCESSFUL TRANSFORMATION

This paper addresses the issue of grid fees in Germany. Meeting this challenge constructively represents a decisive step towards the transformation and decarbonization of the industry. And therefore also a decisive step towards achieving the climate targets. Energy policy is industrial policy.

1.1 RESISTANCE HEATING PLUS THERMAL STORAGE: MAKING PROCESS HEAT GENERATION WITH ELECTRICITY ECONOMICAL

Power-to-heat means converting electricity into heat. The principle is familiar from the household sector: whether stoves, ovens, kettles or hair dryers – it is common for these applications to rely on electricity-based heat generation. What works on a small scale is already working on an industrial scale.

"THE CONVERSION OF ELECTRICITY INTO HEAT IS ALMOST LOSS-FREE WITH AN EFFICIENCY OF 99%."

The conversion of electricity into heat is almost loss-free with an efficiency of 99% using resistance heaters. Such efficiency is very unusual in the energy system. Fuels, whether renewable or not, hardly achieve values of 50%. In terms of efficiency, resistance heaters are only surpassed by heat pumps, which use the ambient temperature to generate many times more heat than the amount of electricity used. Up to now, however, heat pumps have reached their limits at around 200 degrees Celsius. Above this temperature, resistance heaters with "only" 99% efficiency must be used.

For the economic use of power-to-heat systems, the electricity procurement for process heat generation must be optimized on the electricity market, i.e. to take advantage of favourable electricity prices on the electricity exchange and to guarantee an optimal feed-in of the heat into the process. A pure generation unit consisting of resistance heaters without thermal storage would not be economically viable: This is because the company is then directly dependent on current electricity prices and these are significantly more expensive than the competition, natural gas, in most hours today. This also applies if the price of CO_2 certificates is included.

"THERMAL STORAGE SYSTEMS MAKE IT POSSIBLE TO TAKE ADVANTAGE OF FAVORABLE ELECTRICITY PRICES ON THE ELECTRICITY EXCHANGE AND THUS OPEN UP ECONOMIC OPPORTUNITIES FOR COMPANIES."

Such direct electrification would also be poison for the energy system. Because flexibility is then not possible. Demand must be always drawn from the grid. Companies must therefore be able to act flexibly to optimize costs and, from the perspective of the electricity system, it is precisely this load-side flexibility that is needed to keep an electricity system based on renewable generation stable. Both can be achieved with thermal storage systems.

"DIRECT ELECTRIFICATION OF INDUSTRIAL PROCESSES WITHOUT THERMAL STORAGE WOULD BE POISON FOR THE ENERGY SYSTEM."

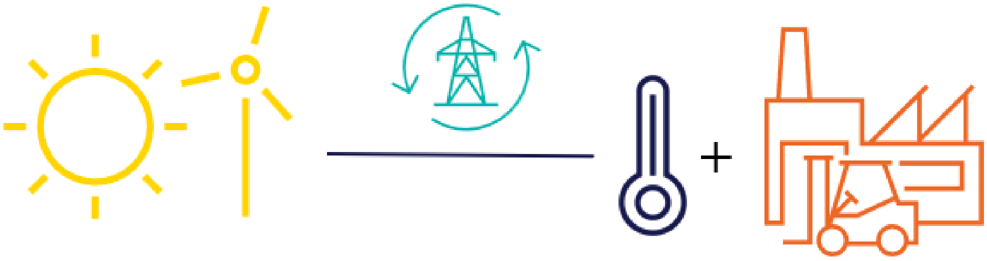


Figure: Renewable electricity generation, public supply grid, power-to-heat system with thermal storage at an industrial customer

1.2 STORAGE TEMPERATURES OF UP TO 1300 DEGREES CELSIUS ENABLE USE IN A LARGE NUMBER OF INDUSTRIAL PROCESSES

The range of applications for PtH systems with thermal storage is very broad and covers a variety of different processing and production processes in trade and industry. From low-temperature applications, for which a heat pump generates the required thermal energy, to high-temperature applications in the 1300 degree Celsius range, there are technologically suitable solutions that have already been tested and proven. Even large CHP or combined heat and power plants can be decarbonized via thermal storage and integrated into the renewable electricity system. The steam is provided via the electricity-based thermal energy generated by the storage system and can be converted into electricity as required. There are very few processes that cannot be decarbonized using electricity-based PtH systems.

2. THERMAL STORAGE - THE SWISS ARMY KNIFE OF THE ENERGY TRANSITION

2.1 DECARBONIZATION OF INDUSTRIAL PROCESSES

System combinations of resistance heaters and thermal storage enable the flexible generation of industrial process heat from renewable electricity. As the energy transition progresses, this combination of systems will gradually replace fossil fuels. As the proportion of renewable electricity in the power mix increases, the specific emissions of process heat generation from electricity will fall in line with the growth in renewable generation.

"RESISTANCE HEATERS IN COMBINATION WITH THERMAL STORAGE UNITS WILL GRADUALLY REPLACE FOSSIL FUELS IN THE INDUSTRY."

2.2 STABILIZATION OF THE ELECTRICITY MARKET THROUGH NEW SALES MARKETS

The electricity market is currently suffering from a highly volatile feed-in from PV and wind systems. The high feed-in peak of PV systems in particular leads to many hours with negative electricity prices. This poses a problem for the sustainable expansion of further generation plants, which cannot earn any money during these hours. The electrification of process heat in industry counteracts this challenge. This is because large amounts of energy are required to generate heat.

PtH systems are designed with a thermal storage system in such a way that energy consumption on the electricity market can be optimized. This means that the storage system is dimensioned in such a way that the low-price hours on the electricity market are utilized. The load consumption is dimensioned accordingly large so that several hours of process heat can be generated for one hour of electricity intake from the grid. Load consumption is thus shifted to times of high renewable electricity production and can actively counteract the shutdown of wind and PV systems. This gives the electricity market a stabilizing factor that can be used to ensure the profitability of investments in generation plants.

"ELECTRIFICATION OF PROCESS HEAT PROVIDES THE ELECTRICITY MARKET WITH A STABILIZING FACTOR THAT CAN ENSURE THE PROFITABILITY OF RENEWABLE GENERATION PLANTS."

2.3 FLEXIBILITY AND GRID STABILITY

PtH systems offer flexibility for the electricity grid. They are technically capable of reacting extremely quickly to fluctuations in the electricity supply and thus contribute to grid stability. Shutdowns can thus be prevented. PtH systems with thermal storage can also offer negative balancing energy. If we consider the high demand for heat in industry, it becomes clear how great the potential for flexibility and grid stability is in this sector: the share of process heat in final energy consumption in Germany is approx. 28% (UBA 2025). The potential for flexible operation, which can have a system and grid-stabilizing effect, is particularly important because the challenges in terms of flexibility and grid stability are growing rapidly with the increase in renewable generation.

2.4 INCREASE IN SYSTEM EFFICIENCY

By dimensioning thermal storage systems to enable intake at times when electricity prices are low, the shutdown of renewable generation plants can be reduced. This increases the efficiency of the overall system and reduces emissions in energy-intensive sectors.

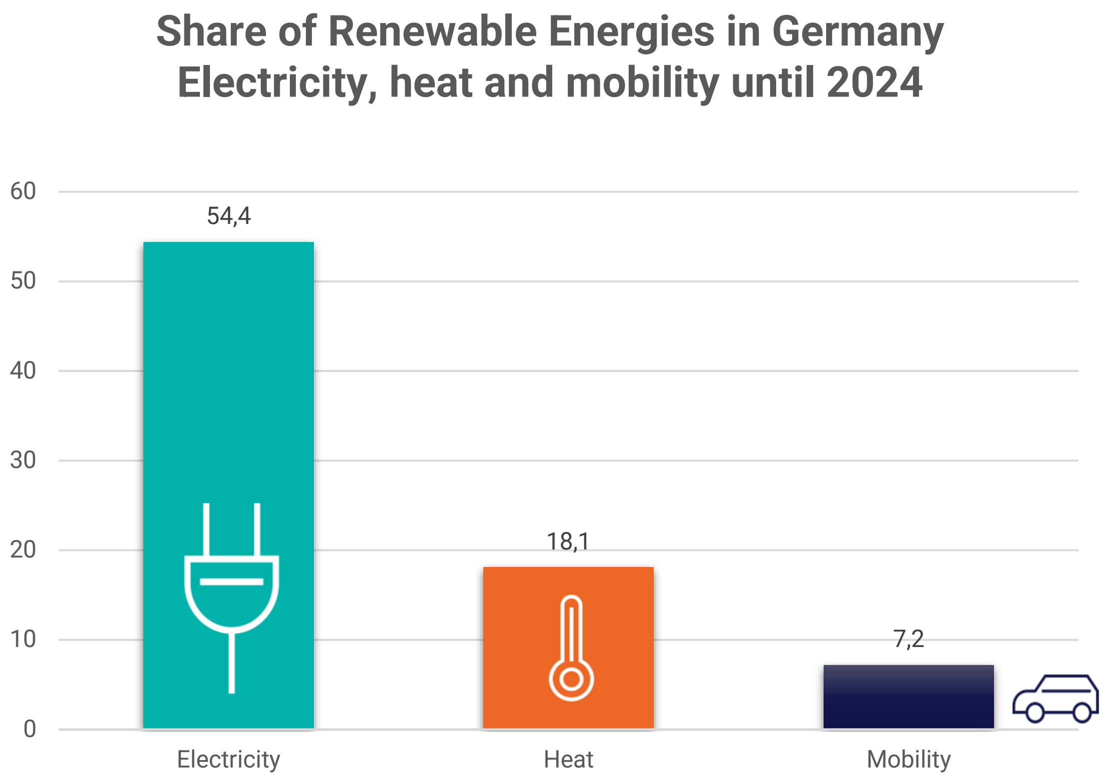
2.5 SECURITY OF SUPPLY THROUGH INDEPENDENCE FROM ENERGY IMPORTS

Fossil energy supplies represent an ever-increasing risk for companies due to their dependence on imports from politically unstable countries. Independence from the uncertainties of a fossil energy supply can be circumvented by electricity-based process heat generation. Electricity-based process heat generation therefore means an increase in security of supply and greater resilience for companies.

"ELECTRICITY-BASED PROCESS HEAT REDUCES INDUSTRY'S DEPENDENCE ON FOSSIL FUELS."

3. POLITICAL GOALS, MARKET POTENTIAL AND THE CURRENT STUDY SITUATION

The political goals and expectations in the field of electrification of process heat are high. However, political declarations of intent and scientific modeling of future energy use will have no impact whatsoever if the framework conditions and the regulatory framework are not changed in such a way that the modeled scenarios correspond to business cases and the possibility of economic implementation of projects in industry and commerce.



Data from the Federal Environment Agency 2025

THE HEATING SECTOR IS LAGGING BEHIND THE SAVINGS TARGETS

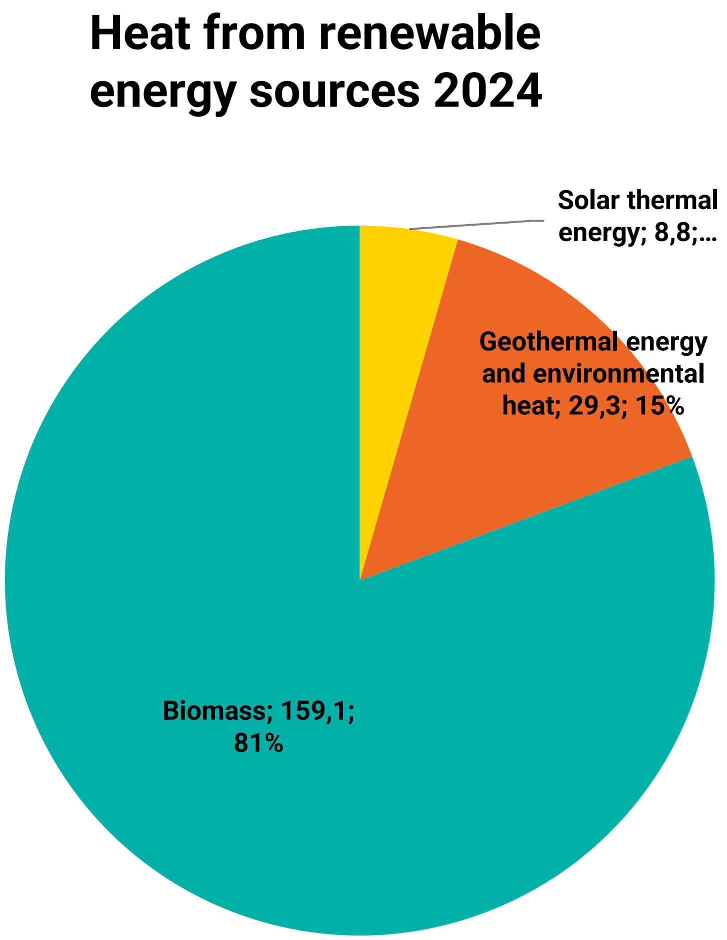
The heating sector is lagging behind the savings targets in a very problematic way. The Federal Environment Agency lists 18.1% renewable heat. However, the figure for renewable heat is primarily based on heat production from biogas. This cannot be scaled any further due to lag of agricultural land. A maximum has been reached here. Electrification only plays a subordinate role in the 18.1%:

"POLITICAL DECLARATIONS OF INTENT TO ELECTRIFY PROCESS HEAT WILL HAVE NO CONSEQUENCES IF THE REGULATORY FRAMEWORK IS NOT ADAPTED."

ELECTRICITY-BASED HEAT GENERATION IS NOT RECORDED STATISTICALLY

Data from the Federal Environment Agency shows that over 80% of renewable heat production is realized through biomass. The remaining percentages are accounted for by geothermal energy and environmental heat (heat pumps) as well as solar thermal energy. Electrification with resistance heating does not appear in the statistics.

The aim of this chapter is to show the extent to which electricity-based process heat is nevertheless part of future scenarios. Without regulatory changes, however, these scenarios will not be realized and thus an important component of the energy transition will simply fail to materialize.



Federal Environment Agency data 2025

The following documents are analyzed:

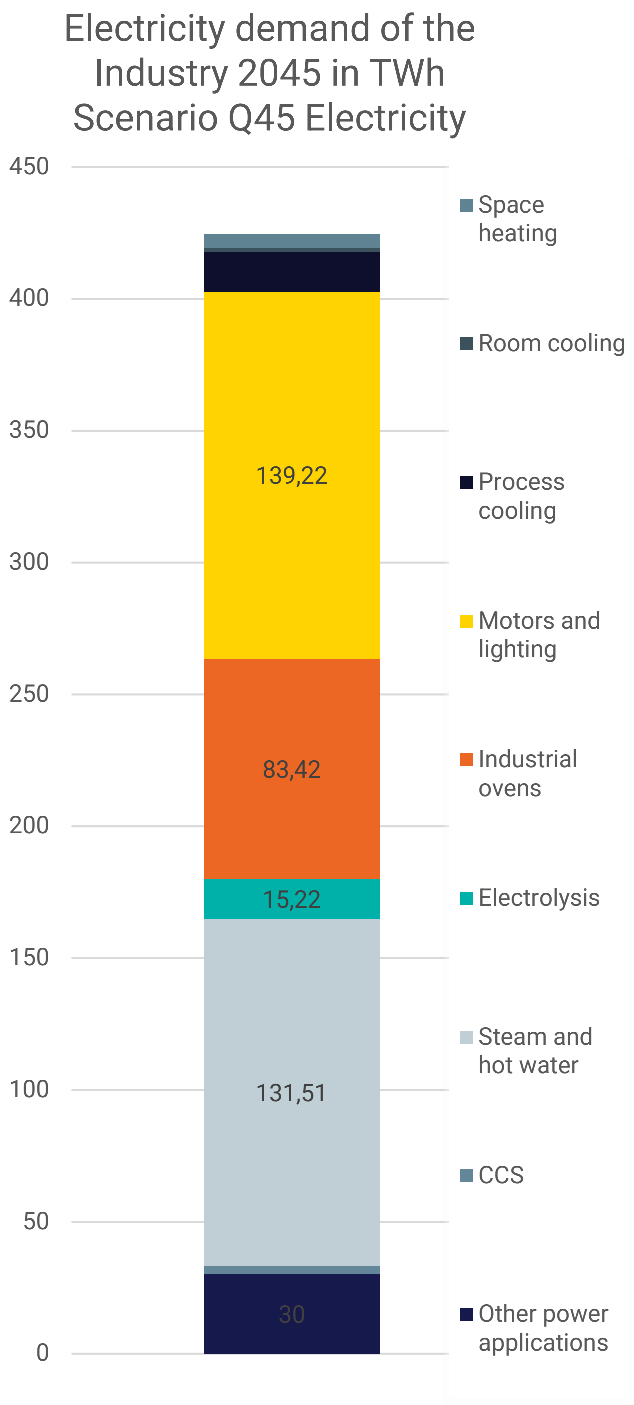
1. Long-term scenarios of the German government
2. Network development plan of the (NDP) of the German transmission system operators
3. The analysis of the Forschungsanstalt für Energiewirtschaft (FfE) on which the NEP is based,

Electricity-based process heat is not only about decarbonization and the flexible integration of renewable energies, but also about a global market for the technologies required for this. German companies are leading the way here. Setting the right course therefore also means securing market shares for industrial companies in the long term and tapping into major export potential.

"ELECTRICITY-BASED PROCESS HEAT IS PART OF ALL SCIENTIFIC FUTURE SCENARIOS BUT IS NOT YET STATISTICALLY RECORDED AT ALL."

3.1 THE GERMAN GOVERNMENT'S LONG-TERM SCENARIOS

The German government's long-term scenarios are a large-scale project to provide a study-based foundation for the discussion on the ongoing energy transition. With regard to industry and process heat or process steam requirements, the development towards decarbonized energy sources up to the goal of a CO_2-neutral economy in 2045 is described.



The scenarios make it clear that electricity-based process heat and process steam generation are of central importance:

In 2045, electricity demand is expected to be 83TWh for industrial furnaces and 132TWh for steam and hot water. Together 215TWh.

"215TWH ESTIMATED FOR ELECTRICITY-BASED HEAT APPLICATIONS IN INDUSTRY IN 2045"

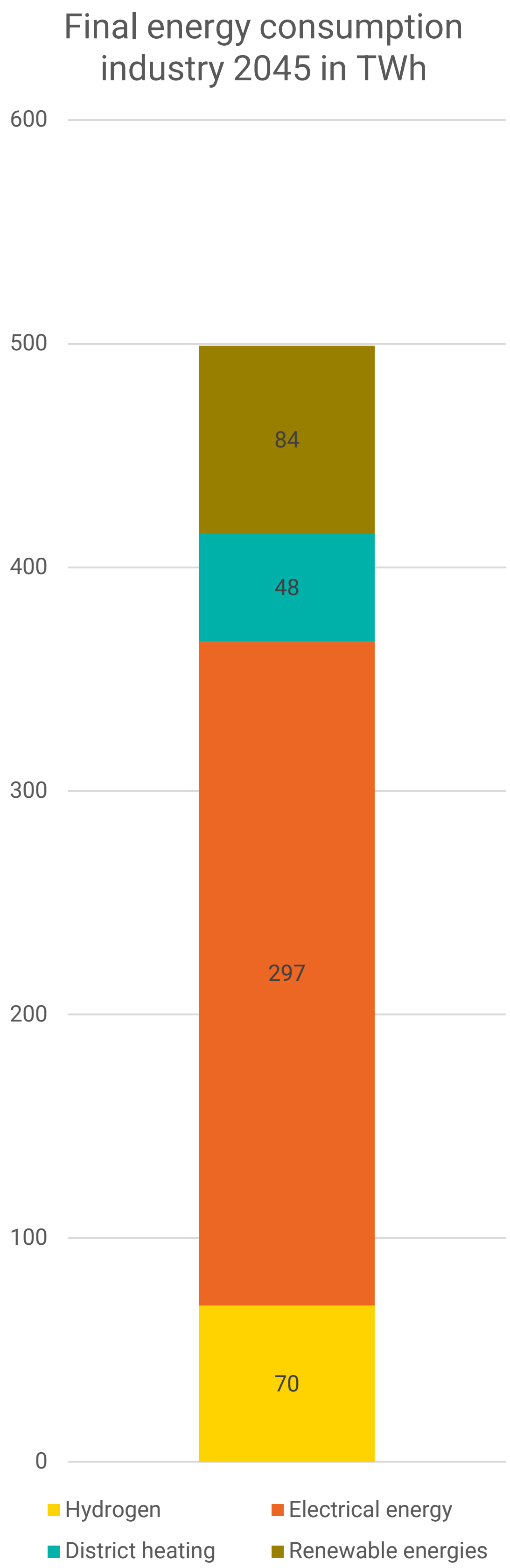
3.2 GRID DEVELOPMENT PLAN OF THE TRANSMISSION SYSTEM OPERATORS AND UNDERLYING FFE STUDY

The grid development plan of the transmission system operators also expects strong electrification in the industrial sector and is preparing the future grid infrastructure accordingly. Here, too, scenarios are simulated that consider the electrification of industrial processes and power-to-heat applications "to cover industrial heat requirements including process heat" (NEP, p. 32) as central.

This is based on the scenarios in the final report by the Research Center for Energy Economics (FfE). The electrification scenario assumes electricity consumption of 297TWh in 2045 (see diagram).

MAIN DRIVER FOR ELECTRICITY CONSUMPTION: "ELECTRIFICATION AND BURNER REPLACEMENT AT ALL TEMPERATURE LEVELS"

FFE 2022



Data FfE 2022

3.3 CO_2-NEUTRAL PROCESS HEAT GENERATION - STUDY BY THE FEDERAL ENVIRONMENT AGENCY

Electricity-based process heat generation using resistance heaters is examined in detail as part of the Federal Environment Agency's study "CO_2-Neutral Process Heat Generation" and is "an essential part of the economic and ecological considerations due to its high technical relevance". The technology for melting, holding, annealing and drying is considered relevant. Resistance heating is also considered central to steam generation (see UBA 2023, p. 95).

The result of the study is the reference to two essential boundary conditions in order to bring about the economic viability of CO_2-neutral alternative technologies. In addition to a high CO_2 price, "the adjustment of electricity price components" is considered to be decisive. This is because new technologies differ primarily in their "energy-related operating costs" (see UBA 2023, p. 495). Investment costs, on the other hand, are less problematic for reaching the economic viability threshold. In order to further decarbonize plants, regulatory interventions are suggested in order to create the appropriate framework conditions and guarantee "long-term predictability" (cf. UBA 2023, p. 496).

3.4 INTERIM CONCLUSION

The relevance of electricity-based process heat generation is recognized across studies. This is the case even though the potential of electrothermal storage systems, i.e. a power-to-heat system in combination with a thermal storage system, has not yet been taken into account. However, the flexibilization possibilities associated with storage systems make the use of the technology much more attractive, both for industrial companies and for the energy system.

The decarbonization potential is enormous and the technology is available. It is therefore important to pave the way and make the necessary regulatory adjustments.

"THE DECARBONIZATION POTENTIAL IS ENORMOUS, THE TECHNOLOGY IS AVAILABLE

IT IS THEREFORE IMPORTANT TO PAVE THE WAY AND MAKE THE NECESSARY REGULATORY ADJUSTMENTS

4. ECONOMIC EFFICIENCY CALCULATIONS. THE IMPORTANCE OF GRID CHARGES FOR THE USE OF THERMAL STORAGE SYSTEMS

The heat transition requires the provision of electricity-based industrial process heat in the future. The heating transition means switching from fossil-based generation using oil, coal or gas to renewable energy sources. If electricity is considered as a renewable energy source, the costs compared to fossil-based generation are relevant. These will be considered below. This makes it clear which adjustments are necessary to make a switch to electricity economically viable. In the following, a comparison will be made with gas as the most common fuel used today.

In 2023, industrial customers paid an average of 7.75 cents per kilowatt hour for natural gas (Statista 2023). An even lower gas price of 5 cents per KWh for natural gas is used for this study.

4.1 COMPARISON OF ELECTRICITY AND GAS PRICES

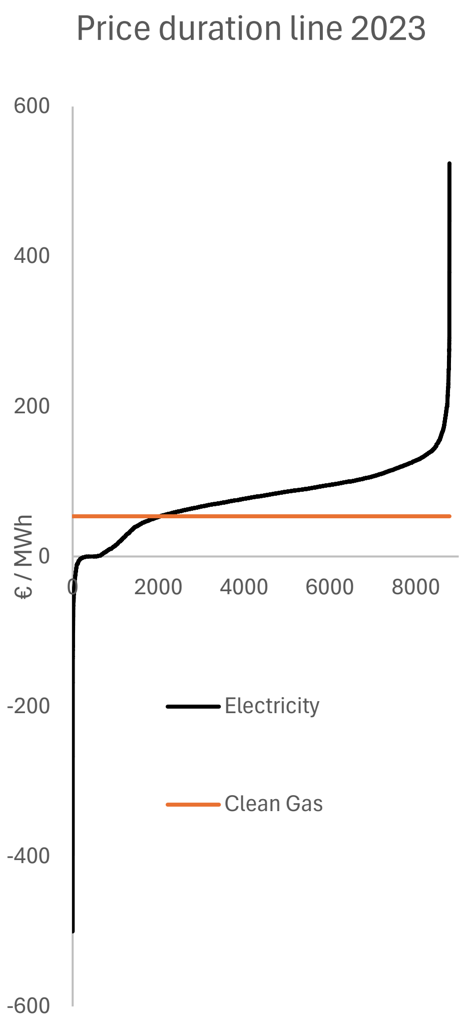
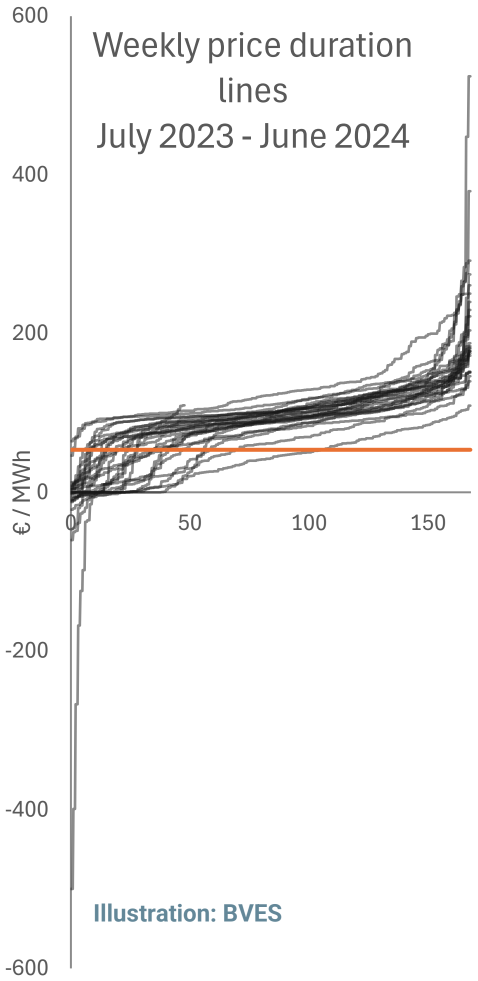


Figure: Price duration line, electricity and gas in comparison, illustration: BVES

The price duration line shows the hours of a year with specific electricity prices. The line indicates the price for one MWh of gas. It is clear that electricity prices are below the gas price for around 1300 hours a year. In all other hours of the year, the electricity price is higher than the gas price. It should be noted that the grid charges are not included in the electricity prices.

In order to establish competitiveness between electricity and gas, it is necessary to utilize the hours with low prices and at the same time grid fees that do not raise the amount due above the gas price. It is important to consider the distribution of hours with low electricity prices throughout the year. If continuous production of process heat using electricity combustion is to be installed, there needs to be a sufficiently even distribution of relevant electricity prices throughout the year. This is analyzed in detail in the following graph with weekly price duration curves:



The weekly price duration lines show the price distribution across all weeks of 2023. It is clear that in a few weeks, the gas price was not undercut at any hour, while the electricity price was between 10 and 30 hours below the gas price in many weeks. It is important for the incentive to switch to electricity combustion that those weeks in which the electricity price is more expensive can also be covered with a secure supply.

"IN ORDER TO CREATE COMPETITIVENESS BETWEEN ELECTRICITY AND GAS, IT IS NECESSARY TO UTILIZE THE HOURS WITH LOW PRICES AND AT THE SAME TIME GRID FEES THAT DO NOT RAISE THE AMOUNT DUE ABOVE THE GAS PRICE

4.2 TAKE ADVANTAGE OF FAVORABLE ELECTRICITY PRICES WITH THERMAL STORAGE

The illustrations show that the switch from fossil-generated process heat to the combustion of electricity can only be achieved if sufficiently dimensioned thermal storage systems are part of the industrial plants. Only then can the hours of favorable electricity prices be used for continuous operation. Without thermal storage, companies would be tied to the current electricity price and would be forced to purchase electricity continuously in order to make continuous operation possible.

"WITHOUT THERMAL STORAGE, COMPANIES WOULD BE TIED TO THE CURRENT ELECTRICITY PRICE AND FORCED TO PURCHASE ELECTRICITY CONTINUOUSLY."

4.3 PRICE COMPONENT GRID CHARGES - CURRENT STATUS AND WHAT NEEDS TO BE DONE

The component of grid charges is decisive for the economic efficiency of electrothermal storage systems. Grid charges mask the market signal of the electricity price. The following graph shows the number of hours in which a thermal storage system with a power-to-heat system could be charged as a function of the grid charges. The electrothermal storage system is dimensioned in such a way that three hours of feed-in can be realized with one hour of charging. This configuration makes it possible to make optimum use of the (few) hours with very favorable electricity prices.

"HEAT SECTOR COUPLING ONLY WORKS IF THE COSTS FOR THE ELECTRICITY GRIDS FALL SIGNIFICANTLY."

The graph shows that with full grid charges, the storage facility would only be charged for 53 hours of the year. This would result in a feed-in duration of 212 hours. With a grid fee reduction of 80%, as envisaged by the current reductions, the number of hours increases to 883, which means that a feed-in duration of 3,518 can be realized. However, only a complete exemption from grid fees would result in a feed-in duration of over 4,500 hours per year.

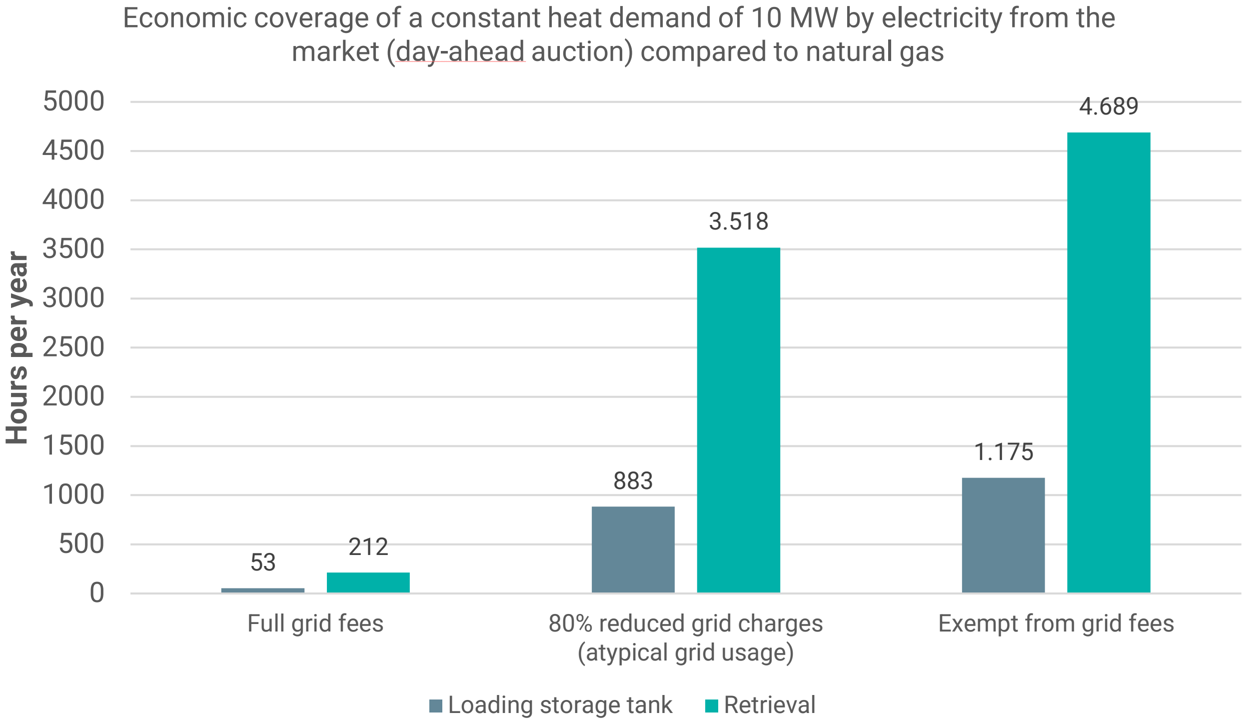


Figure 1: Storage loading with different grid charge loads (Illustration: BVES)

The following diagram illustrates the importance of grid fees even more clearly. This is because in most scenarios, the costs for grid fees alone exceed the costs for gas including gas grid fees and the CO_2 price. The grid fees are shown as a function of operating hours, broken down into energy and capacity prices. These prices are based on the current incentive mechanisms of the Federal Network Agency for individual grid fee agreements with industrial customers.

Again, a comparative line for the gas price is shown, here at 5 cents per MWh. It is clear that up to a figure of 3,500 annual operating hours, the grid fees alone are higher than the energy price for natural gas. Only above this number of annual operating hours do the grid fees fall below the gas price due to the corresponding incentive structures still in place at the Federal Network Agency. The electricity price is not even considered here.

"IN MOST SCENARIOS, THE GRID FEES ALONE ALREADY EXCEED THE COSTS FOR GAS INCLUDING GAS GRID FEES."

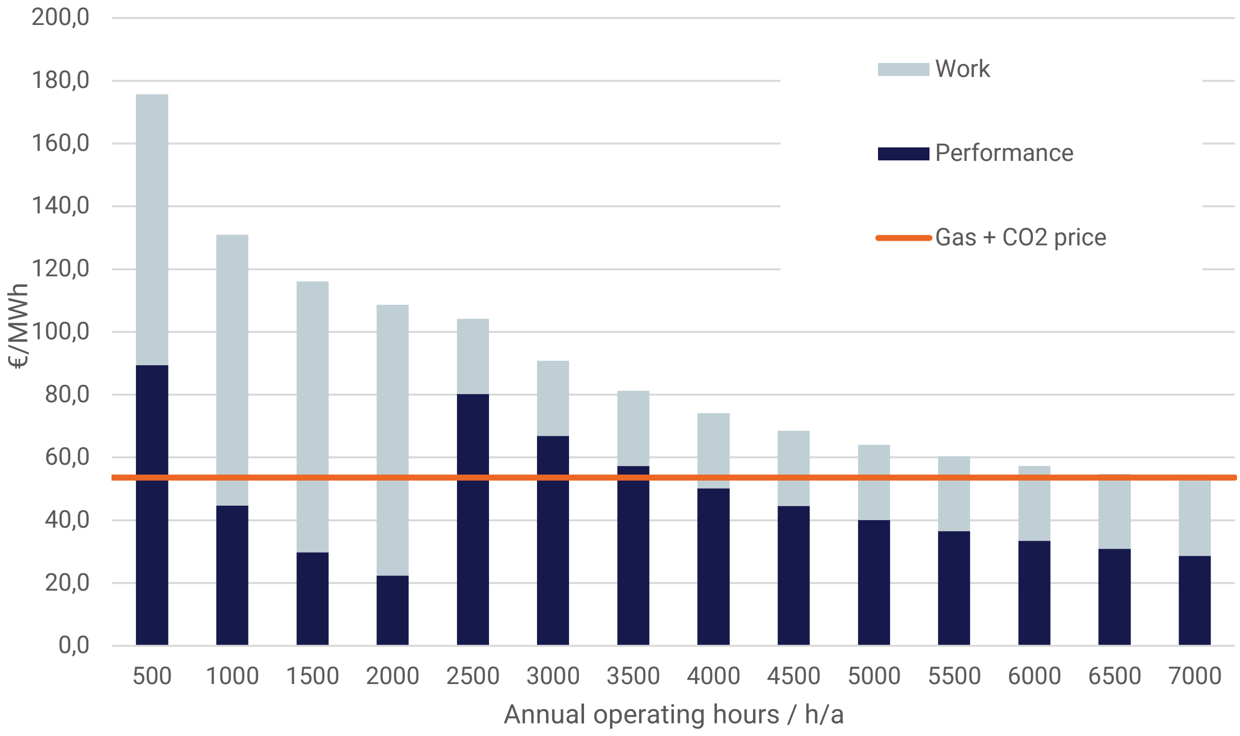


Figure: Grid charges as a function of annual operating hours, illustration: BVES

As the grid charges in the grid areas differ, we analyze three grid areas below to give an impression of how the problem behaves in different grid areas:

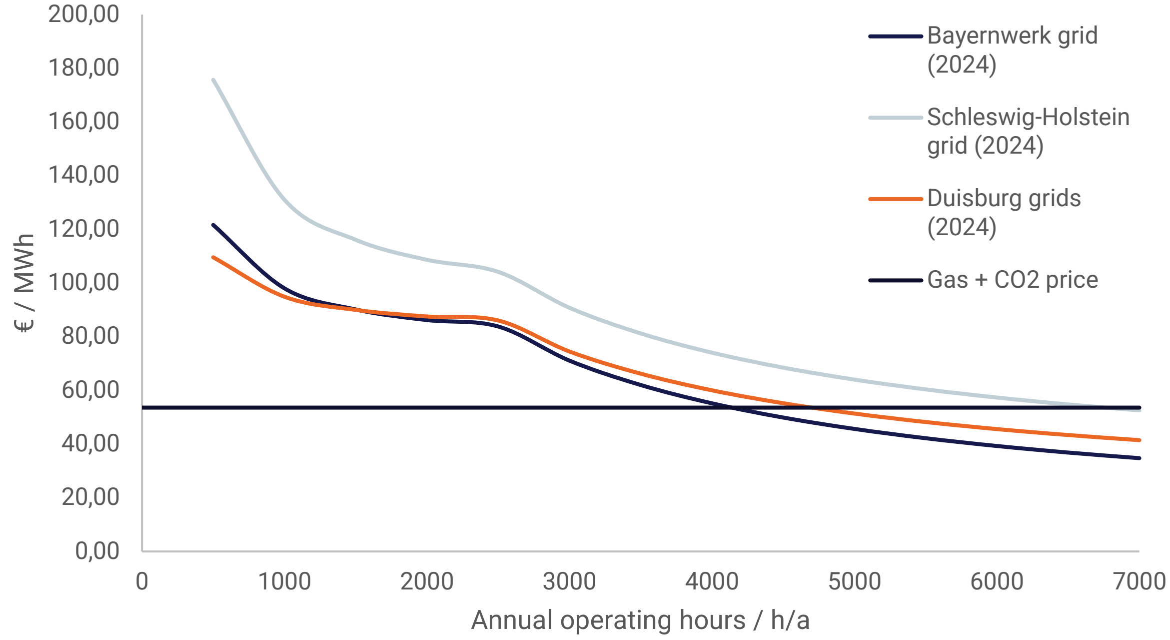


Figure: Grid charges in different grid areas, illustration: BVES

When comparing different grid areas, it becomes clear that the problem differs depending on the grid area, but can be found in all the grid areas examined. The grid areas were selected so that one is located in the north of Germany (Schleswig-Holstein), one in the south (Bayernwerk Netz) and one in NRW (Duisburg). This covers central grid areas in Germany.

"THE GRID FEE PROBLEM CAN BE FOUND IN ALL GRID AREAS."

4.4 PRICE SIGNALS IN THE ELECTRICITY GRID – GRID CHARGES AND ELECTRICITY PRICE IN RELATION TO THE GAS PRICE

If we now combine the electricity price components and the previous incentives of the Federal Network Agency, assuming a thermal plant with 10 MW, an availability of 90% and a supply capacity from the electricity grid of 50 MW, we currently arrive at a very small number of hours in which the gas price can compete with the electricity price. This is primarily the case when the electricity price slips into negative territory.

"WITH TODAY'S ELECTRICITY PRICE COMPONENTS, ONLY A VERY SMALL NUMBER OF HOURS ARE ECONOMICALLY VIABLE FOR ELECTRICITY PROCUREMENT."

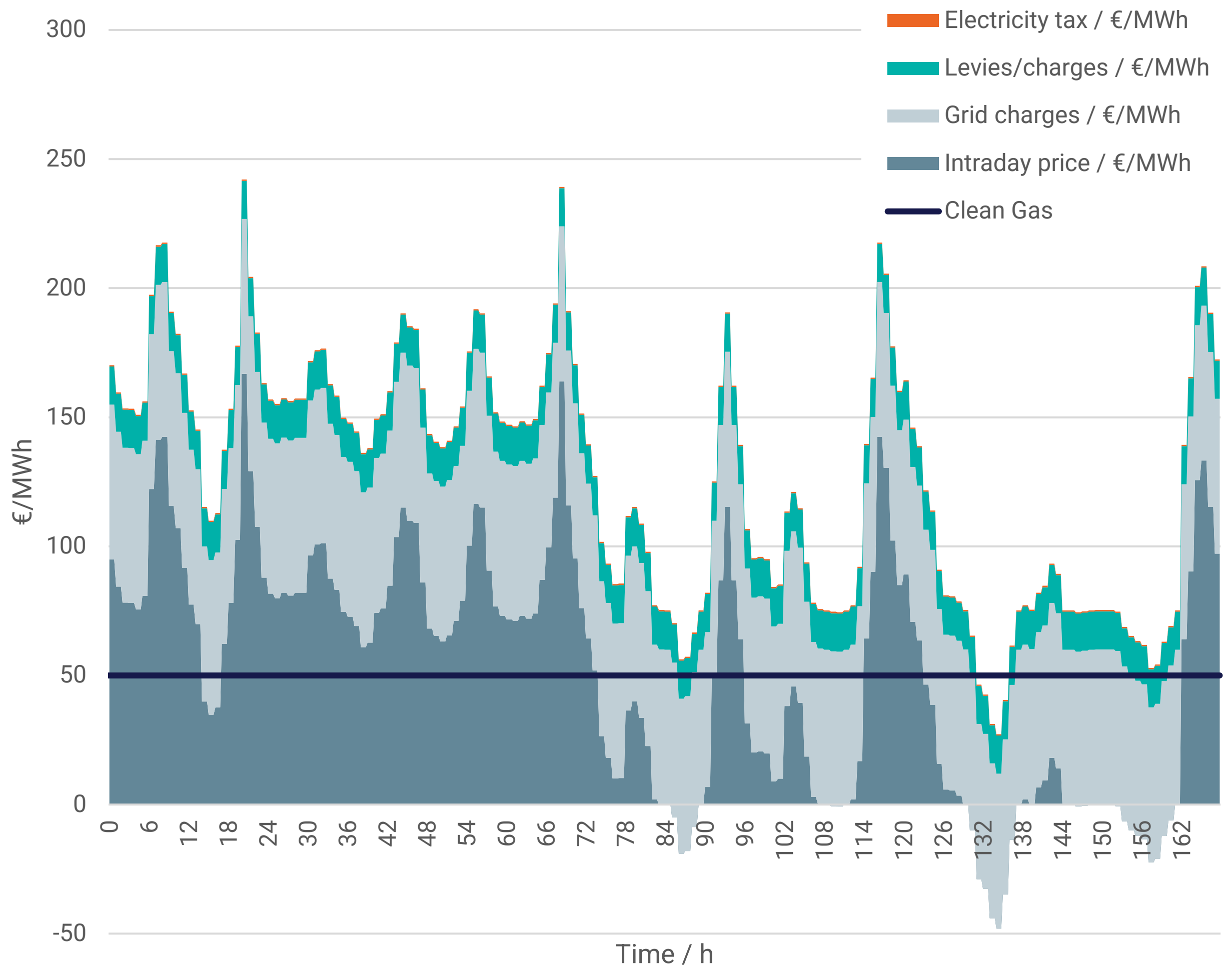


Figure: Electricity price components and their share over an exemplary calendar week, illustration: BVES

4.5 THE DECARBONIZATION POTENTIAL IS HIGH AND STILL COMPLETELY UNTAPPED

Competitiveness in terms of energy costs must be at the heart of the energy transition in industry. However, savings in CO_2 emissions must also be taken into account. This is because the political targets for reducing emissions are ambitious and companies will face additional costs in the form of CO_2 certificates in the coming years, which will increasingly become part of cost calculations.

This is shown in the following diagram. The scenario here is a hybrid operation of a gas boiler and electrified process heat generation, which always kicks in when the electricity price falls below the gas price. The red diamonds show the CO_2 emissions. Full grid charges result in higher energy costs. From a reduction in grid charges of 80%, energy costs fall below those of pure natural gas operation. The CO_2 emissions are already significantly reduced here (by approx. 60%). With an exemption from grid fees, energy costs fall significantly and emissions are also reduced by a further 2700 tons per year.

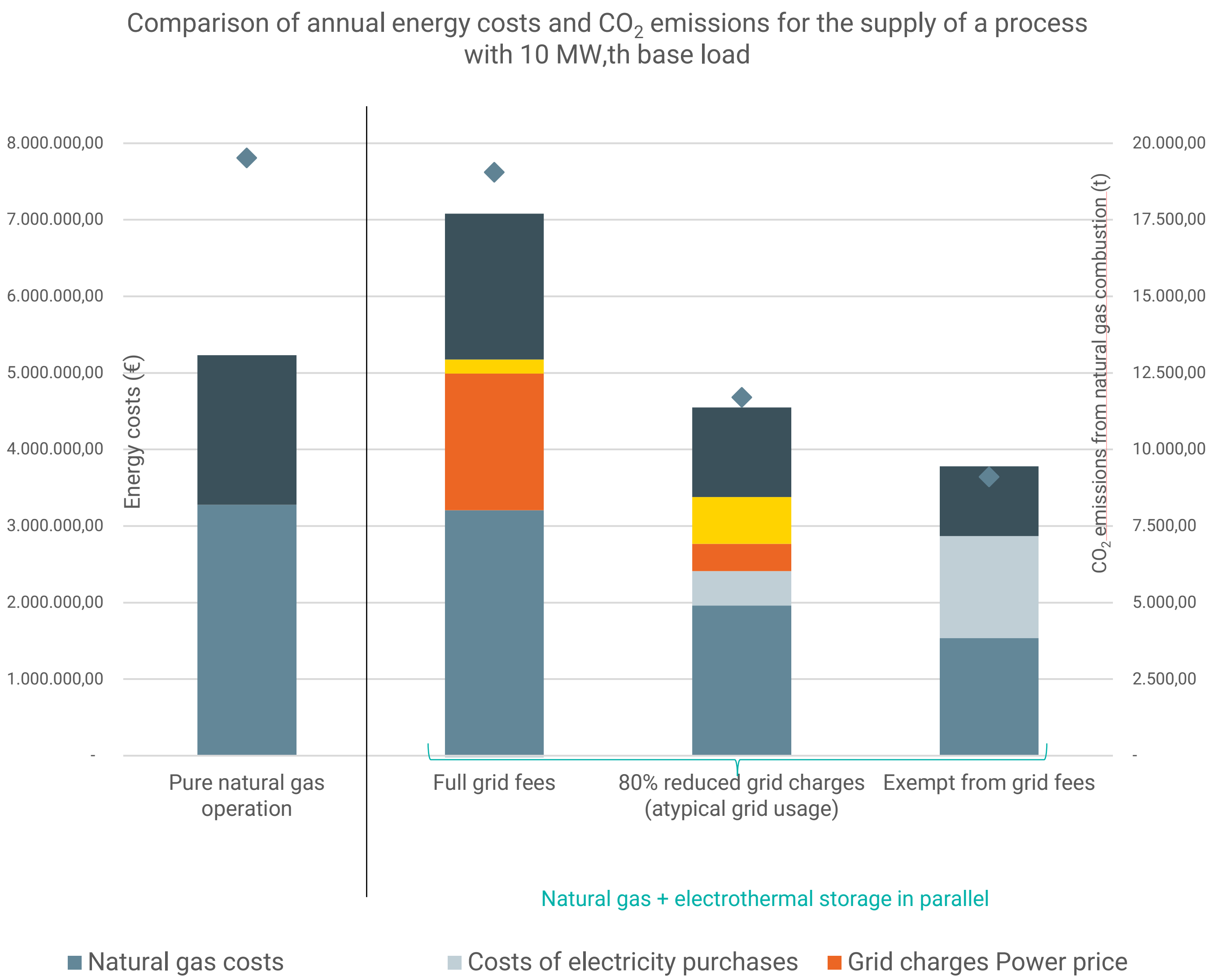


Figure: Comparison of annual energy costs and CO_2 emissions for the supply of a process with 10 MWth base load, illustration: BVES

5. CONCLUSION

1. CURRENT INCENTIVE MECHANISMS FOR GRID FEE REDUCTIONS DO NOT ALLOW FOR THE ECONOMIC VIABILITY OF ELECTRICITY-BASED PROCESS HEAT IN GERMANY

The current incentive structures for grid fee reductions by the Federal Network Agency do not allow the hours of favorable electricity prices to be used for electricity-based process heat generation. The reduction mechanisms for grid fees do not take into account the possibility of optimization on the electricity market. The number of hours with sufficiently low electricity prices is significantly lower than the annual operating hours that represent the thresholds for agreeing individual grid fees.

A business model that can stand comparison with the price of natural gas cannot be conceived under these circumstances. This is also particularly damaging for the energy system. Electrothermal storage systems require large amounts of electricity to generate process heat. They would absorb these hours at times of high renewable generation, because the price signals on the electricity market represent the course of renewable electricity generation with a sufficiently precise approximation.

2. SECTOR COUPLING HEAT IS NOT TAKEN INTO ACCOUNT IN THE GERMAN REGULATORY FRAMEWORK

Sector coupling and the use of electricity as a new fuel in industry processes is part of all energy transition scenarios. It is therefore all the more important to set the right course here and initiate the economic use of electricity for process heat generation. Grid fees are the decisive component here. Grid fees mask the market signal of electricity prices and prevent companies from being able to supply themselves with affordable renewable energy.

3. POTENTIAL FOR DECARBONIZING THE INDUSTRY REMAINS UNTAPPED

Electricity-based process heat has great potential for reducing emissions. This remains untapped today. In practice, sector coupling is still in its infancy. However, sector coupling plays a central role in scientific models of industrial transformation.

4. RENEWABLE GENERATION NEEDS NEW AND FLEXIBLE ELECTRICITY CONSUMERS

New and flexible electricity consumers are needed to secure the further expansion of renewable generation plants. Negative market prices are increasingly driving project developers of PV and wind power plants to the limits of their financial viability. This means that the backbone of the energy transition, the generation of renewable electricity, has its back to the wall.

Heat sector coupling has the potential to stabilize the electricity market and at the same time advance the goals of the energy transition. If this potential remains untapped, the current momentum in the expansion of renewable production facilities will slow down significantly.