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# An Approach to Calculate Electricity Costs for the German Industry for a System Efficient Design by Combining Energy Efficiency and Demand Response

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This study analyses the German electricity price mechanism and laws used for the calculation of electricity costs. The goal is to find which price components and regulatory to relief energy-intensive companies are affected by energy efficiency and/or by demand response measures in a German company. Therefore the price mechanism and laws were used in a newly self-developed open source tool to easily and quickly calculate electricity costs. Grid charges increase significantly if the power consumption is increased. Even short peaks in the load profile may prevent individual grid charges for a company, i.e. an increase in electricity costs for companies. This price mechanism makes a flexible power consumption economically unappealing.

## 1. Introduction

One target of the German government is to deliver 80% of the electricity by renewable energies by 2050 to reach greenhouse gas (GHG) emission targets of the Paris agreement. The problem in Germany's energy transition compared to other countries with high shares of renewables is the lack of controllable geothermal and hydropower. Hence, variable renewable energies (VRE) like wind and photovoltaic power are the preferred technologies. They have the lowest energy generation costs in continental Europe but are difficult to implement in the present demand controlled energy system. To reduce GHG emissions it is necessary to increase both energy efficiency and the share of electricity produced by VRE (Schumm G. et al., 2016).
The industry with a share of 29% of Germany's final energy demand is a suitable application for demand response (DR) and energy efficiency. DR can increase the share of VRE electricity (Ladwig, 2018). A new approach combining these two aspects called system efficiency is necessary (Schumm G. et al., 2018).
In this work, total electricity costs for companies in the German industry are calculated. Pricing mechanism and laws relevant for electricity costs were analyzed how they are affected by energy efficiency and DR measures.
The goal is to determine the effects of system efficiency on the costs by varying energy efficiency and the maximum of electrical power. This will help to evaluate energy efficiency respectively DR measures from an economic perspective and helps to find where regulations need to change to prevent unwanted side effects of introducing system efficiency in a German company. Unwanted side effects includes paying a higher price for electricity although less energy is consumed or the company uses more power to relief the electrical grid.
The calculation is based on total electrical energy consumed, maximum power consumed during a year and full load hours. These load statistics are varied to determine their effects. The amount of energy is decreased to simulate the effects of energy efficiency. To simulate the effects of flexibility the maximum power is varied. A software tool was developed to calculate final electricity costs quickly by implementing price mechanism and laws as algorithms.
The study is aimed at the German industry, but it also can help other countries to learn from the German law.
Section 2 provides the background by explaining the German electricity tariff. In section 3, the calculation of the electricity costs is explained. First results gained by analyzing the calculation and using the tool are presented in section 4. Section 5 includes a summary and outlook for future studies.

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## 2. Price components of the German electricity tariff

The electricity tariff in Germany consists of different price components for services, taxes or levies. Some components are used to enable the energy transition and resulted in an electricity price increase (see figure 1). Therefore, many regulations were introduced to relief energy-intensive German industry in order to preserve international economic competitiveness.

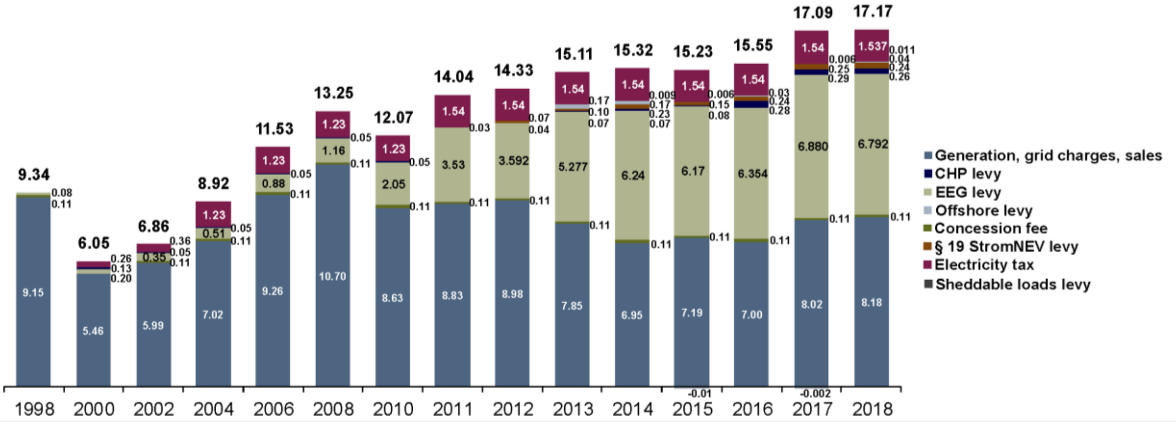


*Figure 1: Development of the electricity costs for German Industry (based on BDEW (2018))*

Döring S. (2015) lists the components of the electricity price for the German industry as:

### Generation and Sales

This is the price either paid at the electrical energy stock exchange or to electricity utilities. Prices at the exchange changes from day to day (for the day-ahead market) and even during the day (intraday markets). Companies with high flexibility may adjust their electricity consumption to the prices at the market and therefore can save money (Walmsley T.G. et al., 2018). Many companies although have long-term contract with a fixed price during this period. The price is negotiated between supplier and company and a steady load profile leads to a better price for the company. For this study the model of long-term contracts with a fixed price is used.

### Grid charges

Grid charges are paid to the transmission system operator (TSO) or to the distribution network operator depending on which voltage level the company is connected to the electrical grid. It is paid for using the electrical grid to obtain electrical energy. Grid charges includes a price paid for energy (per kWh) and a price for electrical power (per kW). Electrical power is the highest power measured in a year. Energy includes the total amount of electrical energy consumed in a year (Döring S., 2015). Grid charges can be reduced by atypical grid usage ((§ 19 subsection 2 sentence 1 StromNEV (Stromnetzentgeltverordnung)) or highly intensive grid usage (§ 19 subsection 2 sentences 2-4 StromNEV). In both cases, the company gets an individual grid charge.

### EEG levy

EEG levy is regulated by the act on renewable energy sources. Utilities producing electrical energy from renewable energy sources must be connected to the grid and the energy produced by these utilities have a higher feed-in priority compared to non-renewable energies. Depending on the type of utility/renewable energy (biomass, solar, wind) and year, the operator of the utilities get paid a specific price for every kWh produced. This compensation is normally higher than the price at the electricity stock exchange. The difference between compensation and price at the electricity stock exchange is financed by the EEG levy. The difference is higher the lower the price at the stock exchange is. The EEG levy is paid by all end consumers. Companies with high electrical energy consumption can reduce the EEG levy. All levies are calculated each year by the four TSO.

### CHP levy

Similar to the EEG levy, this is levy used to increase the share of electrical energy produced by CHP utilities.

### § 19 StromNEV levy

This levy is used to compensate for missing revenues of grid operators caused by § 19 StromNEV (hence the name of this levy). Missing revenues can be due to either atypical grid usage or highly intensive grid usage. The end consumer needs to compensate for the missing revenues. The levy is reduced for energy over 1 GWh.

**Offshore grid levy**

The offshore grid levy refinances costs for connecting offshore wind farms to the electrical grid, maintaining the grid and compensates missing revenues caused by failures or by delayed connecting of the wind farms to the grid. The levy is regulated by Energiewirtschaftsgesetz. The costs are paid by the end consumers.

**Sheddable loads levy**

This component is regulated by Verordnung über Vereinbarungen zu abschaltbaren Lasten and Energiewirtschaftsgesetz. Sheddable loads levy is used to refinance costs when companies turn off loads to stabilize the electrical grid. The costs include operational costs by the TSO and a fee for the companies. Companies can offer sheddable loads in an open competitive bidding. Companies get paid for making the load available and for when the load is actually taken off the grid. Both costs are applied to the electricity price and then paid by the end consumer (Döring S., 2015). Sheddable loads levy cannot be reduced.

**Concession fee**

Concession fee is regulated by the law Konzessionsabgabenverordnung. It is paid to electricity companies for their usage of electrical grids on areas owned by the communities. Concessions fee is paid per kWh. The law regulates the maximum price for the fee. For standard customers (mostly households), the upper limit is determined by the population in a community (up to 2.39 ct/kWh). For special-contract customers (industrial consumers) the limit is by 0.11 ct/kWh. (Döring S., 2015). The upper limits remain constant and will not be determined every year. Special-contract customers do not need to pay concession fee if the company's total price per kWh is below the mean price of all special-contract customers.

**Electricity tax**

If electrical energy is consumed in German tax territory, the electricity tax applies. The tax is regulated by the law Stromsteuergesetz. The tax is 20.50 Euro/MWh or 2.05 ct/kWh. The tax was introduced in 1999 as a part of a green tax (Döring S., 2015). For industrial consumers, the tax can be lowered to 1.537 ct/kWh or even be tax-free for certain types of processes, e.g. electrolysis, metallurgy or chemical reduction.

## 3. Calculation of electricity costs

In section 3.1, the calculation of the costs is explained. The calculation is based on the corresponding laws. The laws were interpreted and transformed into flowcharts as a basis for the software tool (see section 3.2).

### 3.1 Calculation of single components of the electricity costs

This section explains how the total costs for all price components are calculated and the costs the companies have to pay based on the type of their company, amount of electrical energy and maximum electrical power. The calculation is explained for German industrial companies with only one connection point to the electrical grid and 100% supply from the electrical grid, no on-site generation of electrical energy and no electrical energy storage. The steps shall point out the most important points to use the laws for the calculation of the electricity costs. The explanations cannot be considered as legal advice. Regulations may change in the future.

**Grid charges**

To calculate grid charges, the amount of full load hours needs to be calculated with equation (1):

$$\text{full load hours} = \frac{\text{total amount of electrical energy in a year}}{\text{maximum of electrical power during the year}} \quad (1)$$

Prices per kWh and kW depend on full load hours. Usually the prices change at 2,500 full load hours. Depending on the tariff, the costs are calculated by amount of electrical energy times the price per kWh and maximum of electrical power times the price per kW. Over 2,500 load hours, the emphasis is on price per kW, below 2,500 full load hours the emphasis is on price per kWh. Highly intensive usage occurs if the amount of electrical energy is at least 10 GWh and full load hours are at least 7,000 hours. If so, grid operators have to offer individual grid charges (price per kWh and price per kW) based on a fictional price calculation: how much would it cost to connect the company directly to a sufficient power utility. This price is the individual grid charge. It has to be 20% or more of the published grid charges. If full load hours are at least 7,500 hours or 8,000 hours, the grid charges need to be at least 15% or 10%, respectively. In this calculation, the grid charges are reduced to their lower limit. Whereas highly intensive usage reduces the price per kWh and price per kW, atypical grid usage can only reduce the price per kW. To have an atypical grid usage, the company need to need know when the load in the grid is high. These times are published by the grid operators for the next year in advance. To apply for atypical grid usage the load difference between times with low load in the grid (in these times the company can have high loads) and times with high load in the grid (company must reduce their load) must be at least 100 kW and the reduction must be higher than a threshold set by the grid operators. For example, the reduction must be at least 5% for extra high voltage or 30% for low voltage. If both requirements are not met, then the grid charges cannot be reduced. If full load hours are less than 2,500 h, the company can decide which tariff they want to use. After this step, the individual grid charges are calculated. They include the costs for energy times price per kWh and the power for reduced load times price per kW. This individual grid charge must be at least 20% of the published grid charges (otherwise there are set to be 20%).

**EEG levy / CHP levy / Offshore grid levy**

All consumers have to pay full EEG levy for the first GWh. If the amount of energy is less, then the costs for EEG levy is simply energy times the EEG levy per kWh. If more energy is consumed, intermediate costs are calculated by 1 GWh times EEG levy per kWh. For the energy over 1 GWh (denoted as energy*), the full EEG levy is used in the first step. After calculating the costs for energy*, it is checked whether the company can apply for reduction of the EEG levy. The most important requirement is a certain level of electricity costs compared to the gross value added: list 1 of attachment 4 of EEG law and electrical energy costs intensity (EECI) is over 14% OR list 2 of attachment 4 of EEG law and EECI is over 20%. EECI is calculated by the following equation:

$$\text{EECI} = \frac{\text{representative electricity costs}}{\text{gross value added}} \times 100\% \tag{2}$$

Representative electricity cost is the representative electricity price per kWh times the amount of electrical energy consumed. The representative electricity price is a mean electricity price based on amount of energy and full load hours, not based on the actual contract of the company. The law requires using the mean value of the last three years for electrical energy and gross value added. The company applies in year n for the reduction of EEG levy for year n+1 and uses the data from the last three years (years n-3, n-2, n-1). In this study, checking for the requirements and applying the price reductions happens in the same year or period. No previous data is used. This is a simplification in regard to the law. If requirements are not met, the costs for energy* is not reduced and added to the intermediate costs. The same EEG levy is paid for the total energy. Otherwise the EEG levy for energy* can be reduced. Depending on whether the company is in list 1 or list 2 and on the value of EECI (must be at least 14%), the EEG levy for energy* is reduced to 15% or 20%. If the EEG levy is reduced to 15%, then there is a cap for the costs. Depending on the value of EECI, the costs are capped at either 4% or at 0.5% of gross value added. This cap is an upper limit for the EEG levy. Similar to this upper limit, there is a lower limit for the costs. The lower is given in ct/kWh. The costs for energy* are added to the intermediate costs.
For CHP levy and offshore grid levy calculations, EEG levy replaced by the value of CHP levy or offshore grid levy. The lower limit for CHP levy and offshore levy is different than the lower limit for the EEG levy.

**§ 19 StromNEV levy**

Up to 1 GWh of electrical energy, every consumer has to pay the full price per kWh (group A) for § 19 StromNEV levy. If the company is in the manufacturing industry and the costs for electrical energy is 4% compared to the revenue, a lower price per kWh for the amount over the first GWh is valid (group C). Otherwise a higher price is used (group B), but still less per kWh then the price per kWh for the first GWh.

**Electricity tax**

Manufacturing industry may reduce their tax duty. Other companies have to pay the full price (2.05 ct/kWh). For companies in the manufacturing industry, electrical energy for processes like electrolysis is tax-free and subtracted from the relevant amount of energy. A possible tax relief is calculated by relevant amount of energy times the tax reduction (0.513 ct/kWh). If this tax relief is less than 250 Euro, then there is no tax reduction. If the tax relief is over 250 Euro (at least 50 MWh of electrical energy), then 250 Euro are subtracted from the tax relief. This new tax relief is subtracted from the total tax. If the tax still exceeds 1,000 Euro, the amount over 1,000 Euro can be reduced. The amount over 1,000 Euro is reduced to ten percent and added to the 1,000 Euro. The amount over 1,000 Euro can be reduced down to 10%, but is capped by payments to the pension insurance. This cap is ignored to simplify the tax calculation. In a real case, the tax might be higher.

**Concession fee**

If the company is no special contract consumer, the price for concession fee is based on the population in the county where the company is. This study uses always the maximum price per kWh. If the company is a special contract consumer (which normally it is), the price per kWh is less. Using this concession fee, the total price per kWh for this specific company is calculated. If this total price per kWh is less than the mean price per kWh for all special contract consumers from two years before, then the company does not have to pay concession fee. Therefore, an already low price is reduced again.

### 3.2 Software tool developed for calculation

A newly self-developed open source software tool written in Python 3 was used for this study. The tool uses the steps from section 3.1 to calculate the overall electricity costs. The tool enables to calculate the costs automatically for a set of given parameters like tariffs and load statistics. Parameters can easily be varied and the new costs are calculated quickly. The tool can be enhanced and modified for future research. The version used in this paper is available via https://doi.org/10.5281/zenodo.2633767. This link also contains flowcharts to understand the calculation. Newer versions of the tool can be found via https://gitlab.com/stoecklm/eleccosts.

## 4. Results

In this section, the results are presented. The results are structured by the price components.

- EEG / CHP / Offshore grid levy**:** Reducing the consumption of energy may increase the amount for all three levies, if the gross value added remains constant. Reducing the amount of energy may lead to a lower EECI (see equation (2)). If the EECI falls below a threshold, the three levies will not be reduced or less reduced. Therefore less energy can lead to higher costs. Increasing power does not directly affect the costs, since the levies are paid per kWh. Although, reducing/increasing the amount of energy and/or the amount of maximum power influences EECI via the representative electricity price. As a rule of thumb, the price increases with less energy and less full load hours. So a higher power may lead to a little bit higher EECI and may influence to over/under a certain boundary. The effect of lowering EECI is damped in the reality, because the mean value of the last three years is used, but the effects can also occur over a longer period.
- § 19 StromNEV levy**:** If less energy is consumed, then the amount of total costs for this levy decreases. The more energy over one GWh is consumed, the smaller the levy per kWh gets, but total costs still increases. It either converges to the prices of group B or group C. Not affected by the maximum power consumed.
- Electricity tax**:** Flexibility does not affect the tax, but it is influenced by energy efficiency. The total amount of tax decreases if less energy is consumed, whereas the amount per kWh decreases if more energy is consumed and the company is in the manufacturing industry or more energy for specific processes is consumed. After a certain amount of energy, the tax can be reduced. The more energy is used, the more the mean price per kWh decreases. The total amount of money can only increase. The price per kWh converges to 0.1537 ct/kWh, which is 10% of the reduced tax rate.
- Concession fee**:** The price per kWh for concession fee is not directly related to energy efficiency and flexibility measures, but the other price components have influence in whether the company has to pay concession fee or not. If EEG levy or grid charges are high, the electricity price for a company exceeds the mean price and the company needs to pay concession fee.
- Grid charges**:** Only component that is directly paid per kW. Other components are only affected indirectly by the costs per power. Figure 2 shows how the costs decreases if full load hours are increased (i.e. power consumption decreases if energy remains constant). If full load hours are over 2,500, then the costs per kW is more than the costs per kWh. If full load hours are less than 2,500 hours, the ratio between costs per kW and kWh changes. For < 2,500 h, more power does not increase the costs rapidly, contrary to > 2,500 h.
- Highly intensive grid usage**:** If a company uses slightly over 10 GWh and around 7,000 full load hours, then the company may not reduce their energy consumption or increase their power consumption because this may increase grid charges up to 80%, because the company will not receive individual grid charges.
- Atypical grid usage**:** Since only the price per kW is reduced, energy efficiency leads to lower costs. If the maximum power is only increased in times, when the load in the grid is low, then more power does not increase costs. The company needs to be strict in its production planning in order to fulfil the requirements for atypical grid usage. This is the opposite of a variable energy consumption (IKEM et al., 2018).

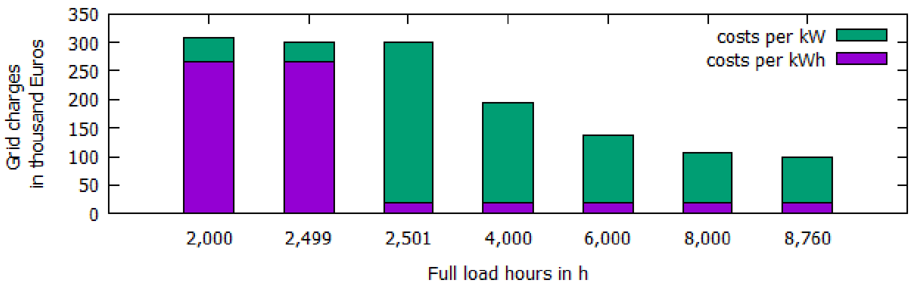


*Figure 2: Grid charges for 7 GWh in dependence of full load hours*

## 5. Conclusion and Outlook

A new open source tool was developed to determine electricity costs for German industry. The tool uses energy, power and full load hours, company statistics and the German regulations for electricity prices to calculate the total electricity costs. This tool can be a basis for more intensive studies since it can be used to automate price calculations and can be enhanced in the future. All price components are paid per kWh (only grid charges are also paid per kW). Therefore, consuming less energy is always appealing to companies and should be the goal from an economic and ecological point of view. There are laws to relief energy intensive companies and some strict thresholds and boundaries were introduced. If a company is just a little bit over the boundary, reducing energy consumption is less appealing. Based on the tariffs, a higher consumption of power leads to higher grid charges for the companies (without atypical grid usage). Even if this reliefs the grids, the companies pay more for grid charges (dena, 2018). The high rise in costs, if more power is consumed, makes a flexible approach in power consumption less appealing to companies (Jahn A. et al., 2019). Individual grid charges for 10 GWh and 7,000 full load hours are contrary to the goal to use more VRE when they are available. As a result of this study, new regulatory to reward grid relief and high usage of VRE are necessary. Grid charges policy is from before the energy transition and therefore must adapt to the new situation (Consentec, 2018).
Possible enhancements are to study the optimal ratio between grid supply and on-site generation. On-site generation of CHP offers a possibility to reduce energy and electricity costs (e.g. reduces EEG levies). The software tool needs be enhanced for the regulations of on-site generation costs. For generation and sales the model of long-term contracts were used. If the tool should use spot market prices, load profiles (time series for power) need to be used as a more complex model than load statistics.

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