Westfälische Wilhelms-Universität Münster
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School of Business & Economics

Center for Interdisciplinary Economics
Discussion Paper

4/2018

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Center for Interdisciplinary Economics
Discussion Paper Series

Center for Interdisciplinary Economics
Discussion Paper
4/2018

June 2018

ISSN 2191-4419

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Abstract

The increase in network costs within the German electricity grid, due to a rising share of renewable energy generation, has led to higher network charges in recent years. We use socioeconomic data in order to investigate distributional effects within the period 2010-2016, and employ three different inequality metrics – the Gini coefficient, the Theil index and the Atkinson index – all of which unambiguously indicate regressive effects of network charges. The three metrics show an increase of economic inequality of at least 0.6 % when accounting for network charges. This finding is due to 1. the relative inferiority of electricity, 2. the regressive impact of a fixed component of network charges, 3. considerable regional disparities, and 4. the higher prevalence of prosumers within high-income households.

JEL-Codes: D63, Q40, Q42
Keywords: network charges, renewable energies, economic inequality

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1 Introduction

German energy policy has changed dramatically in recent years. Federal government stated in its "Energiekonzept 2050" that up to 80 % of electricity should be renewably generated by 2050 (Bundesregierung 2010). This goal induces a structural change which not only includes power generation and technologies themselves, but also the need for an efficient and capable electricity grid. New challenges arise from decentralized power generation through photovoltaic (PV) systems and wind mills, which are often not located in load centers, thus necessitating quantitatively more and more capable transmission grids. The costs of this network expansion have to be borne ultimately by the customers, since the grid costs are reflected in the network charges which in Germany, are a component of the electricity bill. However, network charges are lower for industrial users and even differ for private households – so-called *prosumers* (i. e. households with roof-top PV systems or interruptable consumption systems) are partially exempt from paying the charge. Furthermore, network charges are defined locally by the distribution system operators (DSOs), which have to pay network charges to the transmission system operators (TSOs) themselves. This induces substantial regional disparities in the financial burden exerted by network charges – for example, households in regions with a low population density have to pay for a relatively costly grid. As a consequence, different households in different regions of Germany are charged differently for the maintenance and extension of the grid. This finding has been further aggravated by rising network charges in recent years and had induced households to pay a considerable proportion of their disposable income for network charges.

The distributional effects of different energy-market policies have been investigated extensively in the past. In a cross-country comparison, Flues and Thomas (2014) find that taxes on electricity are more regressive than those on other energy sources. Concerning Germany in particular, the distributional effects of the EEG feed-in tariff – which is a subsidy to producers of renewable energies financed by a surcharge on the electricity price – have been analyzed at length (Grösche and Schröder 2014; Löschel, Flues and Heindl 2012; Neuhoff et al. 2012; Techert, Niehues and Bardt 2012; Többen 2017).

Yet, the distribution of the increasing grid costs has solely been investigated at a regional level (Hiersig and Wittig 2015). Hinz, Schmidt and Möst (2018) forecast future regional disparities in network charges, depending on various tariff designs. They find that regional average network charges will diverge further by 2025, if the current tariff design is maintained. Households in Mecklenburg-Vorpommern would have to pay

12.1 ct/kWh (+41 % compared to 2015), whereas those in Berlin would be charged only 6.5 ct/kWh (+10 %).

Indeed, the literature described above neither calculates the financial burden of network charges at a household level, nor does it link this burden to household income in order to test whether the charges are characterized by substantial regressive effects. Nevertheless, this form of analysis is promising and goes beyond other studies concerning the regressive effects of electricity prices or feed-in tariffs, since network charges firstly consist of a two-part tariff and secondly differ regionally. Both of these characteristics might affect the regressiveness of the charges.

The present study firstly examines how much German households effectively pay for network charges annually – in absolute and relative terms measured as a share of income. Secondly, we quantify the distributional effects on overall economic inequality. In order to address these issues, we analyze data on network charges for households during the period 2010–2016 and match them with socio-economic panel data. We exclude both commercial customers and indirect effects from our analysis. These might additionally affect redistributive effects. We find that the regional definition of network charges leads to a substantial gap between the North and East of Germany on the one hand, and the South and West of Germany on the other hand. Since the total financial burden exerted by network charges increased by approximately 17 % between 2010 and 2016, these regional disparities are gaining importance. The average German household had to pay 209 € in 2016 for network charges – but only about 150 € in some regions and up to nearly 300 € in others. In addition, different quintiles of the income distribution spend considerably different shares of their income on network charges – 1.6 % in the lowest quintile and 0.4 % in the highest. In addition, we observe that households in urban areas had to pay about 30 € less than those in rural areas. We employ three different inequality metrics – the Gini coefficient, the Theil index and the Atkinson index – in order to derive the overall impact of network charges on the distribution of disposable incomes. As a result, we notice an unambiguously regressive effect of network charges, as all metrics increase by at least 0.6 % when accounting for network charges. This yields an additional (and increasing) welfare loss due to increased economic inequality.

We proceed as follows: Section 2 describes the tariff structure of network charges in Germany, Section 3 derives three hypotheses concerning the distributional effects of network charges. Section 4 presents our methodology and the underlying datasets and in Section 5, we test our hypotheses empirically. Finally, Section 6 concludes.

2 Financing distribution grids in Germany

The German *Energiewende* triggered tremendous changes in energy policy in order to start the transition from fossil and nuclear to renewable energy. The objective of this transition is to revolutionize the German energy system. The installation of new generation plants for renewable power generation has led to a rising emphasis on the electricity distribution grid in recent years. This is a result of the increasing share of renewable energy in gross electricity consumption, which already represented 33.1 % in 2017 (Statistisches Bundesamt 2018). Hence, renewable energy already constitutes the largest share of gross electricity consumption and is planned to reach a share of 80 % in 2050 (Bundesregierung 2010). In this section, we focus on the reasons for the recent rise in network charges and on the definition and tariff structure of these network charges. Finally, we define the customer group on which we concentrate in our empirical investigation.

The focus on renewable energy (especially on onshore windpower systems and PV systems), and the resulting increase of decentralized energy supply as well as the regional shift of generation systems, have led to higher (technical) requirements for the German electricity grid (Bundesnetzagentur 2015, p. 9).[1] Thus, the transmission and distribution grids need to be extended and their capacity increased in the future. Studies on different expansion scenarios until 2020 (the share of renewable energy in gross electricity consumption in 2020 is predicted to be about 39 %) forecast grid-expansion costs between 0.9 and 1.6 bn. €/a (Deutsche Energie-Agentur 2010, p. 13). The responsibility for these grid-expansion measures rests (analogous to the Renewable Energy Law, EEG) with the four German transmission system operators (TSOs) for the transmission grid and more than 800 distribution system operators (DSOs) for the distribution grid. The increase in network costs and charges and the regional differences are caused by various factors.

Firstly, the development of network costs depends on the *urbanization level*. The unequally distributed settlement of industrial locations and agglomeration areas leads to a different utilization rate of the grid. The per capita costs and network charges increase with a decreasing number of users of a particular regional grid area. Hence,

[1] The regional shift of generation systems follows from two different factors. Firstly, it is more efficient regarding the environmental and legal preconditions for onshore wind power systems to become established in the northern part of Germany (it is, for example, more difficult to build wind power systems in Bavaria, because of the 10h-rule); the same holds true for PV sytems in South and East Germany. Secondly, there are still a few nuclear power plants in southern Germany which will gradually disappear from the grid.

people in rural areas have to bear higher network charges than those in urban areas, because fewer people have to bear the costs of the grid. Furthermore, the German electricity infrastructure comprises grids of different ages. The older grid in Western Germany, with its lower residual value, has lower network costs than the newer grids in Eastern Germany. Potential future modernization measures could turn this cost situation around.

Secondly, the rise of *renewable energy generation* is associated with rising network costs. The connection and integration of renewable energy systems (e. g. the connection of off-shore wind power systems) are accompanied by higher costs for the TSOs. Furthermore, because of the increase in renewable energy generation plants, the amount of energy which is fed in to the lower voltage grid levels of the distribution grid rises (especially in low and medium voltage levels). This lowers the current consumption from upstream transmission grid levels so that the average costs of the transmission grid per kWh increase and network charges consequently rise. In addition, the quality of the electricity grid cannot withstand the heavy load fluctuations from renewable energy generation (especially from very volatile onshore wind power systems) and needs to be strengthened and modernized. This scenario leads to rising costs. Especially the rising power generation from renewable energy is resulting in a massive and cost-intensive network expansion in North, East and Southern Germany. Finally, decentralized energy generating systems feed in electricity in lower voltage levels and can therefore avoid upstream network charges. The avoided network charges lead to increasing costs, due to the rising number of renewable energy generating systems.

Thirdly, the TSOs have to ensure supply reliability and avoid and face network bottlenecks. Therefore, the TSOs have to intervene via *redispatching measures* and back up power resulting in higher network costs.[2]

The rising costs of the expansion and maintenance of the transmission and distribution grid are passed on to electricity consumers via network charges (Bundesnetzagentur 2015, p. 13). Basically, network charges are a fee paid by the network users for the transport of electricity within the transmission and distribution grid. The TSOs raise these charges to cover the costs resulting from the network. Network charges at the TSO level are highly regulated by the German Federal Network Agency (*Bundesnetzagentur*, BNetzA) via a revenue cap system (RAP 2014, p. 7 et seq. Bundesnetzagentur 2016a, p. 3).

2 For the total list of reasons for rising network costs, see Hinz (2014, p. 40 et seq.) and Bundesnetzagentur (2015, p. 19 et seqq. 2016b).

Downstream DSOs calculate their costs and charges based on reported network charges of the TSOs and invoice the electricity consumers for the final charge.

In general, network costs can be covered via different mechanisms involving all or subsets of network users. A key aspect is whether the network charge is split into a load (L) and a generation (G) cost component. The L-component allocates the network costs to the electricity consumers, whereas the G-component forces the electricity producers to bear part of the costs. Network costs in Germany consist mainly of an L-component.[3] Households and industrial customers pay for a substantial part of the network costs, whereas energy producers only pay the costs of connection to the network, or for voltage transformation substations (Haucap and Pagel 2014, p. 5). German households pay the network charges via their electricity bills. The charges are paid to the DSOs and in part passed on to the TSOs. The network charges (including meter operation, meter reading and billing) comprised nearly 30 % of the electricity price net of value-added tax (*Mehrwertsteuer*, VAT) in 2017 (Bundesnetzagentur and Bundeskartellamt 2017, p. 254).

Due to different customer profiles, the billing of the network charges also differs. There are two different customer groups, namely customers with consumption metering and customers without consumption metering. The former have to transmit their consumption data every 15 minutes to the respective grid operator and are mainly major or industrial customers who are also connected to higher voltage levels. They pay a power price in €/kW (for the peak load within one billing period) on the one hand, and a price given in ct/kWh depending on actual consumption on the other hand. This customer group can be separated further, according to their usage period – i. e. whether they use the grid for less or more than 2,500 h/a. The latter group includes households as well as small industrial and agricultural customers. For some DSOs, there is a maximum consumption of about 10,000 kWh/a as an upper limit. Customers without consumption metering – the focused of the following analysis – have to pay a fixed component (*Grundpreis*, €/a) and a variable component (*Arbeitspreis*, ct/kWh).

The increase in network charges in recent years, as well as their considerable share in the electricity price and corresponding importance for customers make an empirical analysis of the burden of these network costs relevant. In particular, we take a closer look at the distributional effects on a household level. Accordingly, we derive three

[3] In eleven European countries, a G-component is raised in addition to the L-component (Haucap and Pagel 2014, p. 11). Additionally, in Great Britain, Norway and Sweden, for example, the G-component varies with the choice of location of electricity producers (Grimm et al. 2015, p. 14). For an international comparison of network charges, also see Hinz, Schmidt and Möst (2018, p. 98).

hypotheses in Section 3 stating that network charges should exert substantial regressive effects with respect to the distribution of disposable incomes.

3 Hypotheses

Each household i in region j at time t is assumed to have a disposable income of $y_{ij,t}$. In addition, monthly electricity costs $e_{ij,t}$ are given, as well as the monthly demand for electricity, $d_{ij,t}$.

The electricity price $p_{j,t}$ depends on regionally determined network charges $n_{j,t}$ which consist of two parts – a fixed component ($F_{j,t}$) paid annually (with $f_{j,t} = \frac{F_{j,t}}{12}$ as the monthly share) and a variable component ($v_{j,t}$) paid per kWh. These components in Germany correspond to the *Grundpreis* and *Arbeitspreis* (see Section 2). Additionally, we must adjust for the regionally defined concession fee ($k_{j,t}$; *Konzessionsabgabe*). This fee differs regionally (contingent upon community size) and is a further price component paid for using public infrastructure, i. e. the electricity grid. The national average electricity price $\bar{p}_t$, the national average network charge $\bar{n}_t$, the national average concession fee $\bar{k}_t$, as well as the regional network charge, define the final average electricity price (FAEP) of household i in region j at time t:

$$\bar{p}_{ij,t} = \bar{p}_t - \bar{n}_t + v_{j,t} - \bar{k}_t + k_{j,t} + \frac{f_{j,t}}{d_{ij,t}}. \tag{1}$$

All values are gross, i. e. they include the 19 % VAT. The electricity costs $e_{ij,t}$ of a household can be defined as the product of the FAEP and electricity consumption.

$$e_{ij,t} = f_{j,t} + d_{ij,t}(\bar{p}_t - \bar{n}_t + v_{j,t} - \bar{k}_t + k_{j,t}). \tag{2}$$

The partial derivative of electricity costs with respect to income yields

$$\frac{\partial e_{ij,t}}{\partial y_{ij,t}} = (\bar{p}_t - \bar{n}_t + v_{j,t} - \bar{k}_t + k_{j,t})\frac{\partial d_{ij,t}}{\partial y_{ij,t}}. \tag{3}$$

As we assume electricity to be a normal good (i. e., $\frac{\partial d_{ij,t}}{\partial y_{ij,t}} > 0$), this term can be expected to be positive. Additionally, the income share of electricity costs $\tilde{e}_{ij,t} = \frac{e_{ij,t}}{y_{ij,t}}$ can also be differentiated with respect to income:

$$\frac{\partial \tilde{e}_{ij,t}}{\partial y_{ij,t}} = \frac{\frac{\partial e_{ij,t}}{\partial y_{ij,t}} - \frac{e_{ij,t}}{y_{ij,t}}}{y_{ij,t}}. \tag{4}$$

Furthermore, assuming electricity to be a relatively inferior good[4] leads to a negative link between income and the income share of electricity costs. The numerator of equation (4) has to be negative accordingly. The income elasticity of electricity costs is positive, but smaller than one and as a consequence:

$$\epsilon_{e,y} = \frac{\partial e_{ij,t}}{\partial y_{ij,t}} \frac{y_{ij,t}}{e_{ij,t}} \qquad \in \qquad (0,1). \tag{5}$$

Total network charges paid by the household are

$$N_{ij,t} = f_{j,t} + v_{j,t} d_{ij,t} = \frac{f_{j,t}(\bar{p}_t - \bar{n}_t - \bar{k}_t + k_{j,t}) + v_{j,t} e_{ij,t}}{\bar{p}_t - \bar{n}_t + v_{j,t} - \bar{k}_t + k_{j,t}}, \tag{6}$$

where $d_{ij,t}$ can be derived from equation (2) as

$$d_{ij,t} = \frac{e_{ij,t} - f_{j,t}}{\bar{p}_t - \bar{n}_t + v_{j,t} - \bar{k}_t + k_{j,t}}. \tag{7}$$

The income share of total network charges ($\tilde{N}_{ij,t} = \frac{N_{ij,t}}{y_{ij,t}}$) can be differentiated with respect to income:

$$\frac{\partial \tilde{N}_{ij,t}}{\partial y_{ij,t}} = \frac{v_{j,t}\left(\frac{\partial e_{ij,t}}{\partial y_{ij,t}} - \frac{e_{ij,t}}{y_{ij,t}}\right) - f_{j,t}\frac{\bar{p}_t - \bar{n}_t - \bar{k}_t + k_{j,t}}{y_{ij,t}}}{(\bar{p}_t - \bar{n}_t + v_{j,t} - \bar{k}_t + k_{j,t}) y_{ij,t}}. \tag{8}$$

As both the denominator and the subtrahend in the numerator are positive, this expression is below zero, especially when the minuend of the numerator is negative. This is true in our case, because of the relative inferiority of electricity consumption (i. e., $0 < \epsilon_{e,y} < 1$). Therefore, income and the income share of total network charges are negatively associated. This effect can be attributed to two components: firstly, electricity costs as a share of income decrease with rising income. Secondly, the fixed component of network charges plays a minor role, due to fixed cost degression once a household consumes a substantial amount of electricity – which occurs especially in high-income households. Thus, the income share of total network charges not only decreases with

[4] This assumption is supported by robust empirical evidence from throughout the world (see most recently for Germany: Schulte and Heindl 2017; Jamaica: Campbell 2018; Singapore: Loi and Le Ng 2018) estimating the income elasticity of electricity demand between 0 and 1. For a meta-analysis on the income elasticity of electricity demand, see J. A. Espey and M. Espey (2004). Fouquet (2014) finds that the income elasticity of electricity demand followed an inverted U-shaped curve over the past 200 years – which results in relatively inelastic electricity demand in industrialized countries nowadays.

income, because electricity is a relatively inferior good (minuend in the numerator), but also because the marginal network charge is smaller than the average network charge, because of the fixed component (subtrahend in the numerator). The latter effect would vanish if network charges consisted only of a variable component. We can therefore now derive Hypothesis 1 for our empirical analysis.

Hypothesis 1. *A household's financial burden via network charges is regressive. This regressiveness can be expected to be stronger, especially if the fixed component of network charges is higher:*

$$\frac{\partial \tilde{N}_{ij,t}}{\partial y_{ij,t}} < 0 \ \wedge \ \frac{\partial^2 \tilde{N}_{ij,t}}{\partial y_{ij,t} \partial f_{j,t}} < 0.$$

Furthermore, regional disparities might lead to a correlation between income and the variable component of network charges. In rural areas, incomes are usually lower and network charges higher; this generally also applies to the new federal states of Germany (East Germany). Accounting for a relationship $v_{j,t} = v_{j,t}(y_{ij,t})$ modifies equation (8):

$$\frac{\partial \tilde{N}_{ij,t}}{\partial y_{ij,t}} = \frac{v_{j,t}(\frac{\partial e_{ij,t}}{\partial y_{ij,t}} - \frac{e_{ij,t}}{y_{ij,t}}) - f_{j,t}\frac{\bar{p}_t - \bar{n}_t - \bar{k}_t + k_{j,t}}{y_{ij,t}}}{(\bar{p}_t - \bar{n}_t + v_{j,t} - \bar{k}_t + k_{j,t})y_{ij,t}} + \frac{\partial v_{j,t}}{\partial y_{ij,t}} \frac{\bar{p}_t - \bar{n}_t - \bar{k}_t + k_{j,t}}{(\bar{p}_t - \bar{n}_t + v_{j,t} - \bar{k}_t + k_{j,t})y_{ij,t}} d_{ij,t}. \tag{9}$$

The derivation of equation (9) can be found in the appendix. With $\frac{\partial v_{j,t}}{\partial y_{ij,t}} = 0$, the second summand disappears, leaving equation (8) as a special case of equation (9). Otherwise, Hypothesis 2 is as follows.

Hypothesis 2. *The regressiveness of network charges increases (decreases) if income and the variable component of network charges are negatively (positively) correlated, i. e. if*

$$\frac{\partial v_{j,t}}{\partial y_{ij,t}} < 0 \ \left(\frac{\partial v_{j,t}}{\partial y_{ij,t}} > 0 \right).$$

Additionally, prosumers are not charged any network tariffs for the share of their electricity demand which they have themselves produced. If the feeding-in of PV electricity is distributed equally along household incomes, this has no implications at all for the incidence of network charges. However, when there is a positive relationship between household income and the use of PV systems, high-income households are on average faced with a lower burden from network charges than low-income households. This once again increases the regressiveness of network charges. Hypothesis 3 summarizes this issue.

Hypothesis 3. *Since monthly net demand for electricity is calculated as the difference between consumed and fed-in electricity, network charges can be avoided by producing electricity. The regressiveness of network charges increases (decreases) if the feeding-in of PV electricity and income are positively (negatively) correlated.*

4 Methodology and data

4.1 Methodology

In order to quantify the overall impact of network charges on economic inequality, we employ three different distribution metrics: the Gini coefficient, the Theil index and the Atkinson index. Furthermore, we vary the parameters of the Theil and Atkinson index in order to test the robustness of our results. This selection of inequality metrics basically follows the approach of Grösche and Schröder (2014), who analyze the distributional effects of the German feed-in tariff. We only omit the 90/10 percentile ratio, since it does not include the entire distribution data, but only measures the relationship between two points within the distribution. As a percentile ratio, it is very selective and limited in scope. An axiomatic comparison of the inequality metrics can be found in the aforementioned study (Grösche and Schröder 2014, p. 1363 et seq.) as well as in Sen (1973). In this subsection, we rely on a brief definition of the three chosen inequality metrics for weighted survey data.

4.1.1 The Gini coefficient

The Gini coefficient (Gini 1912) is probably the most common inequality measure in economics. It can be derived from the Lorenz curve which plots the cumulative income share of the bottom $x\,\%$ of the population. The Gini coefficient is normalized to the interval $[0, 1)$, with 0 indicating perfect equality (every household has the same income) and values close to 1 indicating perfect inequality (only one household has a positive income).[5] For weighted survey data, it is defined as

$$\mathcal{G} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \omega_i \omega_j |y_i - y_j|}{2\bar{y}} \tag{10}$$

[5] Note that the Gini coefficient cannot reach a value of 1 for finite populations, as this is a limit value.

where y_i is the income of household i, $\bar{y} = \sum_i \omega_i y_i$ is its weighted mean, n the total number of observed households and $\omega_i = \frac{w_i}{\sum_i w_i}$ the relative weight of household i (with w_i as the projection factor).

4.1.2 The Theil index

The Theil index (Theil 1965) is a special case of the generalized entropy index family stemming from information theory. Originally, it measured the informational content of a number of observations. This content is assumed to be minimal if every observation has the same probability – the entropy reaches its maximum value. By contrast, the informational content increases with decreasing entropy. This measure has been applied to the empirical investigation of economic inequality. The "informational content" of an income distribution increases the more it differs from perfect equality (i. e. with lower entropy). Usually, the Theil L ($\alpha = 0$) and the Theil T ($\alpha = 1$) index are distinct from one another. These indices are defined as

$$\mathcal{T}_\alpha = \begin{cases} \sum_{i=1}^{n} \omega_i \ln \frac{\bar{y}}{y_i} & \text{if } \alpha = 0, \\ \sum_{i=1}^{n} \omega_i \frac{y_i}{\bar{y}} \ln \frac{y_i}{\bar{y}} & \text{if } \alpha = 1 \end{cases} \tag{11}$$

with the definitions introduced in Section 4.1.1. Generally, the Theil T index is more common in empirical economics (see e. g. Grösche and Schröder 2014, p. 1346). The Theil indices can take any nonnegative value and increase with inequality.

4.1.3 The Atkinson index

The Atkinson index (Atkinson 1970) defines the maximum share of mean income a society would be willing to give up in order to reach perfect income equality. As this depends on the level of inequality aversion ϵ, this implies a social welfare function which is concave in individual incomes:

$$W_\epsilon(\boldsymbol{y}) = \begin{cases} \sum_{i=1}^{n} w_i \frac{y_i^{1-\epsilon} - 1}{1-\epsilon} & \text{if } \epsilon \in \mathbb{R}_{>0} \setminus 1, \\ \sum_{i=1}^{n} w_i \ln y_i & \text{if } \epsilon = 1 \end{cases} \tag{12}$$

where $\boldsymbol{y}$ is the vector of household incomes. Based on this social welfare function, we can define the corresponding equally distributed equivalent income $\tilde{y}_\epsilon$ – i. e. household income in a perfectly equal society, which is associated with the same level of social welfare as the actual income distribution.

$$\tilde{y}_\epsilon = \begin{cases} \left(\sum_{i=1}^{n} \omega_i y_i^{1-\epsilon}\right)^{\frac{1}{1-\epsilon}} & \text{if } \epsilon \in \mathbb{R}_{>0} \setminus 1, \\ \prod_{i=1}^{n} y_i^{\omega_i} & \text{if } \epsilon = 1, \end{cases} \tag{13}$$

which yields the weighted geometric mean for $\epsilon = 1$. Finally, we normalize:

$$\mathcal{A}_\epsilon = 1 - \frac{\tilde{y}_\epsilon}{\bar{y}}. \tag{14}$$

Since, for concave social welfare functions (i. e. for a positive inequality aversion $\epsilon > 0$), the equally distributed equivalent income $\tilde{y}_\epsilon$ is always smaller than the weighted mean $\bar{y}$, the Atkinson index is normalized to $\mathcal{A}_\epsilon \in [0, 1]$ with higher values denoting higher inequality.

Consequently, we are able to calculate a "welfare loss" arising from income inequality. This welfare loss is the difference of mean and equally distributed income at a household level or

$$L_\epsilon = \sum_{i=1}^{n} w_i \left(\bar{y} - \tilde{y}_\epsilon\right) = \sum_{i=1}^{n} w_i \mathcal{A}_\epsilon \bar{y} \tag{15}$$

at an aggregate level. It can be interpreted as society's willingness to pay for eliminating income inequality, and is calculated for our purposes in Subsection 5.3.

4.2 Data

The underlying data consists of two merged datasets: socio-economic household data from the German Socio-Economic Panel (SOEP) (SOEP 2018, version v33.1) on the one hand and panel data on regional network charges from ene't GmbH (2018) on the other hand.

From SOEP data, we include monthly net household income (*inc*) and electricity expenditures (*elec*) as financial variables in our analysis. Furthermore, we include the household's number of persons aged 14 or above ($adult14$) and the number of remaining persons, i. e. children aged 13 or below (*children*). These variables are needed so as to calculate equivalent incomes according to the OECD-modified equivalization scale. We include binary variables for the existence of PV electricity generation (*solar*) in our analysis. Each household is assigned either to a rural or urban area (*rural*) and to a *Raumordnungsregion*[6] (*ror*).

However, our analysis has to focus on the period 2010–2016, since electricity expenditure was not surveyed before 2010. Additionally, monthly electricity costs are only available for rental households, whereas households with home ownership were asked to specify their annual electricity costs in the previous year. We include the latter by dividing these costs by 12 and accounting for the annual increase in electricity prices in the corresponding year. The data appears to be comparable, although households with home ownership paid on average 80.18 € per month in 2016 which is 20.29 € or about a third more than rental households. Nevertheless, this seems plausible when taking into account the fact that at the same time, the average household income of owners (3,195 €) was 48 % higher than that of rental households (2,159 €). Additionally, the average number of persons in the household (2.2 compared to 1.8) and the dwelling size (122.3 compared to 72.8 m^2) were considerably higher for households which owned their own housing. Ultimately, owners spent about 3.2 % of their income on electricity, whereas rental households paid 3.5 %. This finding conforms perfectly to our assumption of electricity as a relatively inferior good.

Finally, there are 97,194 observations which include information on electricity costs – equivalent to 13,601 (2010) to 16,539 (2013) observations per year. In 2015, owners were not asked to give their electricity costs: the costs are only available for 8,642 rental households. Therefore, 2015 is excluded from our analysis at every point for which we do not control for ownerhsip. Furthermore, the number of observations does not allow a more detailed geographic division: a valid statement on the average burden exerted by network charges in each of the over 11,000 communities (LAU 2) or 400 districts (NUTS 3) could not be made because of the small sample. At the ROR level, there are *on average* 140 to 170 annual observations which might be sufficient for a quantitative analysis of regional disparities. However, there are still eight RORs which exhibit less than 50 observations in at least one year (leaving out 2015 data).[7] As a consequence, single values should be interpreted with caution and the emphasis should rather be on the overall picture.

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6 A *Raumordnungsregion* (ROR) which can be translated as “spatial planning region”, is a German geographic division standard somewhere between the NUTS 2 (*Regierungsbezirke*/government regions) and NUTS 3 level (*Kreise*/districts). In total, there are 96 RORs across Germany.

7 The overall response rate for 2010–2014 and 2016 amounted to 87.9 %, which yields a representative analysis.

From ene't data, we include network charges for the period 2010–2017, which consist of the fixed component (GP) and the variable component (AP). Furthermore, we include the regional concession fee (KA, measured in ct/kWh). Network charges as well as the concession fee, are available at LAU 2 level, and are aggregated by calculating weighted averages for RORs. This enables us to match households and the corresponding network charges.

Merging the datasets further allows us to calculate electricity consumption according to equation (7) and the total burden of network charges according to equation (6). Since the electricity price is taxed at 19 % VAT, the effective burden must include the additional tax burden. Therefore, as already explained in Section 3, network charges are gross values in the following analysis.

5 Results

5.1 Descriptive statistics

As shown in Figure 1, network charges increased substantially in recent years. The federal average network charge for a representative household with annual electricity consumption of 3,500 kWh amounted to 7.44 ct/kWh in 2016, compared to 6.13 ct/kWh in 2010, which corresponds to an increase of 21.3 %. Even after accounting for inflation (7.7 %), a real increase in effective network charges of 12.7 % remains. This development is caused by both an increase in the variable and the fixed component: whereas the *Arbeitspreis* rose from 5.73 ct/kWh in 2010 to 6.34 ct/kWh in 2016 (+10.7 %), the *Grundpreis* even grew more strongly and nearly tripled (from 14.03 €/a in 2010 to 38.32 €/a in 2016, +173.2 %). Whereas the *Grundpreis* grew gradually, the *Arbeitspreis* reached a peak in 2013 and remained at a high level from then on.

Also, the distribution of network charges has changed: network charges increased especially in the Northeast and in the Southwest of the country. The Northeast is especially affected by the modification and expansion of the grid, due to the connection of renewable energies and having been a region with a relatively low level of network density. In the Southwest, costs are in part driven by a well-advanced diffusion of PV systems. The Gini coefficient measuring the inequality of average network charges across communities increased from 9.6 % in 2010 to 11.3 % in 2016. This means that network charges tended to increase more in communities where they were also higher in 2010. Looking at the long term, this trend became even more intense over the last decade (2007: 7.3 %; 2017: 12.0 %).

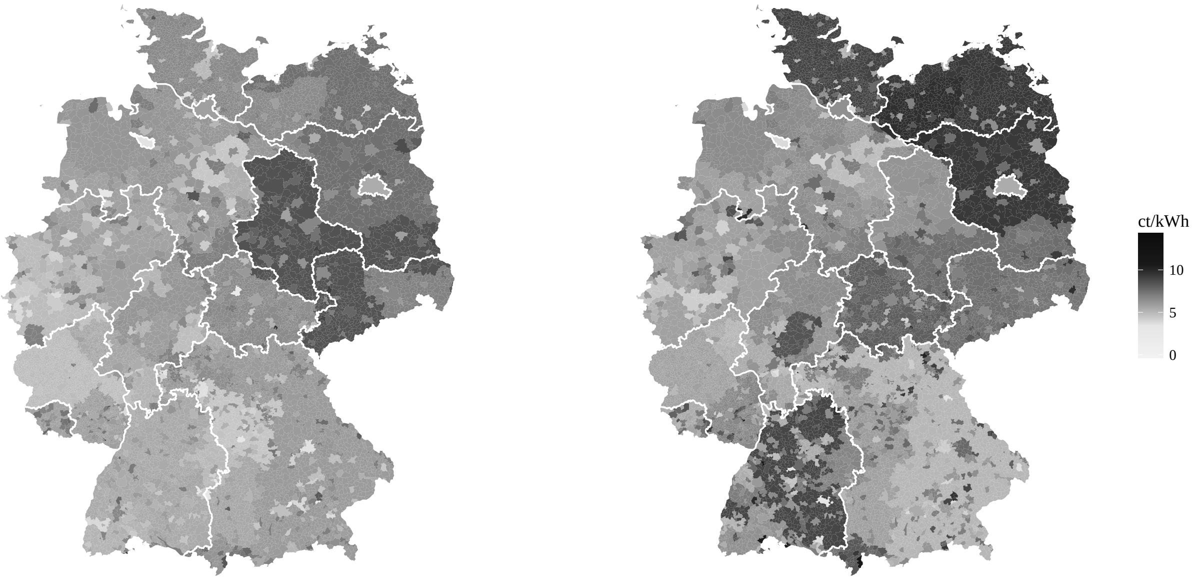

Figure 1: Average gross network charges (ct/kWh) in 2010 (left) and 2016 (right) for a representative household with electricity consumption of 3,500 kWh/a at the community level. Source: own illustration and calculation based on ene't GmbH (2018).

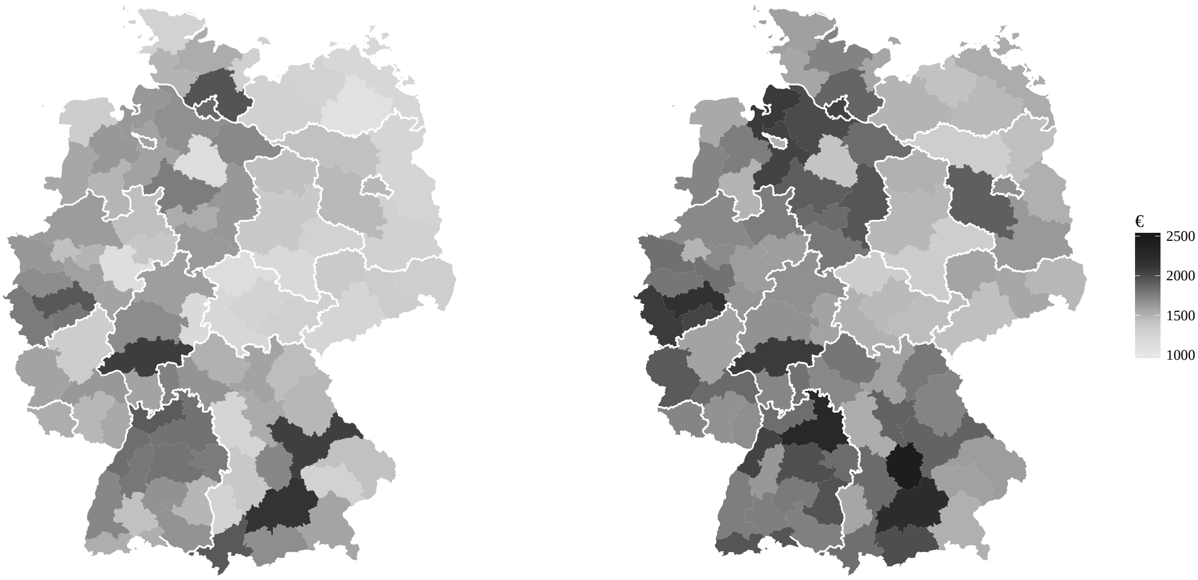

Figure 2: Average monthly net equivalent household income (€, OECD-modified scale) in 2010 (left) and 2016 (right) at ROR level. Source: own illustration and calculation based on SOEP (2018, wave v33.1).

In order to display regional income disparities, we equivalize household net income by applying the OECD-modified scale. According to this procedure, each member of the household is assigned a certain value (first adult 1, other adults 0.5, children < 14 years 0.3) and the household net income is finally divided by the sum of these values. The equivalization is better able to account for the different needs of households with a different composition. Net equivalent household income (OECD-modified scale) increased by 12.3 % in the period 2010–2016, which corresponds to an annual growth rate of 1.9 %. Since inflation amounted to 7.7 %, real incomes also increased on average. However, huge income differentials appear when analyzing average incomes at the ROR level. Income is unequally distributed across RORs in Germany. The Gini coefficient (weighted by the number of ROR inhabitants) measuring regional income inequality was mainly between 7.7 % and 9.0 % in recent years and exhibited a moderate downward trend (2010: 9.0 %; 2016: 8.2 %). In 2016, average equivalent incomes reached from 1,350 € in Anhalt-Bitterfeld-Wittenberg to 2,449 € in Ingolstadt. This heterogeneity is persistent over time and extends back to the division of Germany into GDR and FRG until 1990. Even over 25 years later, the East-West income differential is substantial, is decreasing very slowly and easily can be seen in Figure 2.

In 2016, monthly electricity costs amounted to 75.79 € on average, which was about 3.2 % of net household income. These costs are used to calculate electricity consumption and the network charge burden according to the procedure in equations (6) and (7).

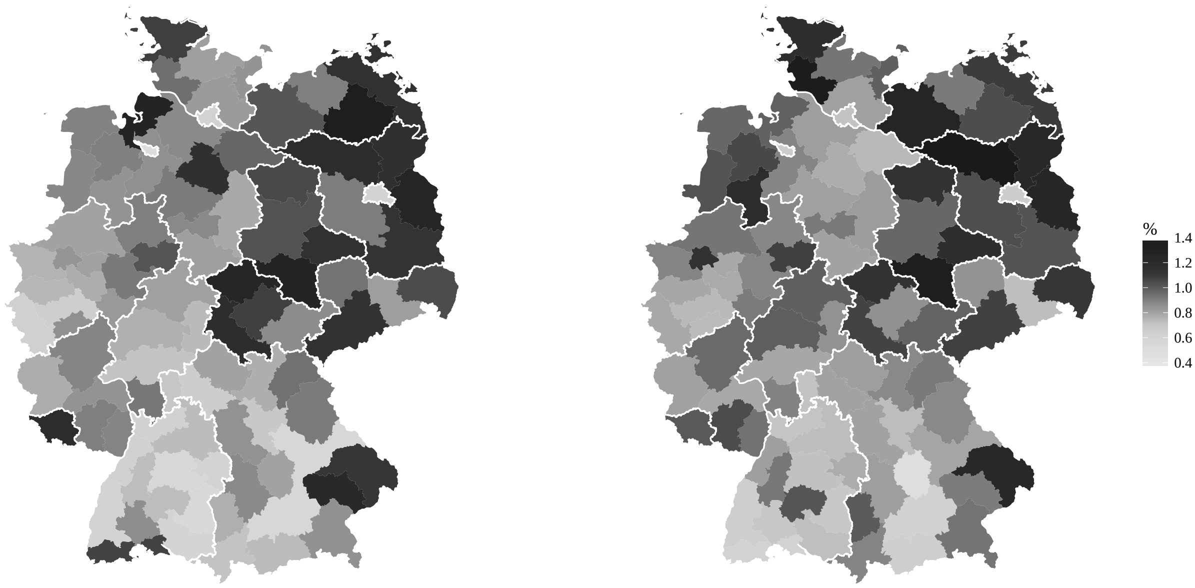

Figure 3: Average annual network charge burden (% of net household income) in 2010 (left) and 2016 (right) on ROR level. Source: own illustration and calculation.

The burden exerted by network charges increased by 17 % – from 178.95 € in 2010 to 208.74 € in 2016. Most recently, the regional disparities were quite considerable – ranging from 142 € in Berlin to 288 € in Bremerhaven.[8] The disparity is also large when expressed as a share of income: people in Ingolstadt spent 0.49 % of their income on network charges, whereas those in Prignitz-Oberhavel paid 1.39 %.[9] When analyzing relative burdens at a federal level, the North and East are charged disproportionately compared to the South and West of Germany (see Figure 3). But the burden also increased at a household level: whereas 21.5 % of households had to spend more than 1 % of their income on network charges in 2010, this share increased to 25.4 % in 2016. On the other hand, the share of households paying less than 0.5 % decreased more slowly from 26.3 to 24.2 %. These findings motivate the following analysis which is an attempt to determine the overall impact of network charges on economic inequality in Germany.

5.2 Impact on economic inequality

First of all, we have to test whether electricity is a relatively inferior good in our data, as assumed in Hypothesis 1 and in the literature described in Footnote 4. We regress our estimate of log electricity consumption on the logarithm of equivalent income in a two-way fixed-effects weighted least squares model.[10] We find that the income elasticity of electricity consumption is slightly but significantly above zero (0.058), even when accounting for heteroskedasticity robust standard errors. Consequently, we confirm the results of previous studies, and electricity appears to be a relatively inferior good.

As assumed in Hypothesis 2, the variable component of the network charge is negatively correlated with income. Whereas the lowest income quintile had to pay 5.34 ct/kWh in 2016, the highest income quintile only had to pay 5.24 ct/kWh. This difference is small, but persistent over time,[11] which can only be explained by regional disparities,

[8] It may seem obvious that these huge regional disparities stem from small samples at the ROR level. However, the inequalities persist when analyzing network charge burdens at a federal state (*Bundesland*) level: Whereas households in Bremen or Berlin only spent below 150 € on network charges in 2016 and households in Thüringen and Sachsen spent below 200 €, households in Brandenburg and Schleswig-Holstein had to pay more than 240 €.

[9] At the federal state level, this share ranged from about 0.67 % in Bremen and Berlin, to above 1.1 % in Brandenburg, Mecklenburg-Vorpommern and Sachsen-Anhalt.

[10] This technique is most able to extract the *ceteris paribus* influence of income on electricity consumption: time-fixed effects such as efficiency gains and societal changes in consumption habits are represented, as well as entity-fixed effects such as individual usage behavior and wastefulness.

[11] Actually, this gap amounted to higher values in the past: 0.26 ct/kWh in 2010, 0.22 ct/kWh in 2012, and 0.17 ct/kWh in 2014. In addition, we have to keep in mind that these values are net of VAT and that these gaps increase with the factor of 1.19 when calculating effective financial burdens.

since the *Arbeitspreis* does not vary *within* a region but only across regions. This result is somewhat in line with our previous findings: households in rural areas usually have lower incomes, but have to pay for a grid used by relatively few people, due to the low population density in rural areas. This finding is also supported by the conditional means of the variable network charge, given a certain urbanization level. In 2016, households in rural areas had to pay on average 5.7 ct/kWh. By contrast, people in urban areas had to pay only 5.2 ct/kWh.[12]

The use of rooftop PV systems is indeed correlated with household income as assumed in the context of Hypothesis 3: whereas only 3.3 % of households in the lowest income quintile produced solar power in 2016, it was 8.9 % in the third, and up to 14.3 % in the fifth quintile.

As all the assumptions underlying our hypotheses are met and can be found in our data, we expect network charges to display considerable regressive effects. In a first step, we calculate total annual network charges and the income share of annual network charges for each quintile of the distribution of net equivalent incomes. As shown in Table 1, the absolute financial burden of network charges increased for all households by about 2–3 € per month, which corresponds to an annual additional burden of about 30 €. Independent of the year, the income share of network charges is decisively lower in higher income quintiles: whereas the lowest quintile has to pay more than 1.5 % of income for network charges, the highest quintile has to spend less than 0.5 %. When analyzing the intertemporal development of relative financial burdens, we conclude that the increase in network charges in the period under consideration mainly affected the lower quintiles, inducing them to spend higher shares of their incomes on network charges. By contrast, the income shares of network charges remained nearly constant in higher quintiles.

These findings can be attributed to multiple causes. Firstly, the relative inferiority of electricity induces a sub-proportional increase in electricity consumption with rising incomes. As time goes by, this leads to a higher additional burden in lower quintiles during periods of extensive economic growth. Secondly, the relevance of the fixed component of the network charges increased, thus strengthening its regressive impact. Thirdly, the regional disparities of network charges increased as outlined in Section 4. Since network charges are negatively correlated with incomes, this promotes the regressive effects of network charges once more. And fourthly, incomes grew sub-proportionately in the lowest quintile (by 7.9 % compared to 12.2–15.7 % in higher quintiles).

[12] This also holds for the fixed component: The *Grundpreis* in rural areas amounted to 36.80 €/a, but only to 30.07 €/a in urban areas. In the end, households in rural areas (229 € in 2016) pay nearly 30 € more annually than households in urban areas (200 €).

In order to quantify the impact of network charges on economic inequality, and following the approach of Grösche and Schröder (2014), we finally calculate different inequality measures of equivalent incomes – gross and net of network charges. We employ the Gini coefficient, the Theil T and L index and the Atkinson index – the latter with different parameters.[13] The results are shown in Table 2 for the years 2010 and 2016 as an example.

All indices suggest that economic inequality is amplified by network charges. In 2010, inequality metrics increased by 0.60–1.49 % when accounting for network charges. Looking at the Theil and Atkinson indices, we conclude that this effect is qualitatively independent of the chosen parameter (α, ϵ), although it increases with an increasing inequality aversion. In 2016, this inequality-promoting effect even grew stronger: inequality metrics increased by 0.64–1.53 % when accounting for network charges. Looking at the years in between, this development reflects an ongoing trend. Consequently, network charges have a positive and increasing impact on inequality and thereby exert a regressive impact on the distribution of disposable incomes.

5.3 Welfare loss

Finally, we attempt to estimate the additional welfare loss caused by the regressiveness of network charges according to the procedure described above (Subsection 4.1.3). The results are shown in Table 3.

The welfare loss for German households which can be derived from the Atkinson index depends crucially on the presumed inequality aversion parameter. The additional welfare loss which is due to unequally distributed network charges amounted to at least several million Euros per year, but the estimates have a large variance: at $\epsilon = 2$, the additional welfare loss is nearly six times as high as at $\epsilon = 0.5$. As a consequence, the absolute level of this measure should not be overstated, but the time trend is interesting: the welfare loss increases substantially over time. Assuming an inequality aversion of 0.5 or 1, the welfare loss increased by about a quarter in the period under consideration, whereas it still increased by more than a sixth with an underlying inequality aversion of 2.

[13] The underlying formulas are defined in Subsection 4.1. Note that we interpret these metrics only as a positive measure of inequality and not as a normative criterion. Thus, we only state that inequality rises or declines and do not assess whether this finding can be treated to be fair.

quintile	2010 borders	2010 mean	2010 total network charges	2010 ... as a share of income	2016 borders	2016 mean	2016 total network charges	2016 ... as a share of income
1	< 933 €	717 €	13.92 €	1.47 %	< 1,000 €	773 €	15.76 €	1.55 %
2	933 €–1,227 €	1,091 €	14.27 €	0.91 %	1,000 €–1,400 €	1,235 €	17.06 €	0.98 %
3	1,227 €–1,571 €	1,397 €	15.26 €	0.73 %	1,400 €–1,800 €	1,616 €	17.73 €	0.79 %
4	1,571 €–2,000 €	1,801 €	14.88 €	0.58 %	1,800 €–2,333 €	2,058 €	17.40 €	0.60 %
5	> 2,000 €	2,957 €	15.92 €	0.41 %	> 2,333 €	3,318 €	18.55 €	0.42 %

Table 1: Monthly financial burden of network charges by quintiles of net equivalent income distribution. Source: own calculation based on SOEP (2018, wave v33.1) and ene't GmbH (2018).

index	2010 inequality of equivalent income	2010 ... net of network charges	2010 percentage change	2016 inequality of equivalent income	2016 ... net of network charges	2016 percentage change
Gini	0.2767	0.2783	+0.5980 %	0.2757	0.2775	+0.6381 %
Theil's L ($\alpha = 0$)	0.1293	0.1310	+1.3474 %	0.1279	0.1297	+1.4363 %
Theil's T ($\alpha = 1$)	0.1396	0.1412	+1.1482 %	0.1347	0.1363	+1.2364 %
Atkinson ($\epsilon = 0.5$)	0.0643	0.0651	+1.1954 %	0.0630	0.0639	+1.2834 %
Atkinson ($\epsilon = 1$)	0.1212	0.1228	+1.2611 %	0.1200	0.1217	+1.3452 %
Atkinson ($\epsilon = 2$)	0.2250	0.2283	+1.4877 %	0.2245	0.2280	+1.5307 %

Table 2: Impact of network charges on economic inequality measured by different inequality indices. Source: own calculation based on SOEP (2018, wave v33.1) and ene't GmbH (2018).

index	2010 welfare loss without network charges	2010 welfare loss including network charges	2010 additional welfare loss of network charges	2016 welfare loss without network charges	2016 welfare loss including network charges	2016 additional welfare loss of network charges
Atkinson ($\epsilon = 0.5$)	4,161M €	4,183M €	22M €	4,750M €	4,778M €	28M €
Atkinson ($\epsilon = 1$)	7,844M €	7,891M €	47M €	9,044M €	9,103M €	59M €
Atkinson ($\epsilon = 2$)	14,556M €	14,676M €	121M €	16,916M €	17,058M €	142M €

Table 3: Welfare loss of income inequality and relative welfare loss, due to inequality-promoting network charges. Source: own calculation based on SOEP (2018, wave v33.1) and ene't GmbH (2018).

6 Conclusion

Network costs increased substantially in recent years and have been passed on to electricity customers in the form of higher network charges. We show that in absolute terms, the average German household paid 209 € for network charges in 2016 starting from about 179 € in 2010. As a component of the electricity price, these charges exert regressive effects on the distribution of disposable incomes *net of network charges* due to four reasons. Firstly, electricity is a relatively inferior good so that the income share of electricity is negatively related to income. Secondly, the fixed component of network charges leads to lower average network charges for households with higher electricity demand. Thirdly, network charges differ regionally. Both the variable and the fixed component of network charges are negatively correlated with regional average income. This leads to a higher burden for (relatively poor) households in regions with higher network charges. Fourthly, prosumers are exempt from network charges, but are high-income households, in many cases. As a consequence, low-income households are *de facto* often faced with higher costs due to network charges although network charges are not *de jure* contingent upon income.

As a result, households pay on average a share of 0.9 % of their income for network charges. But different quintiles of the income distribution spend significantly different shares of their income on network charges – 1.6 % in the lowest quintile and 0.4 % in the highest quintile. Because of the negative regional correlation of network tariffs and income, even households with similar economic preconditions are charged differently in different parts of the country. Households had to pay only 150 € in some regions and up to about 300 € in others. Finally, there are apparent differences between rural and urban areas: households in rural areas paid nearly 229 €/a and about 200 €/a in urban areas. This corresponds to higher network costs per household in rural areas.

Using different inequality metrics, we find that network charges increase overall inequality of disposable incomes net of network charges by at least 0.6 %. This effect has increased since 2010 as network charges have also increased substantially in the respective period. As network costs are expected to increase further in the near future, distribution issues will become increasingly important in this area.

The maintenance and expansion of the distribution grid is essential for the integration of renewable energies in order to fulfill the requirements of the *Energiewende*. Thus, the distribution of the corresponding costs among the population is a fundamental determinant for the political acceptance of such an energy transition. To the best of our knowledge, the present study is the first to analyze the relative financial burden imposed by increasing network charges to households. It shows that the tariff structure and the regional differentiation of network charges are able to exert significant (regressive) effects on the distribution of disposable incomes. Consequently, they have the potential to jeopardize the political feasibility of the German *Energiewende* and have to be analyzed thoroughly.

Yet, these findings do not suggest automatically that the distribution of the financial burden of network charges can be treated as unfair. On the one hand, we did not include commercial customers to our analysis. However, their share in financing the grids is considerable and it appears to be promising to analyze this "functional" inequality. On the other hand, there is an emerging debate in the literature concerning distribution issues and whether or how far fairness norms should be applied to the realm of energy policy (Gawel and Korte 2012; Gawel, Korte and Tews 2015). In the context of network charges, a more detailed discussion of relevant normative criteria is still pending. This will be an interesting challenge for future research in order to scrutinize the current tariff design of network charges and to make useful policy recommendations. Furthermore, a comparative analysis of the distributional effects of various tariff designs in different countries appears to be promising. This might lead to the identification of best practices. However, this firstly relies on a normative evaluation of distributional effects and secondly poses the question how far tariff designs of some countries can be transferred and implemented in other countries and how far different systems are able to learn from each other, accordingly.

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Appendix

Derivation of Hypothesis 2

The income share of total network charges is given by

$$\tilde{N}_{ij,t} = \frac{f_{j,t}(\bar{p}_t - \bar{n}_t + \bar{k}_t + k_{j,t}) + v_{j,t}e_{ij,t}}{(\bar{p}_t - \bar{n}_t + v_{j,t} + \bar{k}_t + k_{j,t})y_{ij,t}}.$$

Differentiating with respect to income yields:

$$\begin{aligned}
\frac{\partial \tilde{N}_{ij,t}}{\partial y_{ij,t}} =& \frac{(\bar{p}_t - \bar{n}_t + v_{j,t} + \bar{k}_t + k_{j,t})y_{ij,t}\left(\frac{\partial v_{j,t}}{\partial y_{ij,t}}e_{ij,t} + v_{j,t}\frac{\partial e_{ij,t}}{\partial y_{ij,t}}\right)}{(\bar{p}_t - \bar{n}_t + v_{j,t} + \bar{k}_t + k_{j,t})^2 y_{ij,t}^2} \\
&- \frac{[f_{j,t}(\bar{p}_t - \bar{n}_t + \bar{k}_t + k_{j,t}) + v_{j,t}e_{ij,t}][(\bar{p}_t - \bar{n}_t + v_{j,t} + \bar{k}_t + k_{j,t}) + y_{ij,t}\frac{\partial v_{j,t}}{\partial y_{ij,t}}]}{(\bar{p}_t - \bar{n}_t + v_{j,t} + \bar{k}_t + k_{j,t})^2 y_{ij,t}^2} \\
=& \frac{\frac{\partial v_{j,t}}{\partial y_{ij,t}}e_{ij,t} + v_{j,t}\frac{\partial e_{ij,t}}{\partial y_{ij,t}} - \frac{f_{j,t}(\bar{p}_t - \bar{n}_t + \bar{k}_t + k_{j,t})}{y_{ij,t}} - v_{j,t}\frac{e_{ij,t}}{y_{ij,t}}}{(\bar{p}_t - \bar{n}_t + v_{j,t} + \bar{k}_t + k_{j,t})y_{ij,t}} \\
&- \frac{[f_{j,t}(\bar{p}_t - \bar{n}_t + \bar{k}_t + k_{j,t}) + v_{j,t}e_{ij,t}]\frac{\partial v_{j,t}}{\partial y_{ij,t}}}{(\bar{p}_t - \bar{n}_t + v_{j,t} + \bar{k}_t + k_{j,t})^2 y_{ij,t}} \\
=& \frac{v_{j,t}\left(\frac{\partial e_{ij,t}}{\partial y_{ij,t}} - \frac{e_{ij,t}}{y_{ij,t}}\right) - f_{j,t}\frac{\bar{p}_t - \bar{n}_t + \bar{k}_t + k_{j,t}}{y_{ij,t}}}{(\bar{p}_t - \bar{n}_t + v_{j,t} + \bar{k}_t + k_{j,t})y_{ij,t}} \\
&- \frac{\partial v_{j,t}}{\partial y_{ij,t}}\frac{\bar{p}_t - \bar{n}_t + \bar{k}_t + k_{j,t}}{\bar{p}_t - \bar{n}_t + v_{j,t} + \bar{k}_t + k_{j,t}}\frac{f_{j,t} - e_{ij,t}}{(\bar{p}_t - \bar{n}_t + v_{j,t} + \bar{k}_t + k_{j,t})y_{ij,t}} \\
=& \frac{v_{j,t}\left(\frac{\partial e_{ij,t}}{\partial y_{ij,t}} - \frac{e_{ij,t}}{y_{ij,t}}\right) - f_{j,t}\frac{\bar{p}_t - \bar{n}_t + \bar{k}_t + k_{j,t}}{y_{ij,t}}}{(\bar{p}_t - \bar{n}_t + v_{j,t} + \bar{k}_t + k_{j,t})y_{ij,t}} + \frac{\partial v_{j,t}}{\partial y_{ij,t}}\frac{\bar{p}_t - \bar{n}_t + \bar{k}_t + k_{j,t}}{\bar{p}_t - \bar{n}_t + v_{j,t} + \bar{k}_t + k_{j,t}}d_{ij,t}.
\end{aligned}$$

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