DISTRIBUTION NETWORK CHARGES IN LUXEMBOURG

Assessment of alternative models for distribution network charges

Institut Luxembourgeois de Régulation

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Objective:

The objective of this project is to compare three alternative models for future proof distribution network charges.

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1 INTRODUCTION

The Institut Luxembourgeois de Régulation (hereafter ILR) has initiated a debate on future-proof network tariffs. In light of trends of electrification and decarbonization, increasing scepticism has been voiced that the current network tariff design can sufficiently ensure cost reflectivity, system sustainability, and efficiency. Arguably, today's reliance on a high share of the volumetric fee is unable to reflect network cost structure. The detachment of invoiced network fees from network costs leads to suboptimal incentives to adapt behaviour and a misallocation of economic burdens.

Against this background, it has been put to question how network tariff designs can be improved to ensure cost-reflectiveness, non-discrimination, and transparency, take into account the need for network security and flexibility and reflect actual costs incurred.[1] This study shall inform the debate on this question by supplying a conceptual evaluation of the three most promising design options for future proof tariff designs.

A previous study for ILR developed a subscription-based tariff model, characterised by a relatively low volumetric fee (eurocent/kWh), a fixed fee per month depending on the subscribed bandwidth (euro/month), and a relatively high financial capacity extension fee for consumption outside the subscribed capacity (a financial capacity expansion; eurocent/kWh) (DNV, 2021). The subscription-based model for Luxembourg was a specific application of the bandwidth model developed by DNV (DNV GL, 2019).

The present study constitutes a high-level evaluation of different tariff designs that may be considered a potential improvement to the current system. In specific, key characteristics of subscription-based models are compared to the characteristics of measured capacity models and of time-of-use models (chapter 2). The comparison follows along a defined set of criteria of economic principles and feasibility criteria (chapter 3). These criteria are assessed for the tariff design's impact on a representative variety of network users, such as traditional households, prosumers and industrial scale network users. In addition, mitigation strategies to major challenges of the distinct models are addressed and included in the comparison (chapter 4). Following from this approach, the models are scored against the criteria from which a recommendation for a future proof tariff design is derived (chapter 6).

The economic nature of electricity networks (natural monopolies) implies a dilemma. Optimality of prices generally (for normal sectors or industries) imply that prices should be set according to short-term marginal costs. Over time, sector expansion will be such that short- and long-term marginal costs converge. This is not fully applicable to regulated natural monopolies who have their revenue determined such that prices on average must correspond to average costs. As a consequence, it is not possible to device a price scheme for such network services that provide perfect price signals for 'everything'; (marginal) use, location, timing, expansion, multiple grid levels with peaks/constraints at different times, etc. Hence, the ambitions for network tariffs cannot be to solve **all** problems or challenges related to electricity networks. Tariff design is essentially a choice of what incentives to prioritise or 'leave' to the tariff system, and what concerns that must be addressed by other means than prices for connecting to and using the network.

A common example of this choice is the DSOs' need for local flexibility. Arguably, grid tariffs may provide incentives, e.g., to reduce peak load or to encourage self-consumption. However, grid tariffs will typically refer to all grid customers of a DSO, or at least a relatively large area. In the case of Luxembourg, DSO-tariffs are harmonised across all DSOs. Furthermore, DSOs (and presumably their customers) tend to prefer that tariffs are relatively stable over time. Local flexibility needs are, on the other hand, typically more dynamic and location specific. To the extent such needs can be managed by economic signals, local flexibility markets or arrangements such as connection agreements might be more efficient measures, as a supplement to the standard grid tariffs. By asking for explicit demand response, either directly to the grid customers or via aggregators and alike, the DSOs can tailor their purchase of flexibility in a much more precise manner than what can be achieved by an otherwise well-designed but 'general' network tariff.

[1] The recast regulation on the internal market for electricity (2019/943), article 18(1).

Along the evaluation process, DNV has been in close contact with Luxembourg's distribution system operators (hereafter DSOs) and the regulatory authority to align the procedural steps, the models of comparison, and the evaluation criteria.

2 THREE ALTERNATIVE MODELS

The approach to the high-level evaluation comprises the specification of the tariff design models to be assessed and the definition of the evaluation criteria. The process of specification and definition includes alignment with the regulatory authority and the DSOs. The features of the models have been assessed against the criteria, resulting in scores for meeting the respective criterion (score A), conditionally meeting the respective criterion (score B), and not meeting the respective criterion (score C). The model scores were then compared in light of the relevance of the individual criteria and the potential mitigation possibilities in case of not or only conditionally meeting the respective criterion. The evaluation is concluded by a recommendation stating the merit and potential pitfalls of the best evaluated tariff design model.

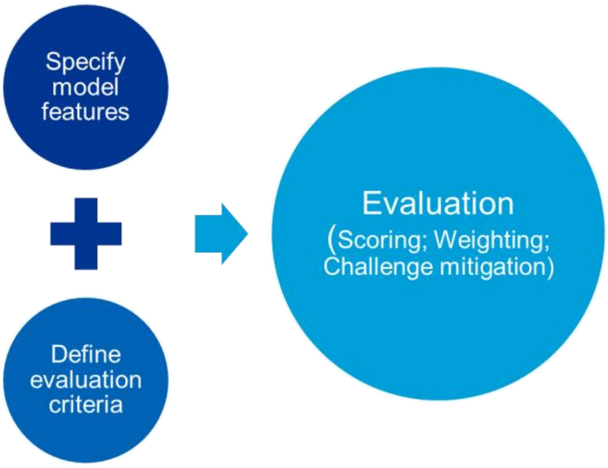

Figure 2-1: Schematic overview of Approach

Three tariff design models are evaluated. The pre-selection of the models was based on the concurrent debate on future-proof tariff designs and approaches undertaken by other advanced countries such as Norway and the Netherlands.

2.1 Common principles for all alternatives

Some key principles are common for all assessed models. These principles reflect choices and tariff design elements that are not subject to discussion or evaluation within the current project.

1. The five DSOs of Luxembourg use the same tariff scheme. Not only are the principles and the structure the same, but all tariff elements are identical with all DSOs. Hence, the total network charge is fully independent on which DSO a network user is connected to. This also implies that the DSO tariff does not reflect completely the costs of the individual DSO. As a consequence, a transfer between DSOs is necessary to ensure the total tariff revenue is split according to the allowed revenue for each DSO.

    - Whether this is line with the cost reflectivity requirement is not part of our assessment, but it is not clear that this practice violates the requirement. The benefit of having a uniform price scheme for network users across the country is also a relevant element and may certainly outweigh the imprecision of not having a pure individual price per current DSO, reflecting its individual cost structure.

2. All customers connected to the same voltage level should face the same tariff scheme. There should not be any distinction between network user tariffs based on type of activity; a household and a kinder garden both connected at the same voltage level will be facing the same tariff.

3. It is also assumed for all models, that all costs associated with each voltage level are only relevant for the tariff level of said voltage level. Tariffs for MV or HV customers should not reflect LV cost figures.

4. There are no grid tariffs or fees for injection. Luxembourg is together with Germany one bidding zone in the European electricity market. Both in this zone as well as in most other bidding zones in Continental Europe there are no network fees, neither volumetric nor fixed, for injection. The scope for this project is assessment of alternative models for network charges in Luxembourg considering expected changes in electricity consumption and the future for the electricity distribution networks. While injection in the distribution network is expected to be a part of these future changes, unilateral introduction of injection fees in Luxembourg is a fundamentally different question and out of scope for this assessment.

2.2 Subscription-based tariffs

The subscription-based model is such that network users subscribe to a certain defined level of capacity for a fixed subscription fee. The defined levels of capacity may be defined in larger or smaller (incremental) steps. The subscribed capacity typically spans over the entire year, but seasonal or daytime differentiation constitutes a potential specification of the model both for the subscribed bandwidth and the subscription fee. The capacity may either apply to both withdrawal and injection equally or allow for separate capacity bandwidths.

In addition, a financial capacity extension is required if network users exceed their subscribed capacity (extension fee). The required financial capacity extension may be applied for different time intervals, such as extension for at least 15 minutes or for at least 1 hour. The fee for the financial capacity extension is added to the fixed fee, resulting in the total capacity fee for the customer.[2] As is the case for the fixed subscription fee, the extension fee may entail a seasonal or time differentiation. The level of the fee shall incentivise load shifting to be the dominant customer strategy rather than subscribing to a higher capacity level.

Besides the capacity fee, a limited volumetric fee shall be applied to account for cost contribution with reference to network losses. The objective of this volumetric fee is to reflect such costs and to distinguish between network users on the same subscription level with significantly different energy consumption. This will likely be most important for MV and HV network users (in terms of their heterogeneity) but may apply for ordinary LV network users as well. For very small, subscribed capacities, the volumetric fee could be spared, as the administrative costs would likely surpass the benefit from the additional granularity in design.

In light of the circumstances of the networks and groups of network users in Luxembourg, the principal specification to be assessed for the subscription-based model are as follows:

- **Annually fixed subscribed capacity** to limit the degree of change from the current tariff scheme
    - No capacity limit for injection, in line with the absence of an injection fee at transmission level in Luxembourg
    - For MV and HV network users, time differentiated subscriptions should be considered as an additional option. In this variant, users could subscribe for a capacity per time slot, with subscription fees defined per time slot. The potential for a financial capacity extension may be limited; exceedance might not be guaranteed. Eventually, the model could imply automatic

[2] The fee for the financial capacity extension could most easily be settled in €/kWh: while it essentially is a fee in euro per kW extension for the duration of the exceedance, the result will be a number of euro proportional to the energy consumption above the subscribed capacity.

curtailment of load if violating the subscriptions. The objective of this variant is to offer flexibility and the possibility for network users to tailor their subscriptions to their specific needs within the constraints of actual available network capacities. This approach can ensure better planning and utilisation of the MV and HV network be implemented and is often referred to as Tetris.

- **Financial capacity extension** is required in case of exceedance to allow for behavioural adjustments from network users after they have recognized their (high) capacity demand. This is particularly important in the LV segment, where we think automatic curtailment by the DSO (as is the case in the telecom industry) is not possible or advisable. For professional customers in the MV and HV network, (automatic) curtailment by the DSO could be a core element of the Tetris variant. However, commercial service providers may of course develop curtailment services with an aim to avoid or minimise extension fees, both for LV as well as MV and HV network users.
    - The extension fee may be higher for peak load hours on a working day. Thereby, load shifting is further incentivized; customary behaviour on the weekend is not endangered.
    - The defined levels of capacity and the extent of the extension fee for the LV grid shall be directed at behavioural patterns of EV charging and electricity self-consumption. To a lesser degree heat pump usage shall also be addressed.
        - Third party service providers and retail suppliers, aggregators, etc., are expected to develop and offer apps and solutions to support adequate, automated customer behaviour, such as automatically reducing the EV charging or adapting the utilisation of a heat pump when other loads are high.
- Limited **volumetric fee** (per kWh) to reflect the marginal cost of using existing network capacity (losses)

This model is directly applicable for any group of network users on a local level, but not for national energy communities. A national energy community is from a network utilisation point of view a virtual community, not sharing an electrical connection. As national energy communities are from a network perspective unable to balance their injection against their withdrawal, such community cannot be treated as if they had one connection behind the meter/with shared meter. For national communities, grid tariffs can be applied to the different users on “before-sharing capacity offtake values” while in local communities, the grid tariffs can be applied on after-sharing values (i.e., as for prosumers).

2.3 Measured capacity

The essential design element of the measured capacity model is the determination of the capacity charge as result from measuring the maximum capacity demanded by the network user in a given timeframe. The network user pays a fixed capacity charge for the established timeframe in relation to the maximum capacity required.[3] As is the case in the subscription-based model, the fixed fee may be set in incremental steps, or in larger steps that may lead to a) different consumer behaviour at the threshold and b) unconcerned consumer behaviour far off the thresholds. As the final capacity demand is unknown to the DSO and the network user prior to the end of the timeframe, the charge is effectively determined ex-post. Consequently, this tariff design is prone to high uncertainty until sufficient network user data is accrued and becomes available to DSOs and network users.

[3] The determination of the maximum charge may be restricted to a specified timeslot, such as peak hours during a day. In practice, this means, e.g., that the tariff timeframe is one month, but capacity demand is only measured in the evenings from 6 pm to 10 pm. The highest demanded capacity within this timeslot then determines the fixed charge for the month. For the next month, a new fixed charge is determined from the measured capacity. In this assessment, we do not consider this option.

Besides the capacity fee, a limited volumetric fee shall be applied to account for cost contribution with reference to network losses, reactive power and maintenance cost. For very small subscribed capacities, the volumetric fee could be spared, as the administrative costs would likely surpass the benefit from the additional granularity in design.

In light of the circumstances of the networks and customer groups in Luxembourg, the principal specification to be assessed for the measured capacity model are as follows:

- **Monthly measured capacity charge** to avoid "free-riding" for a long period after high peaks
    - Measured capacity could be determined as the average of the four highest 15-minute periods from four separate days within the month to avoid relatively large financial impact of a few 'random' peaks
    - Capacity to be measured continuously to ensure network users are continuously aware of the impact of capacity on network costs.
- **Smooth continuous function of capacity charge**, as illustrated with the blue lines in Figure 2-2 below, to avoid threshold behaviour. While the dark blue line is based on a fixed price per kW, the light blue line is based on a quadratic function of measured capacity (X); $aX + b – c*X^2$.
    - As the unit cost of electricity network capacity is degressive a quadratic function will better reflect the cost structure of an electricity network than a fixed price per kW. A stepwise linear function (the green line) is also degressive, but triggers other issues, like clustering and suboptimal behaviour around the points of inflection.
    - The unit price for the monthly capacity charge is constant over the year. While it is conceivable to vary the unit price over the year, e.g., in order to let the capacity charge reflect seasonal variation in demand for capacity, this option is here ruled out from the basic model of measured capacity.
- Limited **volumetric fee** (per kWh) to reflect the marginal cost of using existing network capacity (losses).

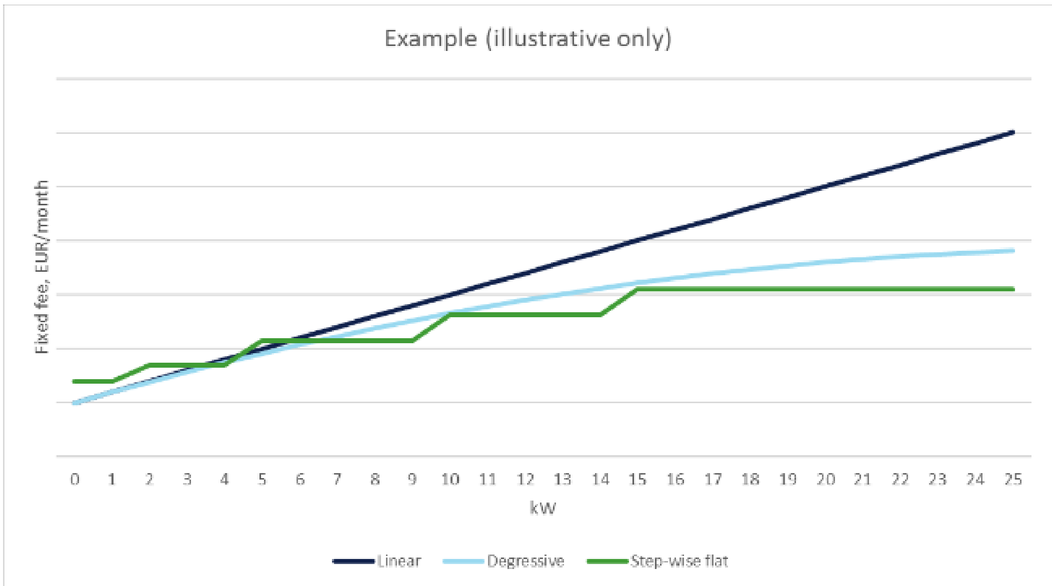

Figure 2-2 Alternative design of fixed fee for measured capacity

Similar to the subscription-based model, this model is applicable for any customer group but national energy communities. The latter, again, are from a network perspective unable to balance their injection against their withdrawal, such that they cannot be treated as if they had one connection with a shared meter. The design and specification of the capacity charge may be differentiated on voltage level.

2.4 Time-of-Use tariffs

In contrast to the two designs subscription-based model and measured capacity model, a time-of-use model is more strongly relying on the volumetric fee. In essence, this model applies a limited fixed capacity fee plus a time-dependent volumetric fee. This time dependency states that the level of the volumetric fee is conditional on the time when the network was used (electricity was withdrawn or injected). Effectively, the condition for the time-differentiation is open for different designs. Historically, a two-part design has been used where electricity withdrawal during daytime was costlier than during night-time. Other designs differentiate between summer and winter season, or by a combination of seasonality and timeslots.

This design is based on the connection between volumetric demand and required capacity. In times of high demand, high capacity is required. While the volume itself does not cause the bulk of the network costs, the demanded volume in critical timeslots (i.e., peak-load hours) constitutes a proxy to the causally relevant network capacity. It follows that the time-dependent volumetric fee is a representation of the required capacity. However, this representation is limited to an average demand during the critical timeslot. The design in its principal format cannot differentiate between a constant withdrawal during the critical timeslot and an unsteady withdrawal with extreme spikes, if the overall demanded volume in the timeslot is the same. This feature can be mitigated by combining capacity-related conditions to the time-of-use model.

Another feature is concerned with the thresholds of the critical timeslot. Unless peak load timing is exogenously fixed (e.g., due to labour laws), network users may react to the increase in the volumetric tariff by significantly shifting their demand to a time shortly after the critical timeslot. Thereby, a new peak may be formed. The novelty of this peak may not only pose a challenge to the network, but (at least hypothetically) to the electricity generation side as well. Expanding the critical timeslot so that such new peak is unlikely to be formed due to exogenous constraints (i.e., sleeping habits) would decrease the correlation between critical timeslot and cost causation of demand.

In light of these issues, the specificities of the time-of-use model to be compared are as follows:

- **Limited annual fixed capacity charge**, collecting less than 50 % of the allowed revenue.
- **Volumetric charge dependent on the time of the day**. This charge shall be conditional on peak-load hours, a seasonal differentiation shall not be made, but a differentiation for weekends may be reasonable. The timeslot shall be such that shifts of consumption are primarily driven by algorithmic solutions rather than changes of cultural habits.
    - Other specifications are of course conceivable, but for the purpose of this comparison, we needed to constrain the possible design options.
- The variation of the volumetric charge between off-peak and peak hours shall be financially notable in order to incentivize peak load smoothing.

Again, this model may be applied for all customer groups but the national energy community which has no benefit on network congestion. In contrast to the other models at hand, the volumetric fee constitutes the crucial aspect of the design such that it cannot be dropped for small network users. Furthermore, a different set of timeslots may be established for different voltage levels.

2.5 Overview of models chosen for comparison

This leaves us with the following main characteristics for the models to be compared in this analyses:

Subscription-based model

- **Annually** fixed subscribed capacity
- **Time differentiated** subscriptions for MV and HV customers to be considered
- Fee for **financial capacity extension** may be higher for peak load hours on a working day
- Limited **volumetric fee**

Measured capacity model

- **Monthly** measured capacity charge
- Measured capacity determined as the **average of the four highest 15-minute periods** from four separate days within the month
- Smooth function of capacity charge
- Limited **volumetric fee**

Time-of-use Model

- Limited **annual** fixed capacity charge
- Volumetric charge dependent on the **time of the day**
- The variation of the volumetric charge between off-peak and peak hours shall be financially notable

Figure 2-3 Overview of models to be compared

3 EVALUATION CRITERIA

The criteria for evaluation of the models at hand may be segmented into economic principles and feasibility criteria. While the former address the model's conceptual ability to create economic signals that represent the underlying functional relationships between supply and demand, the latter are concerned with the ability to implement the model without loss of the sought-after signals.

The recast regulation on the internal market for electricity (2019/943) defines some general criteria for network charges (our highlighting):

- Charges *"shall be **cost-reflective**, **transparent**, take into account the need for network security and flexibility and reflect **actual costs** incurred insofar as they correspond to those of an **efficient** and structurally comparable network operator and are applied in a **non-discriminatory** manner. Those charges shall not include unrelated costs supporting unrelated policy objectives".* (Article 18(1))
- "*Distribution tariffs shall be **cost-reflective** taking into account the use of the distribution network by system users including active customers. Distribution tariffs may contain network **connection capacity** elements and may be differentiated based on system users' **consumption or generation profiles**. Where Member States have implemented the deployment of smart metering systems, regulatory authorities shall consider **time-differentiated** network tariffs when fixing or approving transmission tariffs and distribution tariffs or their methodologies in accordance with Article 59 of (EU) 2019/944 and, where appropriate, time-differentiated network tariffs may be introduced to reflect the use of the network, in a **transparent**, **cost efficient** and **foreseeable** way for the final customer."* (Article 18(7))

However, n contrast to cases of other energy networks such as natural gas transmission, to date no network code or guideline exists for distribution network tariffs in the European Union. Hence, the objectives of the network tariff at hand and the derivative evaluation criteria may be subject to debate. As a consequence, the case at hand has been discussed with the DSOs. The criteria have been adjusted to incorporate the different arguments tabled. Where consensus could not be identified, the different positions are noted. For instance, this is the case for the principle of cost reflectivity. It has been voiced that this criterion should be considered at face value, but it equally has been noted that network tariffs should not only depict network costs but other systemic costs, such as scarcity of electricity supply, as well. In addition, the relevance of political considerations in terms of distributional effects and the protection of vulnerable network users have been stated by some but dismissed by others.

The resulting list of criteria shows stand-alone criteria. These criteria may imply interacting effects as some models can only meet a certain criterion if it does not meet another. In addition, mitigation measures to the most relevant of these deficiencies are discussed. It is our assessment that the selected criteria are sufficient to meet the requirements of the recast electricity regulation.

3.1 Economic Principles

3.1.1 Cost reflectivity

The principal of cost reflectivity is a well-established criterion within economic literature and regulatory determinations. In the context of network tariffs, the principle states that network charges are cost reflective, if they are in accordance with all costs **necessary** for supplying the electricity to the location in the grid. The demand of being "in accordance with" refers to the correct depiction of cost causality. Due to the technological nature of electricity networks, this causality may first and foremost be proxied by the network user's contribution to peak demand. After all, overall peak demand is the first driver for the sizing of the grid, a major network cost component. In addition, the general grid usage implies variable costs of operation and maintenance. Being in accordance means that network charges reveal to the network user the underlying cost of user behaviour.

To assess cost reflectivity, it is necessary to understand cost causation for the network. Two aspects are of specific relevance. On the one hand, the price shall reflect the short-term scarcity of the supply in order to account for the cost of congestion. As supply is constant in the short term, the quantity of demand may and need to be altered. On the other hand, the price shall reflect the long-term cost of network enhancement and extension which are dimensioned for network peak load but have a beneficial impact on available capacity throughout the time. Theoretically, these two aspects are, due to the need of eventual replacement of old assets, both comprised in short-term marginal cost pricing. However, in light of significant uncertainty of future investments solely under short-term marginal cost pricing, it is reasonable to differentiate between cost reflectivity for the existing assets and for future network investments.

The complexity for the tariff design to meet this principle lies in the design's ability to correctly identify the network user's contribution to peak demand, if peak demand is identified as cost driver. In addition, technical constraints, behavioural uncertainty, and different options in cost accounting pose challenges to a straight-forward cost reflective tariff design. Here, the constraints relate to network monitoring, real-time data, and future technological developments. Behavioural uncertainty may be circumscribed as the relevant aspect of network user responsiveness to prices. The options in cost accounting relate to the method of identifying cost causality (see example below).

The economic nature of electricity networks (natural monopolies) also implies a dilemma. Perfect cost-reflectivity of prices generally imply that prices should be set according to short-term marginal costs. Over time, sector expansion will be such that short- and long-term marginal costs converge. This is not fully applicable to regulated natural monopolies who have their revenue determined such that prices on average must correspond to average costs. As a consequence, it is not possible to device a price scheme for such network services that provide perfect price signals about 'everything'; (marginal) use, location, timing, expansion, multiple grid levels with peaks/constraints at different times, etc.

In terms of cost reflectiveness, disagreement among stakeholders has been voiced whether network tariffs shall incorporate political and behavioural incentives apart from network costs. To ensure a clear limit of the costs that shall be reflected, the criterion at hand is restricted to refer to costs as part of the regulatory determined allowed revenue. Other costs, such as energy system costs, are either disregarded or included in other criteria – first and foremost *neutrality with respect to electricity market prices* and *distributional effects*.

Case example for behavioural uncertainty

Consider two cases A and B with two identical networks and two connected customer groups per network that pay the same tariff. Group H has high contribution to peak demand, group L has a low contribution. In case A, the customers are highly sensitive to grid tariffs, in case B they are not. Further assume that sensitivity to grid tariffs increases with contribution to costs.

A new tariff shall be introduced to better reflect the contribution to peak demand. A tariff increase in case A would now significantly decrease peak demand of H. Thereby, the cost contribution of L would increase. In case B, customer group H would not adjust its behaviour and the cost contribution of group L would remain the same. As a consequence, the new tariff of AH should be lower than of BH, the new tariff of AL should be higher than of BL.

Considering that behavioural uncertainty is unknown, here customer sensitivity, it is not clear ex ante if the tariff should be adjusted as if it was for case A or case B.

3.1.2 System sustainability

The tariff design shall be such that the network can operate sustainably. It means the risk of cessation of network operation leading to suboptimal public welfare results shall be minimal. As the tariff design effectively steers the revenue from network operation, such risk may be due to, i.e., liquidity, solvency and profitability issues. This does not mean that any cessation of operation is undue.

System sustainability requires a degree of consistency, and correct signals for actors to enter or exit from the market. In the case of network tariff designs, the market comprises the demand and supply of electricity distribution. Consistency is necessary for network operators for their administrative, financial and technical planning. In particular, the tariff design impacts the cash balance in the short term while investment decisions are in need of robust demand and revenue projections in the long term. While different manifestations of cash balance, investment decisions and alike are permissible, these manifestations profit from a consistent tariff design. It has, thus, been argued that significant changes of the design shall be made very seldomly and with sufficient lead time. Adaptive and dynamic regulation shall be predictable.

In addition, the signals for market entry or exit are of high relevance for networks due to the longevity of network assets. This means that the strong economies of scale need to be deployed for networks to be cost effective and sustainable. One considerable risk for network operators lies in a “death spiral” of network users exiting the market (disconnecting from the grid). As network users disconnect, a lower customer base is available to cover the mostly fixed network costs, leading to higher prices and higher incentives to disconnect. While price sensitivity has been historically low, thereby limiting the risk of such a self-reinforcing behaviour, the trend to PV plus battery systems poses an increasing risk for price sensitivity and disconnections. For system sustainability, it is hence necessary that the tariff design does not give undue merit to customer behaviour leading to a “death spiral”.

3.1.3 Efficiency

The efficiency principle portrays two sides of one coin. On the one side, the network tariff design shall incentivize efficient utilization of the available assets. This may be coined as operational or static efficiency as it relates to output per input in the short term. In particular, the tariff design may be beneficial by reducing congestion and increasing the utilization time of the network components. These imperatives shall, however, not surpass the optimal trade-off between consumer benefits from flexible network utilization and network costs. Due to the fundamental role of electricity in society, this trade-off is implicit i parts, because changes of consumer behaviour are often constrained by external influences such as working hours and temperature. Hence, the most effective tariff design does not result in equal network utilization throughout the day and year but rather in an economic network utilization in view of constrained consumer behaviour.

On the other side, infrastructure cost or dynamic efficiency states that the design shall incentivize efficient investments in the network assets. This side refers to efficient long-term operation of the network. To ensure such operation, the tariff design shall project the correct signals to network users and operators for required network investments and the associated costs. While the operator shall invest where future demand will be located and in line with future consumption and injection behaviour, the network users shall receive the correct signal from the tariff design about their contribution and the associated impact of their behaviour to new investments. This implies that efficiency shall also be ensured with regard to development of demand and supply locations and patterns. Here, the case for investments is the most evident. Yet, efficient decommissioning of assets may be equally considered for dynamic efficiency.

In light of potential changes of the network tariff design, two major challenges are of particular importance. First, as the current network and consumer behaviour is adapted to the current tariff design, a change of the tariff design may lead to customer behaviour for which the network is not prepared. In particular, new incentives to smooth peak loads may lead to shifts of peak loads that surpass the current peak load level or result in a faster ramp-up of demand. Apart from that, a change that leads to different injection patterns by prosumers may shift congestion from one area to another. In both cases, that tariff design change would potentially have had a negative effect on efficiency.

Second, as (future) price sensitivity of network users is unknown, the impact of the tariff design change is equally unknown. This means that even a reasonable tariff design change may have little effect on the efficiency of network utilization and investments due to reasons unrelated to the tariff design.

3.1.4 Impact on self-consumption

Due to the relevance of new appliances for the expected load curve changes, the impact on self-consumption is included as distinct criterion in the evaluation. While self-consumption is by and large included in system sustainability and efficiency considerations, its expected role gives merit to a closer look. As such, the criterion focuses on the tariff design’s treatment of prosumers and energy communities. It portrays the incentives and expected behavioural consequences, as well as the expected requirements to invest.

A tariff design that meets the criterion of impact on self-consumption is such that self-consumption is incentivized when otherwise the network would be congested, and investments would be needed in the long term. In addition, the prosumers’ contribution to network costs shall be sufficiently reflected in their network costs. I.e., if a tariff design is based on a high percentage of the volumetric fee, self-consumption is maximized irrespective of network conditions (i.e., proxied by the time of the day) and the prosumer pays comparably little for the cost contribution it has on the network when consuming grid electricity during peak load hours.

Apart from self-consumer’s impact on net load demand, prosumers may play a role by injecting electricity into the network when little demand exists. While from a network perspective, the network design should reflect the facilitating role of the network and bill injection accordingly, such claims have been historically dismissed in order not to constrain the installation of solar PV modules.

3.1.5 Neutrality with respect to electricity market prices

The *neutrality with respect to electricity market prices* criterion assesses, in how far the network tariff design supports or distorts incentives made by market prices, in how far it creates situations suboptimal to electricity generation profiles and would require amendments to the market design or generation portfolio, and in how far it creates indue transaction costs for customers willing to optimize consumption patterns.

The criterion is concerned with a systemic aspect to network tariff designs. As electricity consumption, and hence the actual use of the electricity network, is driven by network charges, electricity prices, and other fees, taxes and levies, a change of the network tariff design may have consequences on consumption patterns which (in principle) may impact electricity prices and generation patterns.[4] The opposite is also relevant; changes in electricity market prices may have consequences on the utilisation and hence the potential congestion of the electrical grid. In light of the objective to maximize public welfare, the network tariff design should, therefore, be evaluated against its potential impact on the overall energy system.

Different regulatory and market mechanisms interact in this wholistic domain. Thus, while the network tariff incentive for a given hour might be to reduce load (due to limited (local or regional) available network capacity), the electricity market incentive could be increase load due to surplus of electricity generation, e.g., due to high wind generation. Because both

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[4] For Luxembourg, this is rather hypothetical; Luxembourg and Germany are together one joint bidding zone; implying that wholesale prices are the same. It is rather unlikely that even a significant change in demand pattern (e.g., due to a change in network tariffs) within Luxembourg can impact wholesale prices and generation patterns. In a context with local flexibility market, the situation is different – local markets are by definition much smaller and the potential for an impact on such markets due to specificities in network tariffs is high.

root causes can prevail at the same time, it is confusing but not conceptually misleading or wrong that network tariffs and market prices provide opposite signals.

3.2 Feasibility Criteria

3.2.1 Simplicity

Simplicity has been considered as a vital criterion for tariff design implementation by the stakeholders. The criterion entails two dimensions. First, simplicity is required for the DSOs to implement the tariff design. This includes the technical capabilities for measurement, network fee calculation, and invoicing. It is further concerned with the DSO's capabilities to answer to customer requests which may pose extensive challenges, if the second dimension of simplicity is not met. The second dimension relates to the network user's ability to understand the tariff design and adapt their behaviour accordingly. In light of the multiplicity of customer groups and the potential transaction costs that coincide with complex tariff design, a tariff design may be expected to result in easy rules of thumb for the network users. Simplicity is of particular importance for network users as they were comparably unconcerned with network costs in previous years. Hence, a tariff design that leads to a sought-after behavioural change or at least tariff determination on grounds of cost contribution to network assets may require a sensible approach to customer awareness of the difference between network and energy costs. Given this requirement and against the criterion of simplicity for DSOs to implement the tariff scheme, it stands to question, if it lies within the responsibility of the DSO or of some other stakeholder to attend to the sensitization approach.

Apart from this, in some manifestations of tariff design options, network users need to choose their tariff which implies further requirements for the simplicity of the design to be implemented.

Transparency constitutes an underlying factor for simplicity. In case the tariff design is not transparent in its rationale, meaning and consequences, it is unlikely the affected stakeholders, DSOs and network users, consider it sufficiently simple to apply it.

3.2.2 Predictability

A second criterion with two dimensions, respectively the DSOs' and network users' perspectives, is *predictability*. Predictability is a vital requirement for the feasibility of a tariff design. In case network user behaviour is unpredictable for DSOs, translating the allowed revenues into reasonable tariffs is highly uncertain and may lead to large variations of tariffs between the regulatory periods. In case of self-selection into tariff groups by network users, it its equally required for the DSOs to be able to make robust estimations on the number and types of customer groups selecting one or the other tariff level. In addition, customer behaviour should be predictable for DSOs to make sound investment decisions. As investments may have feedback effects on customer behaviour, the sensitivity of customer groups to prices and tariff design manifestations is critical. Oftentimes, a simpler tariff design results in more robust predictions, as less parameters, their interaction and their effects must be considered.

For network users, predictability of the tariff design refers to the expected network charge for one's consumption, and the potential impact of consumption pattern changes. The expected network charge is relevant for regular budget and consumption decisions of households and industries. Therefore, deviations from monthly fixed payments should be the exemption – smaller is better. At the same time, it should be clear how electricity (self-)consumption and injection influences the bill. From this clarity, behavioural changes can be incentivized and inferred, algorithmic optimization for smart gadgets, batteries, electric vehicle charging, and heat pump usage may become cost effective. Without sufficiently predictable costs and cost responsiveness, such decisions are inhibited due to significant uncertainty.

3.2.3 Non-discrimination

Non-discrimination means that the network tariff design shall not discriminate against a customer group or behaviour for any other reason than justified through their network cost contribution. Considering uncertainty of cost contribution, this does not result in an exact allowed allocation of the economic burden, but as bandwidths denoting the implicit relation between cost contribution of different customer groups. Non-discrimination is an often applied and by law mandated criterion. The tariff design is thus obliged to abide by this.

Historically, non-discrimination is a heavily discussed topic. This follows from the bandwidth of seemingly permissible, non-discriminating allocation of economic burden. Therefore, it is of high importance to align with stakeholders their view on the proposed tariff design in order to forestall mandatory changes after the tariff design has first been implemented.

4 EVALUATION

The evaluation of the tariff model designs is conducted by:

1. Assessing the individual designs in light of the economic principles
2. Assessing the individual designs in light of the feasibility criteria
3. Examining the mitigation possibilities for most prominent challenges of the individual designs

In addition, the designs will be evaluated for their fit for non-regular customer groups such as data centres or energy communities in a separate, condensed approach. In contrast, the assessments (1) and (2) comprise the evaluation of the designs against the criteria for all regular customer groups, for which we make the following assumptions regarding the representative energy behaviour:

- **Industrial customers**: Their main characteristic is that they are typically connected to the medium or high voltage grid, they do not show peak demand on the workday evenings, but during workday daytime or not at all (implying a constant or quite stable use of appliances). Industrial customers are more price sensitive such that they are more inclined to adapt their demand to price variation. Industrial customers are typically clustered in industrial areas.
- **Commercial customers**: This customer group includes commercial and public buildings as well as small and medium enterprises that are typically demanding electricity during working hours. Their peak demand revolves around noon. They are price sensitive to the degree of efficiency improvements. Unless they have solar PV systems installed, they cannot shift their peak demand, but smooth it to some extent. For the assessment, it is assumed that a subset of commercial customers has solar PV systems installed.
- **Traditional households**: Traditional households are facing the need to electrify over the next 25 years but currently have limited demand response capabilities as they have neither a solar PV system installed, nor a battery or a flexible heat pump. They may have EV charging at home. Their peak demand is in the workday evenings, another smaller peak is at midday. Due to their limited capability of demand response, they are comparably price insensitive. This group comprises single-person, single-family, and multi-family household connections or buildings.
- **Prosumer households**: Prosumers are network users that do not only withdraw electricity from the grid but produce and may inject electricity as well. The primary energy source is installed solar PV. The installation system may differ with regard to the direction (south to maximize output per installation or east-west to maximize availability) and the existence and use of a battery. The typical load curve of prosumers is similar to the one of traditional households with the difference that at midday the peak is negative, indicating net injection (or storage by charging a dedicated battery). In addition, prosumers are more capable of demand response such that their price sensitivity is higher. Both single-building connections and energy (prosumer) communities are included in this customer group.

The assessment considers the specifications of the individual models and answers the questions, if the model meets the respective criterion in all cases (A), in some cases (B), or in no case (C). Here, the case differentiation is referring to the customer groups, but may also highlight typical alternative specifications of the design, where necessary.

4.1 Tariff design performance according to economic principles

4.1.1 Cost reflectivity

Subscription-based model

The subscription-based model depicts three fundamental features to meet the cost reflectivity criterion.

First, it comprises a relatively high share of the capacity charge in comparison to the volumetric charge. Since network costs are primarily driven by long-term investments limiting the available capacity, and only to a lower extent by short-term costs for usage, this relative dominance of the capacity charge is in line with scarcity and, hence, cost reflectivity. The closer to 70 – 80 per cent of allowed revenue collected by the capacity charge, the better is the cost-reflectivity.

Second, the fixed capacity fee attributes an equal share of cost burden to the network users, weighted by the subscription they use. For the considered design specification, this fee is constant over the entire year.

As the network is dimensioned for its peak load, the peak load is critical for future investments. However, future investments result in higher available capacity over the entire timespan. In the subscription-based model, network users subscribe to a higher level of demand and pay for a steadily higher available capacity. As a grid dimensioning increase results in steadily higher available capacity, the model reflects in its differentiation of subscription levels the cost increase for new network development.

Third, apart from this, congestion is critical during times of network peak loads. The network peak load constitutes the time period where load withdrawal of the individual network users is, in sum, highest. However, this peak does not necessarily coincide with the individual network user’s peak load. To identify the cost contribution by the individual network user, it is hence necessary to approximate their contribution to the network peak load. To approximate the network user’s contribution to the peak load, the subscription-based model applies a fee (financial capacity extension) which may be tailored to a pre-defined period which can be based on the likelihood of a peak load, and hence congestion. Thereby, the additional marginal costs at such a time period are accounted for in the tariff design. In addition, no costs are associated during times of free capacity, but the subscription-based fixed fee that accounts for the general dimensioning of the grid.

While prosumers can benefit from the lack of network charges for injection, traditional households and industrial customers have to pay the burden by facing increased withdrawal tariffs that include the costs associated with injection. But the prosumer’s ability and incentive to shift injection to self-consumption during peak demand hours also yield benefits to the other network users: A subsequent, *ceteris paribus* decrease of required capacity during peak load hours is then beneficial for traditional network users and prosumers alike as less network investments are required. It follows that individual incentives for prosumers due to the financial capacity extension have a beneficial effect on the subscription fee for all network users, if the fee is sufficiently high so that prosumers shift injection to self-consumption, but do not opt out of the network altogether.

The above considerations also hold for network users connected at the MV or HV level. They also hold for the potential Tetris variant, with time-dependent subscription prices such that network users can subscribe for different capacities for different time slots without any rights to financial capacity extension – assuming that the pricing for different timeslots reflects the likelihood of a peak load, and hence congestion, and thus indirectly the dimensioning demand of the network.

Hence, the subscription-based tariff design meets the criterion of cost reflectivity to a high degree (A).

Measured Capacity Model

The measured capacity model displays three different relevant aspects to be considered for cost reflectivity. First, the monthly potential change of capacity payment takes note of seasonal differences of scarcity in network capacity in the short term. Thereby, the tariffs are aligned with forward-looking signals for future investments and the current dimensioning of the system. In months of high network capacity demand, higher simultaneity is reasonably assumed such that the cost contribution to the dimensioning of the grid is higher.

Second, short term congestion and the network user's cost contribution is reflected by the measurement of maximum demanded capacity. Here, the model proposes to use the average of the highest 15min. intervals on four different days in a month in order to mitigate one-time (random) effects and attribute costs to behavioural patterns rather than single incidents, as these patterns are more likely to contribute to network costs. This line of argumentation may be substantiated by a reference to simultaneity considerations: Random peaks are likely to be more evenly spread across network users than exogenously triggered consumption patterns. It stands to question, however, if consumption peaks during off-peak hours should be equally relevant for the determination of the capacity charge as consumption peaks during peak hours. After all, regular individual peaks during off-peak hours have a lesser effect on network peak load than lower individual peaks during network peak hours.

Third, the high reliance on a monthly fixed capacity fee reflects the fact that capacity constitutes the main cost driver for the network. Hence, it may be concluded that the measured capacity model accords to the cost reflectivity criterion, if capacity peaks are measured such that individual peaks are considered in peak load hours rather than off-peak hours. As this specification is straight-forward, the model is scored A, meeting *cost reflectivity* in all cases.

Time-of-use model

In contrast to the subscription-based and the measured capacity model, the time-of-use model upholds the high share of the volumetric fee. While this would generally decrease cost reflectivity of the tariff design, as costs are principally accrued by capacity dimensioning rather than volumetric usage of the grid, the time-of-use model seeks representation of network costs by adjusting the volumetric fee in accordance with network capacity scarcity. This implies that, despite the fact that the volume is priced to a large extent, volume demand in times of low available (free) capacity is priced higher than volume demand in times of extensive available capacity in the grid. Loosely speaking, the time-of-use tariff assumes that capacity is scarce over a constant period and that individual variation in capacity demand is equally distributed across the network users such that individual peaks pose no greater cost contribution than a steady withdrawal. The individual load curve can be understood as noise in the heterogeneity of load curves among network users.

While this approximation constitutes a better fit to cost reflectivity than a non-differentiated volumetric fee, it stands to question if heterogeneity among network users is sufficiently strong such that individual peaks do not play a role in network dimensioning and grid congestion. In particular, exogenous factors such as labour hours and the sunset may pose challenges to this assumption. Considering that an increase in the granularity of differentiated timeslots decreases this risk, it may be stated that the time-of-use model conforms to *cost reflectivity* in some but not all cases (B).

4.1.2 System sustainability

For the model to ensure system sustainability, it is relevant that the tariff is such that invoicing is not far off of payable dates (which would require at least substantial working capital). The discrepancy between invoicing of network users and payments to personnel, shareholders and lenders is primarily driven by a) fluctuation in the tariff and b) the rate of recalibration.

A second aspect for system sustainability concerns solvency and the tariff design's signals for market entry or exit. The risk is that network users opt out of using the network, resulting in the split of the network costs onto a smaller customer base which may lead to further market exits. In that case, solvency is at stake, as the recurring effect may lead to a downward spiral of network users, eventually leaving no one to cover the network costs. To account for this risk, the tariff design needs to take special concern of currently price sensitive customers and their contribution to the network costs.

Subscription-based model

The subscription-based tariff is such that the subscription fixed fee is constant over the entire year (unless the customer ends the contract prematurely due to, e.g., moving households). Consequently, the DSO is assured of monthly fixed invoices to the network user. In addition, extension of subscribed amounts is expected to be dominant in the winter season, as demand is expected to be growing when heat pumps are required. Hence, the DSO may expect additional income when it is dark and cold. While this variation is new in its extent, this seasonal variation is expected to be gradually increasing over time such that the associated liquidity risk is minimal. From a system perspective, it may be expected from the DSO to account for this variation by adjusting working capital.

In the subscription-based model, price sensitive network users have a low incentive to exit the market, as they can minimize their costs without having to exit the network altogether. At the same time, prosumers may have a beneficial effect on price insensitive network users as well, in case they shift their load such that the peak load is smoothed. This encourages self-consumption to the extent of smoothing capacity demand in times of peak load hours, but not to minimize network usage altogether (which would be the case in a volumetric fee dominated tariff model).

The evaluation is the same for the potential Tetris-variant that might be considered for the MV and HV users.

To conclude, the subscription-based design meets the system sustainability criterion to a high degree (A).

Measured capacity model

The measured capacity model implies a monthly ex-post determination of the fixed fee to be paid by the network user. Various models for invoicing exist. For instance, the entire fee may be invoiced for the preceding month, a default fee may be invoiced per month and aggregated deviations over the months may be paid or returned as adjustments at the end of the year, or a default fee may be invoiced per month and monthly deviations are paid each subsequent month. From a liquidity perspective, either option is economically acceptable as the required working capital does not significantly differ from today's invoicing procedure. The principal differences in the invoicing schemes are rather related to signalling and transaction costs for network users, DSOs, and potentially retailers.

In terms of solvency and market entry or exit signals, the measured capacity model shows higher risks. First and foremost, the ability to realize extensive monthly savings may give reason for prosumers to minimize measured capacity demand in summer months such that total tariff payments will vary significantly between winter and summer.

Due to this risk of monthly payment variability and its unforeseen consequences, the measured capacity model only meets the criterion of *system sustainability* in some but not all manifestations (B).

Time-of-use Model

The time-of-use model is relatively unproblematic in terms of system sustainability. On the one hand, the costs accrued by the network users are shifted only within the day; billing may remain largely unchanged from the current tariff design. Therefore, a liquidity risk is unlikely to substantiate. On the other hand, market entry and exit signals are aligned with cost contributions. While prosumers may be incentivized to significantly decrease withdrawal during peak load hours, their decreased demand implies a decreased need to invest in the grid. At the same time, they are not incentivized to decrease demand also during off-peak hours (which would endanger the continuity of the number of network users). Naturally, if the price discrepancy between peak load hours and off-peak hours is so great that a significant number of users opt-out of using the grid for a continued time, then the solvency may be at risk. As it is straight-forward not to determine the tariffs in such manner, the time-of-use model scores A, meeting the *system sustainability* criterion in all cases.

4.1.3 Efficiency

Subscription-based model

The subscription-based model meets the requirement for efficiency, as it portrays signals to the network users for short-term optimization of network usage and to the network operator for long-term investments when socially optimal. In specific, the lump-sum subscription payment allows network users to utilize the network where there is spare capacity for no additional charge. Using the network at times of spare capacity generates societal value as it increases the output without increasing input (apart from losses which are accounted for by the remaining volumetric charge). In addition, the model design requests additional payment at times of potential network congestion. Thereby, network users can optimize their consumption behaviour and decide on whether they consider the additional payoff of using electricity during peak load hours is worth the potential need of future investment into the grid. While traditional households are less price sensitive, prosumers and flexible network users (i.e., industrial customers) benefit from this potential to choose such that the Ramsey Pricing rule is adhered to.[5] This rule may be further ensured by using degressive tariff setting for higher subscription levels.

From the DSO's perspective, the network user's behaviour at peak load hours results in a clear signal for the acceptance of further network investments. As (a subset of) network users optimize their consumption pattern and may show additional willingness to pay for extra peak load, the DSO is better placed to decide for or against further investments into the grid.

The potential Tetris variant for MV and HV network users scores at least as good as the 'plain' subscription model.

It may be, thus, concluded that the subscription-based model is in line with the *efficiency* criterion. Noting that the differentiation between lump-sum payment in form of the subscription and flexible payment for financial capacity extension is fundamental to the model design, it may further be stated that the criterion is met in all substantiations of the model (A).

Measured Capacity Model

The price signals to network users in the measured capacity model carry some risk of resulting in suboptimal efficiency considerations. Two main aspects work against the generally efficiency-enhancing signal carried with the tariffs' alignment to cost contribution. First, the cost of an incrementally higher maximum demanded capacity during measured timeslots (network peak hours) is relatively costly (in terms of eurocent/kWh), as it leads to a general increase of the fixed fee for the month, rather than only for a limited fee for financial capacity extension. It follows that network users face potentially overbearing disincentives to use extra capacity, even though the extra capacity may have great value (yet lower than the monthly fixed fee increase) to the network user. While the disincentive may be optimal for the network at large, the opportunity cost accrued on the customer side may outweigh the benefit to the DSO.

Second, network users are incentivized to increase their capacity usage to a level just below their maximum demanded capacity. The effect of the two aspects combined is that network users are incentivized to use capacity at the end of the month with little disincentive, thereby increasing simultaneity and increasing the risk of a new network peak load. In the beginning of the month, users are wary to increase their use of capacity, as they are uncertain how much capacity they require maximally in the month, which collectively reduces capacity demand. This issue can be overcome by DSO's

[5] The rule implies that, given that allowed revenue shall be met, deadweight loss is minimized by decreasing the markup onto the marginal price for price sensitive customers relative to the markup for inelastic customers (Borenstein 2016).

issuing separate start dates (i.e. not all tariffs start on Jan 1st) for the individual network users. The downside to this is the increase in complexity of the tariff rate calculation and of communication about the tariff and changes in tariffs.

While these aspects pose a risk to signalling efficient network usage, it holds that the general tariff design incentivizes reducing individual peak demand during network peak hours. Therefore, depending on the concrete manifestation of the tariff design, the model may meet the criterion of *efficiency* (B).

Time-of-use model

As identified in the assessment of *cost reflectivity*, time-of-use models run into the risk of the faulty assumption of heterogenous load curves among network users. Due to this risk, the efficiency of the emanating signals is questionable. Rather than disincentivizing high capacity usage, the time-of-use model typically incentivizes lower overall electricity withdrawal during peak-load times as well as during off-peak times. If customer groups are sufficiently heterogenous, then these signals are potentially even more efficient than models that price maximum demand. The opportunity cost for network users is lower in the time-of-use model than in comparable models that charge for individual maximum capacity demand, because it leaves more room of manoeuvre to the network users without resulting in a higher risk of network congestion.

Considering that the assumption of heterogeneity is rather optimistic in many of the time-of-use design manifestations, the model meets the criterion of *efficiency* only in some but not all cases (B).

4.1.4 Impact on self-consumption

While the impact on self-consumption plays a considerable role for meeting all economic principles, meeting the *impact on self-consumption* constitutes a separate criterion in light of its growing relevance. Neither of the models bill injection or self-consumption; the bill is always based on the largest of the net consumption (full consumption minus generation behind the main meter) and zero. Therefore, self-consumption is incentivized.

Prosumers may inject electricity at no direct cost. At face value, this may hypothetically lead to a suboptimal result as congestion may follow in times of high injection and low demand. However, this does not seem to be a realistic challenge in the foreseeable future.

On the other hand, the models differ in how they indirectly impact self-consumption. The opportunity costs for injection imply an indirect incentive for network-beneficial self-consumption. The evaluation below thus concerns such indirect incentives.

Subscription-based model

Due to the risk of exceedance of one's subscription, prosumers are incentivized to use the generated electricity in times of peak load. The strength of the incentive depends on the exact unit prices and fees and are well-defined with no uncertainty for the network customer. From a technical perspective, self-consumption may be undertaken by use of batteries or east-west sided solar PV installations. As self-consumption is only incentivized to smooth the load curve during peak load hours, the optimal sizing of the battery and PV system would be such that withdrawal is relatively constant below the subscription level threshold and injection may spike in times of surplus electricity.

The situation is the same for MV and HV customers, both with a standard application of the subscription model and with the Tetris variant.

As the subscription-based model relies on ex-ante defined tariff components (subscription fee, volumetric fee, etc.) the impact on *self-consumption* criterion is fully met by the subscription-based tariff (A).

Measured Capacity Model

The measured capacity model also has a beneficial impact on self-consumption, as it gives a strong incentive for prosumers to shift injection to self-consumption during each customer's peak load hours. Thereby, the prosumer smoothens the load curve such that the total capacity payment is reduced.

However, the measured capacity model creates additional uncertainty for network customers, particularly in the beginning of each month. The opportunity cost of reduced self-consumption depends on the consumption later the same month. The resulting incentive is ambiguous in the first part of the month – the value or benefit of self-consumption is essentially not known until the end of each month.

Hence, the measured capacity model is scored lower than the subscription-based model, meeting the criterion of *impact on self-consumption* in some but not all cases (B).

Time-of-use Model

The model's impact on self-consumption comes with lower uncertainty for the prosumer and equally with lower benefits to the DSO. As the prosumer needs only to shift injection to self-consumption for any alternative withdrawal during peak load hours, it can use the stored electricity at any time within this timeslot, irrespective of a peak. It follows that prosumers may lead to a new peak after their batteries are discharged. This issue implies for DSOs that they might not benefit from self-consumption as much as from self-consumption triggered by tariff designs focusing on capacity charges. Regardless, the triggered self-consumption may lower network peak demand, if traditional network users have their peak at the beginning of the peak demand timeslot (e.g., 6 pm) while prosumers have shifted their peak demand backwards e.g., 9 pm when all electricity stored is consumed.

Similar to the measured capacity model, the model receives a score B, noting that incentives for self-consumption are only partially beneficial and prone to define new (local) network peaks.

4.1.5 Neutrality with respect to electricity market prices

In the current tariff system, additional withdrawal is costly irrespective of the time of the day. Typical households' major cost component is a fixed Euro amount per kWh for both network withdrawal and electricity. The underlying electricity prices in the wholesale market are averaged and marked-up by the electricity retailers (except for network users who are metered and charged by the hour, with hourly prices). It follows that for most customers, no price signal exists for adapting one's demand pattern to the availability of electricity. For consumers with a dynamic price contract (potentially most relevant for MV, HV), the impact of market prices is typically higher than the impact from network tariffs.

Subscription-based model

The traditional tariff design is optimized for a demand side being served by dispatchable electricity generation from energy carriers like coal, gas, nuclear, and hydropower. Assuming ceteris paribus generation patterns, the subscription-based tariff design would, in the absence of other electricity price signals, incentivize network users to increase consumption in off-peak hours. This follows from the financial capacity extension fee's disincentive to withdraw electricity during peak load hours. In case the merit order curve is constant over the entire period (e.g., day), the resulting decrease of peak load would imply cost savings. In light of the trend to intermittent electricity generation, the assumption of constant merit order curve is, however, questionable. Hence, it may be followed that the new tariff design may shift consumption into time periods with unknown generation patterns.

Network users exposed to a subscription-based model will seek for a price optimum between electricity and network costs. Here, optimal demand could be identified, if both network costs and electricity costs are known and reflect their marginal costs. Since it is uncertain in how far the electricity market design will be adjusted for intermittent and flexible generation, it needs to be acknowledged that the subscription-based design may lead to a suboptimal distortion to the underlying electricity prices – i.e., generation cost. The potential detriments are particularly relevant for prosumers but generally hold for all customer groups.

However, this concern depends on the electricity market design, not the network tariff design. With the subscription-based model, network users know (or may know) the exact cost of using the network at any time; it is determined by the specific tariff elements. The network tariff design is neutral with respect to the electricity market design and performance. The subscription-based model neither weakens nor enhance electricity market signals. The design, therefore, receives an “A”-score.

Measured Capacity Model

The measured capacity model deviates from the subscription-based model in that it introduces uncertainty about the costs of using the network. Apart from this, it shows the same potential detriments in terms of interaction with the electricity market as the subscription-based model to the extent that demand is shifted to non-peak hours irrespective of availability (and hence price) of electricity supply. The model’s efficiency issues may amplify or diminish said detriments.

Hence, mitigating action is required either by adjusting the measured capacity model, or by adjusting retail prices of electricity.

Because the interaction with market prices is more uncertain with the measured capacity model, the neutrality criterion is met only to some degree (B).

Time-of-use Model

As is the case in the subscription-based model and the measured capacity model, the time-of-use model risks a shift of demand into timeslots where electricity supply is scarce. However, the time-of-use model allows for a differentiated behaviour in line with electricity prices within network peak load hours. On the one hand, this may result in beneficial adherence to electricity price signals. On the other hand, strong adherence to such signals implies a further move away from the heterogeneity assumption of load curves during network peak load hours. Hence, it remains subject to the final specifications of the model in how far network tariffs have reasonable interaction effects with market prices.

Unlike the measured capacity model, the time-of-use model does not create uncertainty about the marginal cost of energy use. If the network user has a dynamic electricity price contract the incentive from market price is likely to be much stronger than the grid tariff incentive leaving the latter neutral. With a fixed retail electricity price, the network user is incentivized to shift consumption away from peak periods according to how these are defined in the time-of-use model. The simultaneity between (‘global’) electricity market peaks and local network conditions cannot be taken for granted.

This feature can blur communication quite substantially. When market price signals and network price signals go in the same direction, the price signals will be coherent. However, the opposite is also possible; there is no guarantee that consumption and thus network load will not be higher during low-price periods in the electricity market. Using a volumetric price signal for capacity then sends a directly contradicting message.

Hence, we conclude the neutrality criterion is not met (C).

4.2 Tariff design performance according to feasibility criteria

While the economic principles are met by the subscription-based model to a large extent, the feasibility criteria require an equally dedicated assessment. Different to the economic principles, feasibility shall be assessed both from a customer and a DSO perspective.

4.2.1 Simplicity

The current tariff design is particularly simple. For the network users, the rule of thumb is "the more I consume, the more I pay", regardless the timing of consumption. DSOs charge the network users on the basis of historical demand patterns with little reason to expect a change of behaviour (due to the network tariff itself). A degree of tariff flexibility applies to industrial network users such that DSOs and customers may take note of their capacity requirement and billing.

Subscription-based Model

The subscription-based model turns away from the current simplicity by introducing a fee for financial capacity extension and requiring network users to choose a subscription. Notably, these changes apply for all network users which indicates that no special treatment is called for prosumers or industrial customers. Furthermore, the concepts of subscription and different 'service levels' are known from telecom and broadband, rush hour pricing are known from a variety of sectors (high season vs. off-season travel and accommodation prices). Nonetheless, from the network user perspective, the new tariff design would introduce uncertainty and increased transaction costs for their choosing of a subscription level. In case of many levels, the choice becomes more complicated – in case of few levels, the demand pattern adaptation for network users at the verge of a threshold becomes complex. Furthermore, LV network users are typically unaware of their capacity demand. This implies that the understanding of the concept of exceedance cannot be assumed. On the other hand, the network user only needs to have in mind one capacity value and remember to be careful when approaching it. Electricity suppliers or service providers can easily develop offers to even relatively small network users that automates demand response. The comparability of the tariff with tariffs in the telecom sector is only helpful to some extent, as the extension fee in the telecom sector relates to a volumetric fee and/or to a quality dimension of the service rather than a capacity fee.

For DSOs, the subscription-based tariff's fixed fee does not require a complex billing system. This holds particularly for annual subscriptions; for monthly subscriptions, the technical solution should be equally possible. However, the additional interaction with network users who choose their subscription constitutes additional transaction and operational costs. Depending on the allocation of responsibility, these transaction costs may differ in significance. On top of that, the calculation and billing of fees for financial capacity extension are feasible, but not *simple*. On the one hand, additional technical solutions may be needed for the measurement of the network user's capacity (except if / for hours when the fee for financial capacity extension is set to zero); this required additional capacity would then be translated into the fee for financial capacity extension (which may be subject to different specifications). On the other hand, the split of the allowed revenue between the part to be recovered by the subscription fee and the part to be recovered by the fee for financial capacity extension requires administrative capacity and additional working capital to account for a margin of error.

Due to these complexities of implementation, the subscription-based model only meets the criterion of simplicity in some cases (B) from both perspectives. After all, it may be expected that some manifestations of the tariff design are sufficiently simple to be feasible within reasonable budgetary and timely boundaries.

Measured Capacity Model

The measured capacity model constitutes a novelty for LV network users that traditionally are unaware of the difference between capacity and energy, and hence their own capacity usage. The concept of averaging over the four highest peaks is well intended, while potentially making the model harder to understand and to use as basis for behavioural changes Essentially, the network user's rule of thumb may be simple: The network bill primarily depends on the simultaneity of used electric appliances in a month. However, the tariff gains complexity in its specification of the measured timeslots and the calculation of the fixed fee. These additional features result in a decreased simplicity such that s may have trouble to correctly identify the price signals from the tariff system. For algorithm-based optimization systems, the price uncertainty between the beginning and the end of the month may pose further challenges. Therefore, the model at hand may only be considered *simple* in some but not all cases.

From a DSO perspective, the measured capacity model is relatively simple to understand, to calculate the tariffs and to produce the bill to the customer. Complicating matters may resound in the treatment of faulty measurements and the determination of the measured timeslot, as customer behaviour is uncertain until sufficient historical data becomes available. In light of the general prevalence of issues with regard to faulty measurements and the *predictability* aspect of customer behaviour, the measured capacity model may be considered to meet the criterion of *simplicity* for the DSOs in all most cases (B).

Time-of-use Model

Historically, the time-of-use model is the best-known alternative to the steady volumetric and capacity fees. Despite the fact that it is principally applied for electricity prices, the fundamental mechanism and, hence, understanding of its impact remain the same. Hence, the implications of the model are generally easy to understand as long as a) the timeslot does not become (too) dynamic and b) the number of different timeslots remains minimal. In case multiple timeslots are selected, it may be called for to select timeslots that are aligned to other societal determinations such as winter and summer time in case a seasonal differentiation shall be implemented.

For DSOs, a time-of-use model is similarly simple. While uncertainty exists with regard to the reasonable difference in pricing of the tariffs and the extent and likelihood of behavioural adjustments by the network users, collecting the allowed revenue as well as modelling tariff impacts is comparably straight-forward. It follows that the model at hand may be perceived as A, meeting the *simplicity* requirement in all cases from both perspectives.

4.2.2 Predictability

Apart from the general simplicity of the tariff system and the ability to comprehend and implement the system in general, the tariff design should equally allow for a) predicting one's costs, b) predicting one's revenues, and c) predicting one's impact from consumption behaviour adaptation and changes.

Subscription-based Model

In light of the novelty of the proposed tariff design, predictability is generally impaired in so far as historical data from the same tariff design is unavailable. However, from the customer perspective, the prediction of costs is in parts simpler than the incumbent tariff design in so far as the subscription fee is stable for the entire year. The volumetric fee is comparably small, and the possible need for financial capacity extension is limited by the maximum possible demanded capacity attainable from owned appliances. Due to the likelihood that capacity is a rather unusual object for traditional households' budget calculation, the predictability of costs from subscription extension is low until sufficient historical data and supporting information has spread across customer groups. Only after costs can be predicted by the network users, they will be able to predict the impact of their consumption behaviour. Hence, predictability cannot be assured for network users directly but may require additional fine-tuning of the model and supporting information (B).

For DSOs, the limited predictability is conferred from the network user's limited ability to predict the impact of their consumption behaviour. While the subscription fees may grant significant predictability to the extent of the fee's coverage of the allowed revenue, the extent of the revenue accrued by financial capacity extension is conditional on customer behaviour and, hence, unknown until sufficient (historic) data becomes available. In addition, the setting of the fee for financial capacity extension requires predictability for the price sensitivity of the different customer groups. It follows that the feedback process between setting the fee and the behavioural change from network users due to the chosen fee may be cumbersome and lead to unexpected and suboptimal interim results. Taking note of the feedback process from multipliers in gas transmission system tariffs for seasonal, monthly, and daily capacity booking and the resulting adjustment factor, it may be expected that the complexity for setting a reasonable extension fee does not constitute a feature preventing implementation of this tariff design. Hence, we conclude that this model meets the predictability criterion from a DSO perspective to a large degree (A).

Measured Capacity Model

Predictability constitutes a potential obstacle for the measured capacity model. On the one hand, network users are highly uncertain about their eventual capacity demand at the end of the month. On the other hand, the network user's uncertainty is translated into uncertainty for DSOs to predict customer behaviour and load curves. While a decrease in the duration to a monthly determination of the capacity charge and the implementation of a smooth function of the tariff against the maximum capacity demand decreases uncertainty, the remaining uncertainty remains a significant issue for the model at hand. A further decrease in duration would, while decreasing uncertainty, effectively render the measured capacity model a volumetric model at one point. Hence, the score in its strongest formats is such that *predictability* needs to be ensured by means other than model specification (C) from both a user and a DSO perspective.

Time-of-use Model

In line with the identified *simplicity* of time-of-use models, it appears at first sight that *predictability* is likely to be met. Since it is relatively easy to understand the underlying mechanism and impact of their behavioural change, DSOs can predict the impact of the model at least in terms of demanded volume during peak-load hours. By differentiating price sensitivity between the customer groups, DSOs may be able to identify which network user is going to adapt its behaviour, and which is not. Thereby, tariffs can be set such that little ex-post adjustments are necessary or significant unexpected consequences occur.

However, the behavioural change within network peak hours and at the thresholds of the timeslot is more complicated to predict and requires historical data. It has been argued that time-of-use tariffs lead network users to shift their demand just behind or before the network peak hours, resulting in new peaks rather than a smoothening of peaks. Hence, the time-of-use model is in line with the *predictability* criterion in some but not all cases (B) from a DSO perspective. On the other hand, from a network user perspective, the criterion is meet to a large degree (A).

4.2.3 Non-discrimination

Subscription-based Model

Against the background of the tariff design's ability to meet the *cost reflectivity* requirement, the criterion of *non-discrimination* is likely to be met, since the latter assesses if the tariffs for the distinct customer groups (voltage level) are within a reasonable bandwidth that are aligned to the group's contribution to costs.

Furthermore, the extent to which efficiency is ensured by adhering to the Ramsey Pricing Rule may result in the discrimination of price inelastic network users. However, network users with limited flexibility have a choice, represented by the trade-off between a relatively high subscription with limited need for financial capacity extension and a lower subscription with a correspondingly higher need for temporary extensions.

Hence, it may be concluded that *non-discrimination* is only met, if the tariff design sufficiently takes note of the criterion when determining the tariff rates on the basis of the economic principles. But if this is accomplished, the subscription-based model meets the criteria fully (A).

Measured Capacity Model

In line with the assessment conducted for the subscription-based model, the measured capacity model's propensity to meet the *cost reflectivity* criterion corresponds to a high likelihood that the model also meets the *non-discrimination* requirement. It stands that those network users who have higher capacity demand pay a higher total fee. Depending on the function between maximum capacity demand and tariff, an increase or decrease in simultaneity of additionally demanded capacity may be accounted for. I.e., if it is identified that extremely high measured capacity demand is unlikely to be highly simultaneous to other capacity demand in the network, a regressive function would be reasonable. In case extremely high measured capacity demand is more likely to coincide with network peaks, a progressive function may be called for. Hence, it may be concluded that similar to the subscription-based model, the *non-discrimination* criterion is met, if the tariff design sufficiently takes note of the criterion when determining the tariff rates on the basis of the economic principles. If this is accomplished, the measured capacity model meets the criteria fully (A).

Time-of-use model

The time-of-use model has similarities to the other two models in terms of non-discrimination. The exemption to this similarity is the potential benefit or drawback from the heterogeneity assumption to account for *cost reflectivity*. In case heterogeneity is given, the model discriminates individual network users with their unsteady load curve during network peak hours to a lesser extent than the other models. If, however heterogeneity is not given and individual peaks significantly contribute to network peak demand, then it may be perceived that network users without a peak or an unusual demand pattern are being discriminated against – even with a minimal contribution to the network peak, they face an equally high marginal cost for withdrawal from the network as network users with a very high consumption during peak periods. However, regardless the actual consumption of different network users (on the same voltage level), both are faced with the same potential ‘reward' or cost of a marginal change in consumption; the energy-component of the network tariff for that particular time slot. Hence, the criterion of *non-discrimination* is met in all cases (A).

4.3 Mitigation of challenges to new tariff design

Taken from the general assessment, three major challenges are particularly prominent. First, the measured capacity model faces considerable *predictability* issues in its principal form. Second, the treatment of thresholds has to be considered cautiously in subscription-based models. Third, the time-of-use model, apart from its questionable assumption of heterogeneity among network users, is at risk of creating new peaks. In the following, the potential for mitigating action will be assessed.

Predictability – measured capacity model

The principal underlying reason for limited predictability in the measured capacity model is the limited understanding and knowledge about customer behavioural change. Due to the novelty of the proposed tariff design, it is unknown, if and how network users will react to the change in terms of daily, monthly, and annual consumption patterns. To mitigate this uncertainty, three main mechanisms shall be discussed:

- High share of the volumetric fee
- Shallow increase of capacity charge per maximum capacity demand
- Market analysis on price sensitivity

The first mechanism *high share of the volumetric fee* is concerned with limiting the impact of the uncertainty by reducing the incentive for network users to change their behaviour. The high reliance on the volumetric fee upholds the incumbent understanding of price causation. At the same time, network users perceive – if they read the information on their network bill – a qualitative indication on the relevance of capacity demand. Over time, the share for the capacity charge may be increased such that the tariff is more closely aligned to cost reflectivity and the other economic principles. The gradual increase potentially offers sufficient historic data on customer behaviour and price sensitivity to calibrate tariffs and the tariff design.

While this mitigation action may solve the predictability issue, it carries the risk of faulty predictions by assuming linear behavioural changes of network users (i.e., it might be assumed that every 10% increase of the relevance of the capacity charge leads to 5% of network users smoothening their peak, although network users may have a common technical threshold of smoothening their peak at a capacity charge share of 50%). In addition, a slow introduction of a variable capacity charge may decrease the beneficial effect of the tariff change, as the slow change is not attended to by network users.

Another potential mitigating action is the *shallow increase of capacity charge per maximum capacity demand.* By decreasing the variation of the capacity charge, simplicity is increased such that it becomes less complicated to estimate customer behaviour. This holds as network users are less disincentivized to use additional capacity apart from an understanding of the fact that additional capacity is theoretically costly. The downside to this is that network users pay a very similar capacity charge, irrespective of their level of consumption. It follows that small network users pay disproportionally much and high demanding network users pay too little. Apart from the fact that this increases uncertainty with regard to the willingness to use capacity, it scores badly in terms of non-discrimination and cost reflectivity. This option, therefore, does not appear to be attractive or viable.

A third mitigation option is to analyse price sensitivity by conducting stakeholder consultations and assess historical price sensitivity. While this approach may be time-consuming and costly, if allows to substantiate the prediction on customer behaviour. While network users naturally may act differently than what they claimed, it decreases uncertainty to a degree depending on the completeness of the market analysis. In addition, this endeavour comes with the benefit that the planned tariff design change may be stopped prior to commissioning. In contrast, the other two options might require withdrawing or modifying the tariff design change, if it proves unsuccessful.

Treatment of threshold – subscription-based model

For the subscription-based model, the biggest challenge appears to be threshold behaviour and, consequently the tariff design's treatment of thresholds. Specifically, the risk is that the threshold is arbitrary from a cost causation perspective, the threshold creates undue (dis)incentives for socially optimal behaviour, and network users might not have sufficient information on their consumption pattern to determine the level they should be in. For MV and HV customers, a time-sensitive threshold implies a risk of new network peaks.

To mitigate these risks, the number of subscription levels could be reduced. Thereby, less network users find themselves with an expected capacity demand that requires strategic subscribing. More network users can easily locate themselves in a specific level. In addition, these thresholds could be derived from types of households and their appliances. I.e., the average capacity peak for fully electrified family households (including heating and vehicle charging) may become a benchmark for a high level of capacity demand, and the average capacity peak from two-person households without EV charging are used as the next threshold. Thereby, the benchmarked types of households are prone to strategic subscribing while all types in between can easily locate their preferred subscription level. In addition, decreasing the number of subscription levels may resonate with required investments which, too, do not follow a smooth function but denote stepwise grid expansion investments. While translating these necessary investments to the distinct subscription levels is not an exact science, indicative “as if” calculations may underpin the levels with a techno-economic rationale.

Another mitigation action might be to adjust the fees for financial capacity extension such that they increase with the severity of the exceedance. This action can be added to the mitigation action of decreasing the levels of subscription. By introduction of a progressive extension fee, a minimum extension is less costly than a large extension. Thereby, the risk of exceedance and allocated financial burden is adjusted for the exceedance’s impact on network congestion. It also gives more flexibility to the network user’s and their valuation of capacity demand. Finally, it ensures that prolonged extension is not equivalent to a time-of-use tariff, but accounts for the relevance of individual capacity peaks.

Finally, the subscription level could be re-adjusted *ex-post* in case network users have located themselves in a cost suboptimal level. While this may seem beneficial to the network users, it is not clear what this implies in terms of incentives for the network users. Subscribing for a high capacity can be considered as an insurance solution, as compared to a lower capacity with uncertain payments for financial capacity extensions. An *automatic* ex-post adjustment such that the cost of a ‘too large’ subscription is returned to the network users may thus make the network user ignorant of capacity usage. While the network user still can benefit from flattening demand, the incentive to do so is weaker. By choosing a high subscription level the network user knows that he can always afford to ignore the price signals. This will also effectively transfer the responsibility for the choice of subscription from the network users to the DSO. Therefore, we are not convinced an automatic ex-post adjustment is a sensible option. It rather appears reasonable for DSOs to enlighten their customers about the impact of alternative subscription levels for their network users[6] and encourage the network users to consider an upgrade of their subscription level as an alternative to pay for financial capacity extension. However, as a measure of household consumer protection, an automatic ex-post readjustment may have merit during an implementation period, e.g., during the first couple of years and in combination with a recommendation to consider a different subscription level.

Circumvention of new peaks – time-of-use model

To a greater extent than for the subscription-based model, the time-of-use model carries the risk of shifting demand in a way that leads to new network peaks.[7] Network users may be incentivized to shift demand directly before or after the timeslot. If network users react as expected or intended, this incentive would lead to a highly simultaneous demand at these times. A higher (local) network peak than otherwise realized would become a substantial risk. To circumvent this trend, two mitigation mechanisms are conceivable:

- Additional price levels
- Longer peak hour timeslot

The first mechanism would introduce tariff steps which smoothens the uptake of capacity as smaller subsets of network users act on the tariff change and network users act not as drastically between a single step, because the price differences are smaller. While this is likely to decrease the risk of new peaks, it increases the complexity of the tariff model.

The second option is to increase the duration of the network peak timeslot such that shifting the demand just before or after the timeslot is undertaken by a smaller group of network users, because of external reasons (such as working time

[6] It must be noted, however, that a main reason for the Norwegian DSOs’ opposition against a subscription-based model put forward by the Norwegian NRA (RME) some years ago, was the suggestion that it would be a responsibility of the DSOs to suggest the ‘correct’ subscription level.

[7] The reason why this risk is greater for time-of-use models is that any demand during network peak hours is disincentivized in time-of-use models. In contrast, subscription-based models only disincentivize peaks during these hours.

or sleeping habits). Incidentally, the price difference between the high peak and low peak timeslots would be lower, as a longer time with low capacity and network demand is covered in the peak hour timeslot. Similar to the *additional price level* mechanism, this mechanism will decrease the risk of new peaks. However, cost reflectivity is at risk. Times with low scarcity are priced the same way as peak hours.

4.4 Excursion: Non-regular consumer groups

The general assessment has shown the merit and pitfall of the compared tariff designs with regard to typical customer groups, including prosumers and industrial customers. However, to forestall unforeseen consequences, the impact of tariff designs on non-regular consumer groups is further relevant. These consumer groups may show these principal characteristics:

- Flat consumption over the entire year (e.g., electrolysers maximizing the runtime, data centres)
- Large seasonal differences (e.g., outdoor swimming pools; ice rinks, vacation homes)
- Rare but extraordinary capacity demand peaks (potteries, road tunnel ventilation)

Concerning the first customer group, the subscription-based model appears to be optimal, as both the DSO as well as the network user have full transparency on future demand and costs. From a cost reflectivity point of view, the relatively higher contribution to costs in times of scarce network availability is not depicted, leading to a distortion of reflectivity. However, this distortion is limited in so far as the relative scarcity is primarily due to heterogenous customer demand. If all network users were to withdraw electricity as non-regular group at hand, relative scarcity would be completely reflected in the subscription-based model. The measured capacity model results in a highly similar case. The time-of-use model is again similar, but accounts for the overall network scarcity to the greatest extent. While it is ambiguous to determine which tariff design would be best, it may be posited that any of the three designs accord to the evaluation criteria to a reasonable extent.

Network users with large seasonal differences reveal substantial differences in the tariff designs. For these network users, the subscription-based model covers the underlying cost contribution to the network in the best way. After all, the network is available for the network user also during seasons with little demand. This depiction of underlying costs may incentivize such seasonal demand centres to find a close-by anti-cyclical match or decrease its required capacity demand by investing in self-consumption. In contrast, the measured capacity model and the time-of-use model result in near-zero fees for the month of little use, despite the provided available network capacity. This may be cost beneficial for the seasonal demand centres, but discriminates against other, more regular network users.

The last non-regular customer group comprises network users with rare but extensive capacity demand peaks. In case these peaks are during high peak hours, the subscription-based model might be optimal, as the network user may book a very low subscription fee and pay for the peaks in the form of extension fees. Considering that the capacity needs to be provided in timeslots with scarce capacity, the additional payment is cost reflective but limited. A similar rationale applies to the time-of-use tariff. In contrast, the measured capacity model would pose a considerable burden onto this customer group, because the rare peaks determine the general capacity charge for the group. In case the rare peaks are in off-peak hours, network users face a lower network bill. Particularly, the measured capacity model and the subscription-based model might result in a minimal charge, if peaks are measured during the measured network peak timeslot only. Depending on the extent of the peak and the simultaneity of peaks during of-peak timeslots, this minimal charge may be reasonable. The time-of-use model, however, appears to be more robust in this case.

In conclusion, the three identified tariff designs are appropriate for non-regular network users. A potential outlier is the effect of the measured capacity model and of the time-of-use model for network users with large seasonal differences.

5 IMPLEMENTATION

When changing network tariff structure, a central question is how to move from the current scheme to the new scheme. Conceptually, it can be done overnight, or it can be done gradually over some time. DNV recommends spending some time in implementing the chosen model due to the following reasons:

- It is important but presumably not urgent to implement a more cost-reflective and efficient tariff scheme. If anything, it is more urgent to inform the grid customers that a new model will be introduced than actually introducing it quickly.
- One of the objectives with a new tariff scheme is to ensure grid customers are better incentivised to 'grid-efficient' behaviour. Hence, it is important that customers understand the tariff and its implications for different behavioural patterns.
- By implementing the change over some time, it is easier to adapt the target model based on experiences gained in the initial step(s). Instead of changing the implemented details back and forth, the direction can be adjusted without creating too much confusion among grid customers.
- In addition, DSOs might need time to adapt software, calculate the appropriate prices, prepare other operations processes and duties, and to inform its customers.

Assuming Luxembourg decides to proceed with the subscription-based tariff, we thus recommend this is done by a stepwise approach. There are two fundamental changes to prepare the customers for: the concept of subscription and the change from volumetric to fixed payment domination:

1. To introduce the concept of subscription, there are at least three measures that can be considered. The objective of these is to make grid customers familiar with subscription and financial capacity extension, rather than to provide incentives during the implementation phase. These measures can be undertaken by the DSO, the regulator or by private companies such as benchmarking service providers or electricity retailers.
    a. Start with relatively few subscription levels, e.g., 'small, medium and large', rather than a very detailed schedule. Refinements can be added later if experience suggests this is beneficial.
    b. Provide tailored numerical analyses (e.g., via an app or a web-based service) such that customers can make informed choices about subscription level. In addition, or as an alternative, suggest a potentially 'optimal' subscription level to each customer.
    c. Introduce the model without payment for a financial extension fee. However, reporting to the network customers to what extent consumption exceeds the chosen subscription is useful. After the first year, it could be considered to introduce payment for financial capacity extension.
2. The 'target' for the volumetric share is to reduce it from approximately 75 to a significantly lower share. Instead of changing this in one step, one could gradually decrease the volumetric share and increase the (fixed) subscription payment over a couple of years.

6 SYNOPSIS

The subscription-based model combines the best of two worlds (measured capacity model and time-of-use model) while improving cost reflectivity and, hence, decreasing discrimination among consumer groups.

The model outperforms the time-of-use model in terms of cost reflectivity and efficiency while securing higher feasibility scores compared to the measured capacity model.

The most prominent obstacles to the new tariff design comprise the treatment of threshold consumer behaviour. Both economic principles and feasibility criteria are at risk of being at odds at these thresholds. Consequently, mitigation measures shall be carefully designed to uphold the credibility of the proposed design. These measures may address the design of the fee for financial capacity extension, the number of subscription levels and further administrative and contractual specifications.

The table below summarises the analysis presented on the previous pages. Note that there is no comparison with the current model. While this obviously is feasible, a replacement is considered because the current model hardly meets the *cost reflectivity*, *efficiency*, and *self-consumption* criteria, and therefore is not in line with the requirements set forth in the recast regulation on the internal market for electricity (2019/943), article 18(1). Note that we have not noted any significant differences in the scoring between LV network users and users at MV or HV networks.

	Economic Principles				
	Cost reflectivity	System Sustainability	Efficiency	Self-Consumption	Market Neutrality
Subscription based model	• Low volumetric share • Fixed charge proportional to annual capacity need • Individual peaks	• Stable cash-flow to DSOs • Weak incentives to disconnect from the network	• Supports individual optimisation of usage patterns • Subscription signals desire for capacity	• Correct and well-explained opportunity cost • Multiple options for adapting net withdrawal from network	• Users know exactly the cost of using the network and can easily compare with electricity prices
Measured Capacity model	• Low volumetric share • Fixed charge proportional to monthly capacity use • Individual peaks	• Seasonal variation in cash-flows to DSOs • Risks associated with self-consumption and exacerbated winter costs for users	• High marginal cost of small incremental use • Threshold concerns and within-the-month variation of incentives	• Correct, but uncertain opportunity cost for self-consumption	• Uncertain opportunity cost of using the network complicates comparison with electricity prices
Time-of-Use model	• High volumetric share • Granularity of timeslots as a proxy to expected congestion • Heterogeneity of users	• Seasonal variation in cash-flows to DSOs • Weak incentives to disconnect from the network	• Strong incentives to adapt withdrawal to time-of-use timeslots • Heterogeneity of users	• Potentially too strong incentives to self-consumption • Risk for local network peaks, depending on prosumer technology	• Misleading incentives and communication issue when market and network price are not coherent (high volumetric share)

Figure 6-1 Summary of evaluation, economic principles

	Feasibility Criteria				
	Simplicity (user)	Simplicity (DSO)	Predictability (user)	Predictability (DSO)	Non-Discrimination
Subscription based model	• Necessity to choose subscription is a novelty • Need only to focus on one capacity figure	• Interaction with network users to explain new system • Fee for financial capacity extension not trivial	• Implementation challenge: Users will need time to learn and understand the concept of capacity	• Overall high predictability • Complexity in setting the 'right' fee for financial capacity extension	• Some room for manoeuvring also for non-flexible users • Ensured by proper parametrisation of the model
Measured Capacity model	• Novelty for LV network users • Well-intended but complex averaging of four individual peaks	• Interaction with network users to explain new system • Uncertainty about prediction of revenue	• User uncertain about their capacity demand until the end of each month	• Uncertainty about users' response to their uncertainty • Reduction to shorter periods results in a volumetric model	• Ensured by proper parametrisation of the model
Time-of-Use model	• Resembles well-understood concepts like rush-hours	• Limited changes from existing model	• High predictability for users	• Risk of new peaks outside the expected peak periods	• Ensured by proper parametrisation of the model

Figure 6-2 Summary of evaluation, feasibility criteria

7 REFERENCES

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