On the design of cost-reflective and inclusive volumetric electricity grid tariffs

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Overview

The existing electricity network faces new challenges with higher shares of electrified heating and transportation in the residential sector combined with variable electricity production and the subsequent price fluctuations. In Denmark, the electricity grid is dimensioned for passive households that own internal combustion engines vehicles and heating systems that rely on district heating or gas. The incoming loads due to electrification call for new grid tariff designs that facilitate the new technologies while managing grid constraints to mitigate or postpone considerable grid reinforcement costs. While existing literature already covers optimal volumetric grid tariff designs to send appropriate flexibility signals for residential demand response, commonly applied volumetric grid tariffs might induce imbalances between different residential groups. The European Commission calls for more integrative approaches to limit the potential detrimental impact on poorer, inflexible, households that may face higher electricity bills with limited opportunities for load adjustment. Consequently, this study investigates the distributional impact of a new grid tariff design using a dataset covering 1.4 million Danish household electricity consumption divided into 90 socio-techno-economic categories to provide options based on policy preferences.

Methods

The underlying data is provided in collaboration with the Danish central authority on statistics (Danmark Statistik). It covers hourly electricity data combined with household information on dwelling type and area, occupancy, household income, and technologies such as electric vehicles (EV) and heat pumps (HP) for 1.4 million households. The consumption is anonymized through aggregation based on the categories, and subsequently, the calculations are performed on probability distributions rather than single electricity profiles. The study assumes as a base case the flat volumetric grid tariffs based on Denmark's average distribution system operator (Trefor). The design of new grid tariffs has to fulfill the requirement of revenue neutrality. Accordingly, the system operator maintains its income, and only the redistributive effect of the tested tariffs across household categories is investigated. The financial results of the base case for the different residential groups are then compared with the impact of the new tariff design. The proposed volumetric grid tariff design called Dynamic Individual Critical Peak Price (DICPP) offers two different price levels, a base tariff and a peak tariff and is compared to the previously applied tariff scheme.

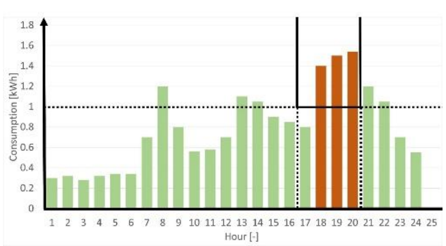

Figure 1 Exemplary DICPP grid tariff design.

Two mechanisms trigger the peak tariff, according to *Figure 1*, which visualizes a representative household consumption during a day. At first, a peak hour is defined based on the national load duration curve. The peak hour is subject to sensitivity, and different levels such as the top 1% or top 5% of consumption, also referred to as trigger percentages, are investigated in this study. Secondly, individual household consumption has to reach over a certain threshold consumption to be facing peak tariffs. Following *Figure 1*, only individual consumption laying in national peak hours (vertical lines between 5 p.m. and 8 p.m.) and simultaneously reaching over the threshold (horizontal line at 1kWh of consumption) is subject to the peak tariff applied to the total consumption during the specific hours (colored in red). Different levels of trigger percentages and thresholds are studied in the following and discussed in the light of several design perspectives and impacts on household categories.

Results

Figure 2 and *Figure 3* summarize the normalized redistribution of cost across different household categories with a constant threshold of 2 kWh and varying trigger percentages between 1% to 40% of the national load curve. Apartments (AP) across different area groups from small (A1) to large (A3) pay consistently less with the proposed grid tariff. In contrast, single-family houses (H) face equal or slightly higher prices with up to 2% more. Consequently, households not owning HP or EV are barely negatively affected by DCIPP while increasing the cost as soon as the households demonstrate a larger area. *Figure 3* shows the difference between a specific household type with and without EV and HP. Households without additional technologies face similar cost effects across all scenarios.

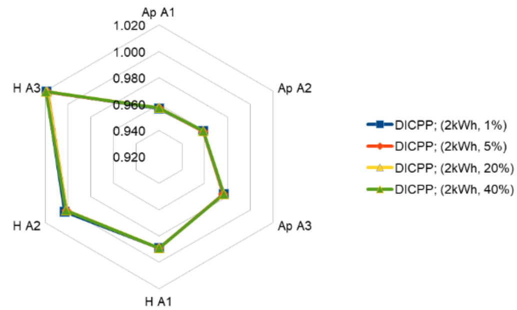

Figure 2 Average relative redistribution of DICPP on Apartments (Ap) and Houses (H) with different dwelling areas (A1-A3). No EV or HP are present in the households.

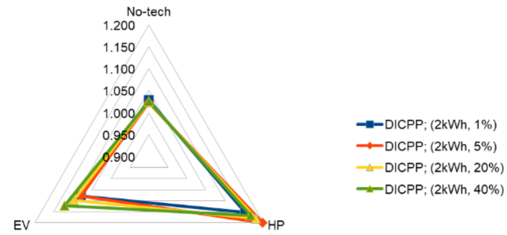

Figure 3 Relative redistribution DICPP on a single-family house (H) with an occupancy of 3-4 (P3) of the high dwelling area (A3) and income group (€3) owning an HP, EV or not owning either of both.

Contrarily, HP owners and EV owners pay up to 20% more in grid tariffs when comparing the costs of the base with the DICPP tariff. Depending on the trigger percentage, HPs take over higher burdens than EV. The fewer hours of the national load curve are defined as peak, the smaller the cost increase for the EV. However, varying the trigger percentage allows for burden shift according to the policymaker's preferences. Increasing the threshold (not shown in the figure) would shift the triangle towards the higher penalization of EV. Consequently, DCIPP offers the possibility to be designed following specific local conditions, technical pathways, knowledge on building stock.

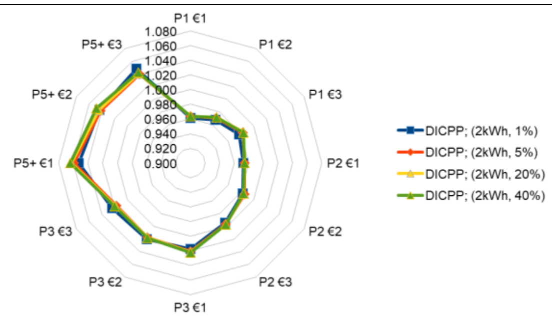

Figure 4 Average relative change in cost with DICPP for households without EV and HP across all dwelling sizes and types.

Furthermore, DCIPP can also be adapted according to other preferences supporting an integrative grid tariff design. Figure 4 summarizes the average impact on households without EV and HP with different occupancy status from single households (P1), over households with 3-4 (P3), 5 or more occupants (P5+) and income groups from the lower third (€1) to the upper third (€3). DCIPP reduces grid tariff expenses almost consistently the smaller the household and the lower the income is. Single houses save around 4% in grid tariff expenses, whereas one more occupant yields a decrease of 2%. Only households with high occupancy (P5+) and low income (€1) seem to have higher expenses compared to the same occupancy with high income (€3). This outlier is explained by the fact that low-income households with five or more occupants have, on average, one more person living in the household compared to the high-income group. DCIPP consequently supports lower consumption per connection primarily indicated by fewer occupants but at the same time also limits adverse impacts on a lower income.

Conclusions

This study investigates the impact of a new proposed volumetric design for electricity grid tariffs on a large amount of different socio-techno-economic household categories in Denmark, under the constraint of revenue neutrality for the grid operator. Dynamic Individual Critical Peak Prices (DCIPP) show that such a tariff can be designed with a large degree of freedom based on local technical requirements and the policymaker's preferences in terms of an integrative design approach to reduce the impact of grid cost increase in the future on low-income households. The design shows that it has only limited effects on households without technologies such as electric vehicles and heat pumps. The smaller the apartment or house is, the higher the possible savings of up to 4%. In contrast, depending on the chosen design of DCIPP, the burden can be freely shifted towards heat pump or electric vehicle owners, increasing their expenses by up to 20% and offering better cost reflectivity and triggering flexibility. Moreover, the smaller and the poorer the household is, the lesser the households are negatively affected. DCIPP subsequently offers to be designed according to technical conditions and social considerations.