Electricity grid tariffs for electrification in households: Quantifying cross-subsidies across grid users

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Overview

The current debate around introducing new electricity tariffs echoes the question of who pays for what and to what extent. This often results in a clash between economic and political arguments, with the former advocating for allocative efficiency and the latter for social equity. The growth of Electric Vehicles (EVs) and Heat Pumps (HPs) further reinforces this dilemma in exacerbating the cross-subsidy effect between flexible and passive grid users on the one hand, and increasingly between rich and poor households on the other hand.

On the economics side, the works of Ramsey and Boiteux lays the theoretical foundation that defines that in a network monopoly situation, the second-best optimum is found when the tariff reflects the average cost of the incremental capacity in peak periods and the cost of operation and losses the rest of the time (Boiteux 1956). The tariff then provides a cost-reflective and time-based signal to induce load adjustments and thus a cross-subsidization of network costs between flexible and passive grid users. The issue of allocative efficiency and cross-subsidization effects is at the centre of many recent works that investigate how the growth of DER, EV and flexible HP create unfair cost transfers between passive and active users and strengthen the financing gap between those who can afford to buy such advanced equipment and those who cannot (Haro et al. 2017; Morell et al. n.d.; Neuteleers et al. 2017; Schittekatte and Meeus, 2020). Going one step further, the uptake of these technologies results in a revenue adequacy risk for grid operators and further shifts the payment of network costs to users who do not benefit from the possibility of self-consumption (Abdelmotteleb et al. 2018; Barbose and Satchwell 2020; Haro et al. 2017; Hoarau and Perez 2019; Neuteleers, Mulder, and Hindriks 2017).

On the political side, the social dimension of grid tariffs is gaining momentum. Policymakers seek to protect vulnerable households from the increase in network costs expected in the coming years due to transport and heating electrification through a fair allocation of the network costs incurred by EVs and HPs (Lamb et al., 2020). The fairness concern for electricity pricing is of significant concern as established in the European Green Deal, and past research has demonstrated how more cost-reflective (or time-based) tariffs strengthen the financing gap between those who can afford to buy advanced equipment and those who cannot (Burger et al. 2020; Ansarin et al. 2020; Sschittekatte et al.2018; Barbose et al., 2021).

The economic and political goals for allocative efficiency and fairness often pull tariff design away from the economically best-case solution. On the one hand, a tariff reflecting network costs supports more flexibility and supports the integration of HP and DER EVs by ratchet effect. On the other hand, these tariffs place an increasing burden on consumers who are not flexible and cannot afford the equipment. Several works conclude that a middle ground can be found with higher subscription charges, alongside the introduction of time-based ToU-type tariffs (Schittekatte et al. 2018; Clastres et al. 2019; Faruqui 2021). Others have also looked at the effects of redistribution factors, notably to identify which grid users (or taxpayers in general) pay a (higher) surcharge to support this expense (Burger et al. 2020). When applied to electricity tariffs, such factors allow the deviations of tariff design to ensure that households living in vulnerable financial situations have fair access to electricity.

The afore-mentioned works inform on cross-subsidy effects at the scale of household types**. However, there exists to our knowledge, no comprehensive study quantifying cross-subsidy effects in a broad population with diverse socio-economic characteristics, with or without EV and HP. This paper addresses this gap.** We test 5 five tariffs on 1.4 million Danish households. We measure in detail and comprehensively present the cross-subsidization effects of each tariff on households, focusing on low-, medium- and high-income households.

Data and method

We use a uniquely large dataset of 1,4 million households in Denmark, providing (fully anonymized) socio-economic information on an individual household basis. We collected 2017 per-hour electricity meter readings from Denmark's TSO, Energinet. This hourly consumption data was combined with individual household data from Danmarks Statistik, incl. income, dwelling type, occupancy and ownership –or not- of an EV or HP. We use these socio-economic factors to define three household groups showing different financial statuses: low-income, medium-income, and high-income, to provide insights regarding potential disproportionate impacts on households with weaker financial status.

We consider five variations of two-part volumetric tariffs. The relative share between the subscription and the volumetric part evolves from 0% to 100% in steps of 25%. The volumetric part corresponds to a two blocks (peak and off-peak) time-of-use structure. We first calculate the grid bill paid by each consumer in the 2017 base case using the

Danish tariff design and cost components that were applied at the time. The aggregated value corresponds to the yearly grid cost recovery. We then simulate how the tested designs reallocate the network cost between consumer groups under the constraint of revenue neutrality. Finally, we test the impact of 10 redistribution factors that redistribute in steps of 10% from 0% to 100% the subscription payment of the low-income household category towards all the other users belonging to the high and middle-income groups.

Results

This abstract only illustrates results for the low- and high-income groups. The relative increase or decrease of grid bill payment per user category is given compared to the 2017 base case.

Average yearly grid bill per user group, with and without advanced equipment shows an inverse relationship triggered by the tariff structure between low-income households without equipment and households with HP or EV which characterizes a first cross-subsidization due to equipment ownership. A second cross-subsidization effect occurs between households without advanced equipment. In this case, the income level marks the subsidization, with an inverse relationship between high-income households making gains (with a subscription tariff) or losses (with a volumetric tariff) and low-income making gains (with a volumetric tariff) or losses (with a subscription tariff). The results reveal the incentive effect of subscription-based tariffs on the electrification of transport and heat and their perverse impact on both low-income households and households without EV and HP (Fig. 1).

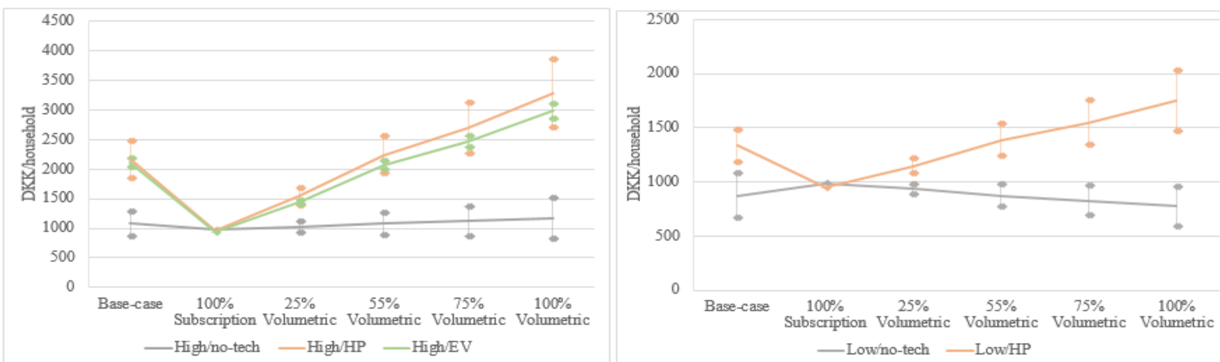

Fig. 1. Average yearly tariff payment per household category (high and low income) with and without EV/HP

Introducing the redistribution factor: Beyond the expected results where the yearly grid bill paid by low-income households decreases and the yearly grid bill paid by the other groups increases, the results indicate several original redistributive effects. First, in the 55% and 75% volumetric tariffs where the factor applies, the yearly average bill increase suffered by high- and medium-income groups due to the factor is marginal but has a considerable beneficial effect on low-income users with an HP. A redistribution factor of 0.2 in a 75% volumetric tariff means that low-income users with HP do not pay a higher yearly bill than the base case, which supports heating electrification for them. Second, the more we move towards a subscription-based tariff, the more the redistribution factor results in a higher burden borne first by medium-income users and then by high-income users without EV/HP. In these cases, a low factor (0.9 or 0.8) is preferable as it strikes a balance between additional costs for low-income users, and too high impact on medium-income households. Beyond 0.6 or 0.5, the redistribution factor associated with 25% volumetric and 100% subscription tariff also results in over-cost for high-income households without equipment (Fig. 2).

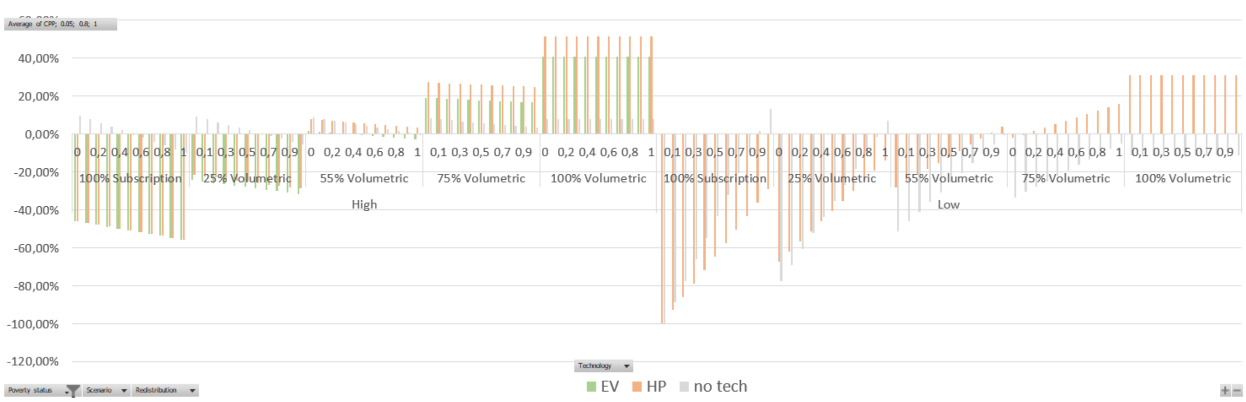

Fig. 2. Impact of the redistribution factor on the yearly grid bill

Conclusions

Our results inform policymakers who aim to increase heating and transportation systems' electrification while ensuring socially desirable targets are met. We show the asymmetrical effects of grid tariff designs between EV/HP owners and low-income grid users without advanced technology. Subscription-heavy tariffs support electrification in allowing households equipped with HP or EV to save on their annual grid bill while volumetric-heavy tariffs result in protecting low-income grid users without equipment from network expense increase. Applying a redistribution factor allows to restore the balance between electrification-friendly tariffs and fair grid costs for low-income households. We show that it is not necessary to apply a strong redistribution factor between classes of consumers to fully alleviate the burden faced by low-income houses, accelerate heat electrification in this consumer group and ensure social justice in network tariffs. However, our results point to a grey zone, where the variations in tariffs associated with the redistribution factor disproportionately penalize the middle-income group without EV/HP while leaving the better-off households out of reach. This is a major outcome of the study, which highlights the lack of a mechanism to close this gap in Denmark's case.

References

Abdelmotteleb, Ibtihal, Tomás Gómez, José Pablo Chaves Ávila, and Javier Reneses. 2018. "Designing Efficient Distribution Network Charges in the Context of Active Customers." *Applied Energy* 210: 815–26.

Ansarin, M., Ghiassi-Farrokhfal, Y., Ketter, W., & Collins, J. (2020). The economic consequences of electricity tariff design in a renewable energy era. *Applied Energy*, *275*, 115317. https://doi.org/10.1016/j.apenergy.2020.115317

Barbose, Satchwell. 2020. "Benefits and Costs of a Utility-Ownership Business Model for Residential Rooftop Solar Photovoltaics." *Nature Energy* 5(10): 750–58. http://dx.doi.org/10.1038/s41560-020-0673-y.

Barbose, Galen Forrester, Sydney Shaughnessy, Eric O Darghouth, Naïm (2021). Residential Solar-Adopter Income and Demographic Trends : 2021 Update. Lawrence Berkeley National Laboratory

Boiteux, Marcel. 1956. "La Vente Au Coût Marginal." *Revue Française de l'èlectricité*:.

Burger, C.R. Knittel, I.J. Prez-Arriaga, I. Schneider, F. vom Scheidt (2020) The efficiency and distributional effects of alternative residential electricity rate designs. *The Energy Journal*, 41 (1) (2020), 10.5547/01956574.41.1.sbur

Clastres, Cédric ; Percebois, Jacques ; Rebenaque, Olivier ; Solier, Boris 2019. Cross subsidies across electricity network users from renewable self-consumption. *Utilities Policy*. Volume 59, 2019, 100925, ISSN 0957-1787, https://doi.org/10.1016/j.jup.2019.100925.

Faruqui, Ahmad, 2021. Rate Advisory Committee Meeting May 27, 2021.

Haro, Sergio et al. 2017. "Toward Dynamic Network Tariffs: A Proposal for Spain." In *Innovation and Disruption at the Grid's Edge: How Distributed Energy Resources Are Disrupting the Utility Business Model*, Elsevier Inc., 221–39.

Hoarau, Quentin, and Yannick Perez. 2019. "Network Tariff Design with Prosumers and Electromobility: Who Wins, Who Loses?" *Energy Economics* 83: 26–39.

Morell, Nicolás, Pablo Chaves, and Tomás Gómez. N.d. *Electricity Tariff Design in the Context of an Ambitious Green Transition*.

Neuteleers, Stijn, Machiel Mulder, and Frank Hindriks. 2017. "Assessing Fairness of Dynamic Grid Tariffs." *Energy Policy* 108: 111–20.

Schittekatte, Tim, and Leonardo Meeus. 2020. "Least-Cost Distribution Network Tariff Design in Theory and Practice." *Energy Journal* 41(5): 119–56.

Schittekatte, Tim, Ilan Momber, and Leonardo Meeus. 2018. "Future-Proof Tariff Design: Recovering Sunk Grid Costs in a World Where Consumers Are Pushing Back." *Energy Economics* 70: 484–98.