Another source of inequality? How grid reinforcement costs differ by income of EV user groups

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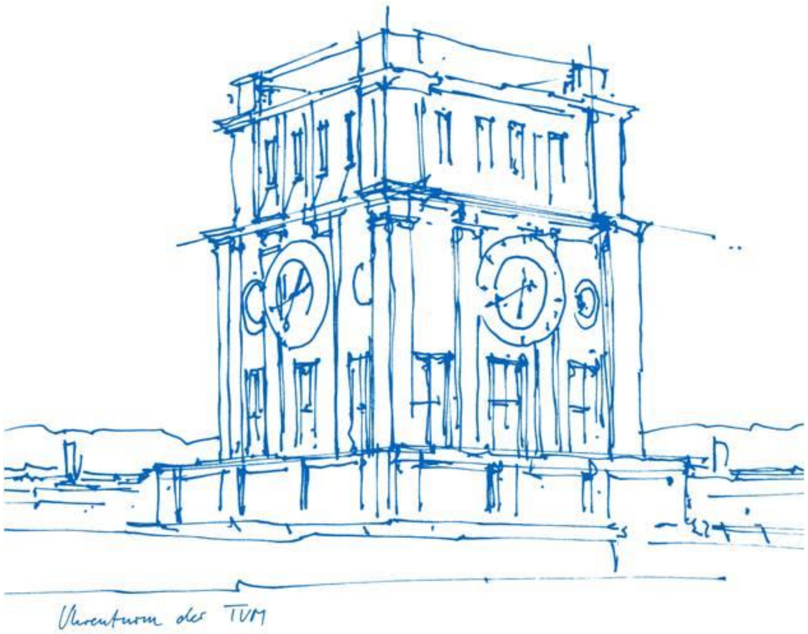
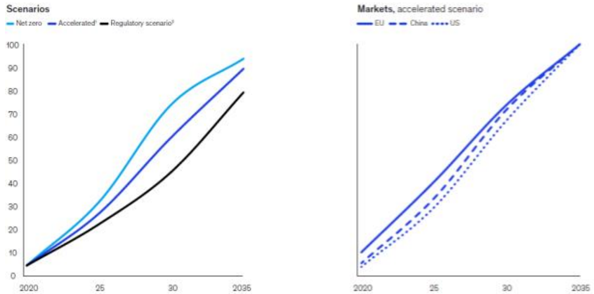


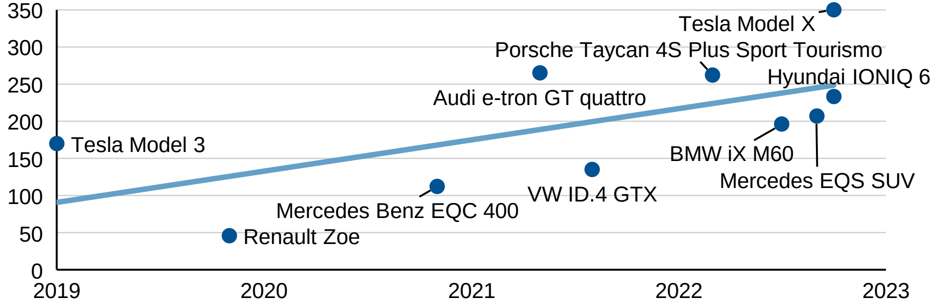
EV adoption and charging requirements are expected to increase significantly, challenging grids and creating costs

In 13 years, key markets are expected to be fully electric…



…with increasing EV fast charging power…

Max. charging power in kW



…which challenges governments and grid infrastructure providers

Current grid development plan just doubled the estimated increases to 12.700 km **(+25% of today's length)** by 2040

E-mobility is expected to become a **significant challenge** to the distribution grid

A recent study estimated that in an unmanaged-charging scenario, the overall cost to upgrade residential transformers could total **more than €5 billion by 2030** in Germany, whilst in 2020, the cost to update the grid for the next 10 years was estimated at €16 billion

Source: MCFM, literature search; ICCT; EVvolumes.com; IHS Markit; OEM websites; www.ev-database.de; Statista; BIP 2019; Umweltbundesamt; Bundesregierung; McKinsey net zero Deutschland report; NEP 2035, Version 2021, 2. Entwurf; McK 6/21; Bundesnetzagentur 2020

Income influences EV charging requirements and hence could impact the magnitude of grid reinforcements needed

Household income has an impact on…

EV adoption

Model choice

Driving patterns

… and hence influences charging requirements and related grid reinforcement needs

Our paper finds that higher income groups cause significantly higher grid reinforcement costs

Research aim

Quantify the **impact of household income** on EV-related **grid reinforcement cost**, uncover potential **inequities in cost allocation** and propose related mitigating **policy actions**

Paper focus

- Electric vehicle (EV) adoption is increasing, but related charging can cause **overloads** and require large **grid reinforcements**
- EV charging loads **differ significantly between income groups**, posing the challenge of a **fair grid cost allocation**
- These costs are usually covered through electricity prices and hence **impact everyone**, creating further inequality
- Our paper simulates the EV charging requirements, grid overloads and required **grid reinforcements** for **above average and below average income neighborhoods**
- We find that **higher** compared to lower **income neighborhoods** would

experience at least **>3 times** the amount of **overloads**

increase related **grid reinforcement costs** by up to the **28-fold**

- **Policy makers** should consider **countermeasures** such as a load-based pricing policy, dynamic pricing or subsidy adjustments to reduce related inequities in cost allocation

The impact of socio-economic factors on EV adoption and usage is well studied, yet excludes grid impacts

Literature on the impact of socio-economic factors on EV adoption, model choice and usage

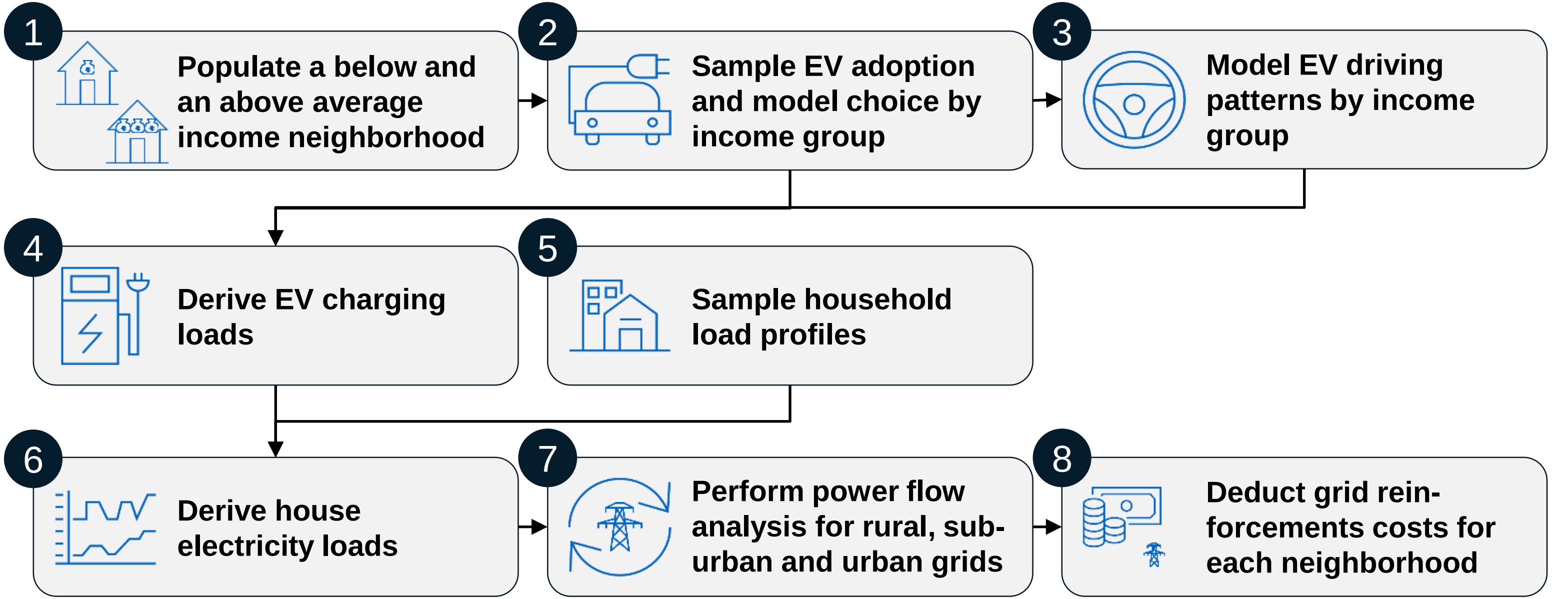
- **Xue** (2021): Sales data from 20 countries (e.g., China, Norway, Germany, US) reveals that **income is the primary driver of EV adoption**
- Researchers find **similar adoption effects** and the tendency of higher income households to buy **more expensive EV models** in the Nordics, Germany or the UK (Sovacool (2019), Chen (2020), Römer (2021), Berneiser (2021), Mühlegger (2019), Lee (2021))
- Socio-economic factors **significantly effects the driving and charging behavior** (Kelly (2012), Langbroak (2017), Zhang (2020))
- **Gauglitz** (2020) **calls to include socio-economic factors in load assessments** as they can result in higher worst-case power flows
- Yet only a **few studies include these factors** in their load assessment and **none of these estimate the related grid reinforcement requirements** (Fischer (2019), Lee (2021)
- **Lee** (2021) raise the issue of an **equitable allocation of grid reinforcement costs**, as they are mostly caused by high income EV users

Literature on the grid impacts of EV charging, yet excluding socio-economic factors

- **Clement-Nyns** (2010): PHEV penetrations levels between 10% and 30% lead to **significant voltage imbalances and power losses** in the Belgian grid
- Building on these findings, numerous authors find **similar results in different countries and grid scenarios** (Lopes (2011), Fernandez (2011), Salah (2015),Yu (2020))
- **Main challenge**: most studies model all households within the simulated distribution grid with **homogeneous EV adoption and usage behavior**

- Connecting to this issue raised by Lee (2021), we focus our analysis on **household income as key socio-economic factor**
- It was identified as a **very significant factor** throughout literature and correlates with other significant factors such as level of education or occupation
- We **quantify grid cost implications** and contribute to the discussion on **social equability of cost allocation**

We simulate EV adoption, model choice and driving patterns by income group to derive grid reinforcement costs



We analyze two scenarios based on Germany's target of 15 mn EVs on the road by 2030

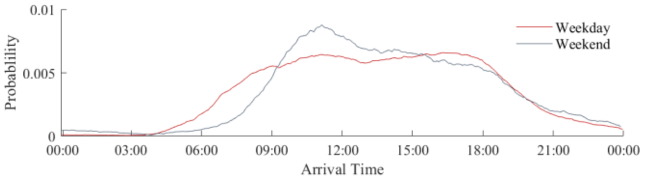
1. **Equal adoption:** Both income classes have an equal EV adoption rate
2. **Differentiated adoption:** Higher income households are three times more likely to own an EV than lower income households (Römer (2021))

Higher income neighborhoods exhibit different driving patterns and cause stronger load peaks

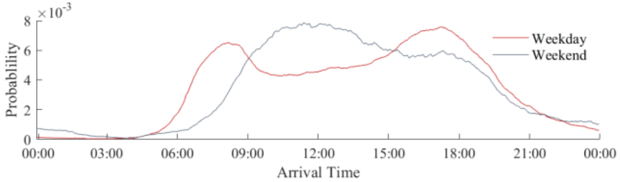
Findings on driving patterns

- Using the German Mobility Panel data, we find that **higher income households perform more trips** per day with an average of 2.2 daily trips vs. 2.0
- They exhibit **longer average trip durations** (42 min vs. 38 min)
- Higher income households show **more concentrated arrival times**

Lower income household home arrivals

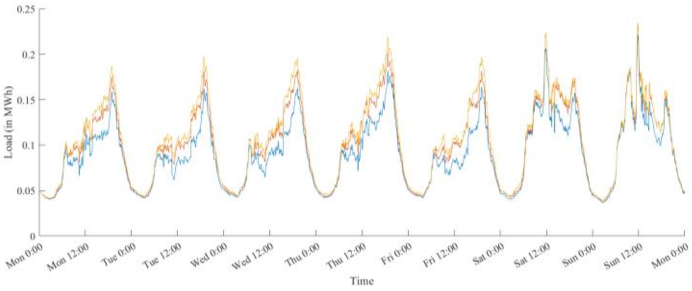


Higher income household home arrivals

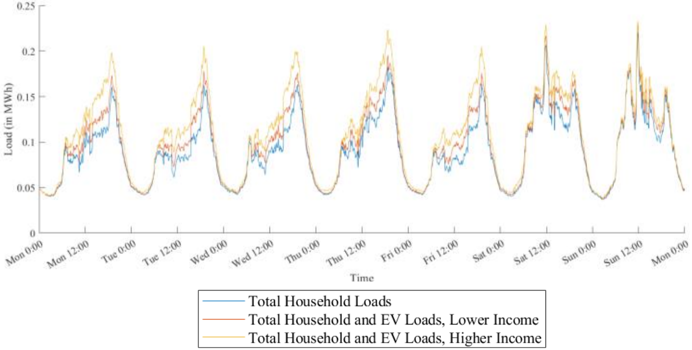


Load profile implications (Rural grid example)

Neighborhood loads, equal adoption scenario

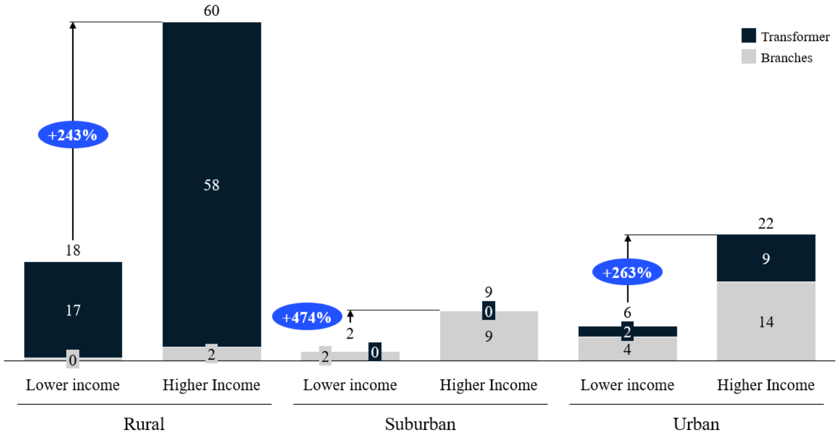


Neighborhood loads, differentiated adoption scenario

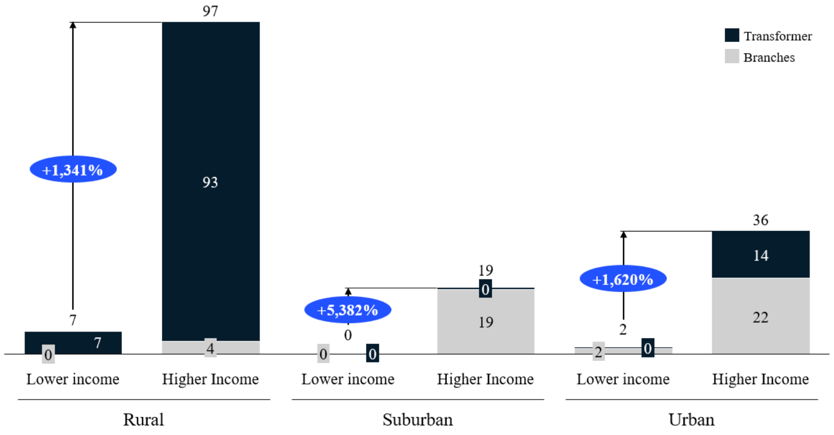


If LV grids are not reinforced, higher income neighbor-hoods would experience twice to >50 times more overloads

Average number of weekly overloads in December, equal adoption scenario



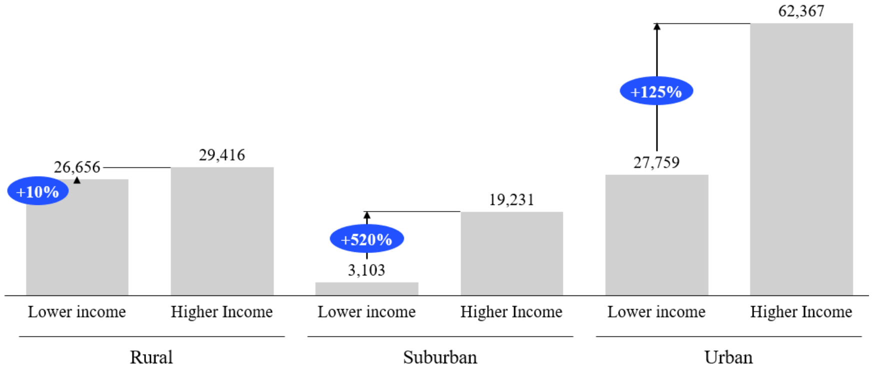
Average number of weekly overloads in December, differentiated adoption scenario



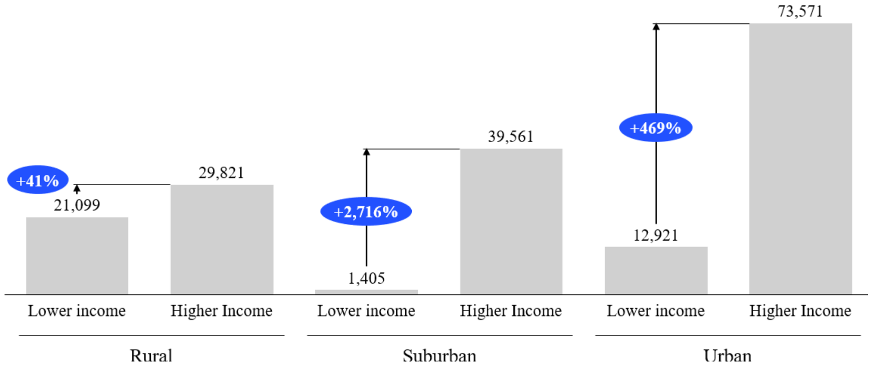
- In line with existing literature, the **rural grid is the weakest** and exhibits the most overloads
- These results imply that **higher income neighborhoods would experience significantly more grid overloads** and would hence **put these neighborhoods higher on the grid operators' agenda for grid reinforcements**

In both scenarios, significant differences in grid reinforcement costs can be observed

Average grid reinforcement costs, equal adoption scenario



Average grid reinforcement costs, differentiated adoption scenario



- The **difference in reinforcement costs is the smallest for rural grids**, as they are the weakest and grid reinforcements are already required for low EV charging demands
- Especially for the suburban and urban grids, **significant differences in grid reinforcement costs between higher and lower income neighborhoods** can be expected for the 15 million EV target of the German government by 2030
- Residential grid **reinforcement costs are currently paid for through the consumer electricity price** and not adjusted for load peaks, confirming the **issue raised by Lee (2021) on inequity in cost allocation**

Conclusion and discussion: Policy makers should consider socio-economic factors for a fair grid cost allocation

- This paper analyzes **difference in grid reinforcement costs** induced by EV charging of **lower and higher income neighborhoods based on Germany's 2030 EV target**
- An **over 240% increase in grid overloads occurs for higher income neighborhoods** in all area types, creating a stronger need for grid reinforcements in these neighborhoods
- While grid reinforcement **costs increase for higher income neighborhoods in rural grids by up to 41%**, we see a **more significant effect in suburban and urban grids**, with costs **increasing by up to 28- and almost sixfold**, respectively
- **Policy makers** should hence consider **adopting a load-based pricing policy** to not assign these costs to all electricity consumers
- **Reducing government EV subsidies** based on electricity consumption or **introducing dynamic electricity pricing** during peak hours could also discourage the negative grid impacts of higher income groups

Source: https://www.kia.com/de/ueber-kia/entdecken/technologie/elektrohub/home-charging/