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Squaring the sunny circle? On balancing distributive justice of power grid costs and incentives for solar prosumers

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ABSTRACT

Solar prosumers are about to revolutionize the power sector. Utilities are challenged in recovering the costs of distribution grids, as parts of their revenue basis decreases through self-consumption. Adjusting the grid tariff sets off a reinforcing feedback loop that increases the attractiveness of solar investments, but also leads to a distribution effect between solar prosumers and conventional consumers. The question is: How to recover distribution grid costs equitable without hampering the diffusion of solar power? Can the two criteria be fulfilled at the same time, or is do we aim for squaring a circle? To address this question, I present a System Dynamics simulation model designed to understand the interactions and assess these competing goals. The occurring distribution effect under the volumetric grid tariff with net purchase and sale appears to be rather limited. Simulation experiments reveal that grid tariff designs strongly influence investments for solar power. A capacity tariff can reduce deviations from the cost causation principle of solar prosumers and incentivizes investments in decentralized storage solutions to reduce peak demand. Nevertheless, also the capacity tariff causes a distribution effect.

1. Introduction

Renewable energies are about to dramatically change the power sector. Impressive technology learning curves and governmental support programs enhance the increasing penetration of renewable energies. Particularly solar photovoltaics (PV) is developing remarkably (IEA, 2014; IRENA, 2015). PV is highly suitable for decentral generation in small units close to demand and is about to reach grid parity in many countries (IEA, 2014; Karneyeva and Wüstenhagen, 2017). Grid parity describes the point where decentrally generated solar power reaches the same level as the retail power price. Consequently, installing solar power with self-consumption becomes an attractive investment option for house owners. And so become consumers so-called prosumers – consumers who consume and produce power (Kesting and Bliek, 2013).

Current power systems are designed for centralized generation to supply fully dependent consumers. Costs of the distribution grid infrastructure are most frequently recovered from consumers based on a volumetric grid tariff, which charges the consumers per kWh of used power. A volumetric tariff is a straightforward design to recover the costs of the grid infrastructure, particularly with an increasing demand basis (Costello and Hemphill, 2014; Felder and Athawale, 2014). However, nowadays net demand became less predictable and shows a tendency to decrease through the diffusion of self-consumption concepts and increased investments into energy efficiency (Ruester et al., 2014).

Under a volumetric tariff, solar prosumers can reduce their power bill by avoiding the full retail price for the amount of self-consumed power. The PV bill savings of solar prosumers appear as missing return on the utility company's income statement. To compensate for the missing return, the utility company increases the grid tariff. In return, higher retail power prices increase the attractiveness of self-consumption concepts. This sets off a self-reinforcing feedback loop. Most researchers expect the cost recovery feedback loop – sometimes also called the "death spiral" – to cause the retail power price to rise (Castaneda et al., 2017; Costello and Hemphill, 2014; Darghouth et al., 2016b; Felder and Athawale, 2014).

On the one hand, grid operators perceive this situation as explicitly negative, as recovering the costs of distribution grid becomes increasingly difficult. Increasing the grid tariff usually comes with large

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administrative hurdles, since grid operators are strongly regulated monopolies. On the other hand, the opportunity of bill savings for solar prosumers fosters the diffusion of PV, hence contributing to national energy and climate policy goals. A distribution effect between conventional consumers and solar prosumers is a potential consequence of adjusting the grid tariff (Eid et al., 2014; Picciariello et al., 2015; Ruester et al., 2014; Satchwell et al., 2015). As the grid assets are highly determined by fixed costs, the current volumetric tariff does not reflect the full costs of supplying prosumers. The issue of cost recovery of distribution grids with solar prosumers is subject to a controversial political debate.[2] A capacity tariff is frequently discussed as a potential solution (Costello and Hemphill, 2014; Eid et al., 2014).

In this study, I simulate and quantify two important interdependent aspects: (a) the long-term dynamics between the diffusion of solar prosumer, with and without storage, and the ability of grid operators to recover the costs of distribution grids; (b) the resulting distribution effect and deviations from the cost causation principle for the distinct consumer groups over time. The paper presents a comparative analysis of a volumetric tariff – comparing a net purchase and sale policy with net metering, a capacity tariff and a flat tariff, contributing to the current academic as well as political debate. The analysis is conducted for the situation of a Swiss distribution grid operator.

This paper is structured as follows: in section two, relevant the background literature on PV bill savings, grid tariff designs, PV pricing mechanisms and distributive justice are discussed; in section three, I present the developed simulation model in a conceptual manner, followed by the equations and the developed measures for distributive justice; in the four section, the simulation results are presented and discussed; in the fifth section, I draw the conclusion and discus the implications for energy policy and the limitations of the study.

2. Background

2.1. PV bill savings under different grid tariff designs and PV pricing mechanisms

Various regulations for self-consumption of distributed generation exist around the globe. The scope of PV bill savings of solar prosumers particularly depends on the applied grid tariff design and PV pricing mechanisms (Borenstein, 2017; Darghouth et al., 2011, 2014, 2016a; Eid et al., 2014). Yamamoto (2012) describes three pricing mechanisms for residential PV, two of which are of relevance for self-consumption concepts: *net metering* and *net purchase and sale*. An overview of grid tariffs and pricing design options and the resulting PV bill savings is given in Table 1.

Most literature addresses the net metering system, typically focusing on the impact of different billing periods on the bill savings of solar prosumers (e.g. Darghouth et al., 2011, 2014; Darghouth et al., 2016a; Eid et al., 2014). A notable exception is the study by Eid et al. (2014), which also considers the net purchase and sale system. This is surprising, as many countries apply the net purchase and sale system because of the unbundling regulation for utility companies, separating the grid operation from power generation. Furthermore, only few studies analyze the effect of solar prosumers with storage in a quantitative manner in the context of grid operators allocating the distribution grid costs (Eid et al., 2014; Grace, 2014). However, self-consumption concepts combined with storage can reach much higher self-sufficiency degrees, but also have the potential to be used in a grid-optimized manner (Santos et al., 2014; Veldman et al., 2013).

Several qualitative studies identify the cost recovery of utility infrastructure under increasing self-consumption as a problematic situation that demands for an adjustment in the regulation (Costello and Hemphill, 2014; Felder and Athawale, 2014; Ruester et al., 2014; Schleicher-Tappeser, 2012). The self-reinforcing aspect and developments over time of the cost recovery are only rarely analyzed in a quantitative manner. Notable exceptions are Cai et al. (2013), Darghouth et al. (2016b) and Castaneda et al. (2017). Cai et al. (2013) find that the strength of the cost recovery feedback loop strongly depends on the share of house owners with a higher tolerance for uncertainty. Potential for further research is located in the more realistic representation of the investment decision for PV (Cai et al., 2013). Castaneda et al. (2017) investigate the conditions that lead to a utility death spiral with a System Dynamics simulation model. They find that under the particular setting of the Colombian power market with unlimited net metering and the assumption that prosumers install clearly more distributed generation than what they consume, a utility death spiral is likely to occur. Darghouth et al. (2016b) find that there is a compensating effect through lowering wholesale power prices caused by larger feed-ins of solar power. The merit order effect from solar power can nearly off-set the increase of the tariff for the end-consumers. In contrast to this, Nelson et al. (2012, p. 298) find that customer benefits from the merit order effect from solar PV are “at best transient, and the overall effect on welfare is adverse”. In this respect, it is decisive whether utility companies really pass on the wholesale price advantage to end-consumers, which depends on the applied utility regulation. In a regime with an integrated service regulation for utilities, as applied in the United States and the study by Darghouth et al. (2016b), reduced wholesale power prices can trigger the described compensating effect. In a regime with unbundling of power generation from the grid operation, as applied in Europe (Eid et al., 2014), the two effects play out in separate business units and therefore can only be considered as indirectly compensating. Most of the literature on the cost recovery of distribution grids assumes an integrated utility service system. In this study, I focus on the situation of a grid operator under the unbundling regulation with a net purchase and sales system for PV remuneration. To address the differences, I simulate the net metering system in a scenario as a comparison. Variants in grid tariff design are tested.

2.2. Distributive justice of power grid costs

Regulatory authorities aim for distributive justice among the power consumers, when defining regulations for cost recovery of power distribution grids. However, what is perceived as fair, is subject to personal views and preferences, as nicely explained by Tabi and Wüstenhagen (2017). When it comes to recovering costs from distribution grids, there seems to be a consensus that an equity principle should be applied. The cost causation principle is one of the most frequently named equity principles for ideal tariff design for power distribution grids,[3] intending that consumers pay for the costs they cause (DNV GL, 2015; Picciariello et al., 2015). Furthermore, the efficiency principle is considered to incentivize efficient use of power, as well as efficient operation and investments for powers grids (DNV GL, 2015; Green, 1997).

Nelson et al. (2011) analyze the taxation burden of a gross feed-in tariff as well as a net feed-in tariff for solar PV for different consumer segments. They measure the distribution effect as the impact of the feed-in tariffs on the annual bills, as well as a share on the household income. Eid et al. (2014), in contrast, measure the occurring distribution effect[4] caused by self-consumption as the share of lost income of utilities, considering different net metering designs. Satchwell et al. (2015) and Castaneda et al. (2017) choose a similar approach by

[2] For instance in Switzerland addressing the grid tariff design is an important topic in the coming revision of the Swiss electricity law Swiss Federal Office of Energy (2015). Revision StromVG.

[3] See for example Swiss Electricity Law (Schweizer Stromversorgungsgesetz), Art. 14, paragraph 3.

[4] In the study by Eid et al. (2014) the distribution effect is called “potential for cross-subsidy”.