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# INVESTIGATING THE ROLE OF FLEXIBLE ELECTRICAL APPLIANCES IN A DEMAND CHARGE GRID TARIFF SCENARIO - A NORWEGIAN CASE STUDY

Kasper Emil Thorvaldsen
SINTEF Energy AS – Norway
Kasper.thorvaldsen@sintef.no

Erlend Sandø Kiel
SINTEF Energy AS – Norway
erlend.kiel@sintef.no

Hanne Sæle
SINTEF Energy AS – Norway
hanne.saele@sintef.no

## *ABSTRACT*

*The Norwegian grid tariff structure has changed, going over to capacity-based solutions to better reflect the actual grid-capacity used by the end-users. With monthly demand charge putting a price on highest peak-consumption, residential users need guidelines and tools on how they can influence their consumption pattern. With increased information on the consumption profile for different electrical appliances, they can shift their appliance activation to reduce peak consumption. This work looks at existing literature regarding electrical appliances and creates representative load profiles for these. These load profiles are used in a case study to see how load shifting on these appliances can be performed to reduce the demand charge grid tariff. By making use of the flexibility for several electrical appliances in terms of activation, the users can reduce their demand charge cost, leveling their consumption profile.*

## INTRODUCTION

Based on new regulations for Norwegian Distribution system operators (DSOs), a monthly demand charge grid tariff was launched to the residential users in Norway July 2022 [1]. The launched version is unique compared to existing single-hour demand charge grid tariffs, in that the cost is based on the average of the three highest single-hour peak consumption time periods, exclusively at different days during the month. The demand charge is divided into cost-steps, where the cost is based on which step your average three peaks lie within [2]. The motivation of the new tariff is to motivate end-users to flatten their consumption profile and avoid unnecessary peaks of electricity import, but also ensure that not just one single day of high consumption increases the grid tariff cost. As such, the grid tariff promotes increased awareness of end-users on their electricity consumption, especially to limit increases to a new cost-step.

In general, residential end-users have limited knowledge about their electricity consumption and how to react towards a capacity-based grid tariff. In Norway, smart meters metering the total electricity on an hourly basis were rolled out by 2019, and the increased information these meters provide have just within the recent years been easily available for end-users through their energy broker [3]. Thus, the time span where users can get a feeling and understanding of their consumption profile and what electrical appliances make up the profile is limited, at the same time as electricity typically has been considered as a "low interest" product [4].

There exist multiple electrical appliances within a home and household that influence the consumption profile [5]. Existing appliances include electric water heaters (EWHs), space heating (SH), dishwashers, washing machines, and in recent years also electric vehicles (EVs). Most of these appliances are operated by the user, but some of these are also passively present like SH. For the end-user to accurately make use of these appliances without a possible rebound-effect on grid tariff cost, they need more overview of how these appliances influence the consumption profile, and to what degree they can change this without negatively affecting their comfort.

In this paper, we look at existing literature regarding electrical consumption of several electrical appliances existing within a household. Example consumption profile of these electrical appliances will be generated. These profiles will be used for a Norwegian case study surrounding two households with real baseload, where we analyze how the appliances can be activated without provoking additional grid tariff costs.

## STATE-OF-THE-ART

Within the energy system of a household, several electrical appliances make up the resulting consumption profile. Common electrical appliances are described in this section and referred to existing work.

### Electric vehicles (EV)

An EV consumes electricity based on the driving pattern and user-behavior and needs to be charged to have sufficient driving distance for the planned trip. User-behavior like driving distance and charging availability, and technical specifications on the charging station at the home, all play a role when charging an EV [6]. The EV is normally plugged in and available for charging between 5 PM and 7 AM [7].

Demographic groups and their typical travelling period were categorized in [8], finding that most groups would travel between 7 AM and 5 PM. The most frequent daily travel distance was between 0-60 km [8]. Based on a survey conducted in [6], the mean driving distance per trip was at about 15.6 km. The expected energy consumption during a trip is related to the conditions during driving, and the type of EV. The energy broker Tibber did a comparison of different EV models and their consumption based on distance [9]. The largest variation was between 0.16-0.24 kWh/km, depending on the size of the EV, supported by the values shown in [10]. By these numbers, a 60 km trip could consume between 9.6-14.4 kWh, giving the basis for daily energy demand.

When charging an EV, the power consumption is set by the charger, and the duration is based on needed energy. From [11], the consumption profile for an EV is primarily influenced by these factors. EV chargers like Easee can offer dynamic charger capacity from 1.4-22 kW, depending on the main fuse [12]. Assuming daily charge of the EV, the energy quantity would be based on the daily travelling distance. The charging capacity is thus more set by the hours available for charging and could be tuned based on optimal timing for charging.

## Electric water heaters (EWH)

EWHs act as storage medium for hot water, providing hot water to the end-users for consumption like tap water or showers. Hot water is provided through an electrical heating element, that is turned on or off based on temperature settings and boundaries [13]. Due to storage potential, the electrical consumption can be irregular. During water-intense activities, like showering, the temperature loss is assumed substantial enough to activate the heating element. As such, showering would provoke electrical consumption from the EWH. The power consumption of the EWH is limited by their rated capacity. The Norwegian EWH provider OSO sells most EWHs with rated capacity between 2-3 kW [14].

Electrical energy for covering heat losses during showering is affected by duration, number of showers taken, water flow and temperature, and so on. Work in [15] looked at shower-related use for different households, and the impact of lowering shower duration down to 4 minutes. By analyzing change in energy use in kWh, showering consumes around 0.16-0.26 kWh/minute. Another work used energy consumption for showering at 2.1 kWh/5 minutes, or 0.42 kWh/minute [16]. Therefore, shower duration is heavily influencing the electrical demand to reheat the water in the EWH.

## Washing machines and clothes dryer

Washing machines have different electrical consumption based on the washing program being initiated, mostly related to heating water. [17] finds that the expected consumption per wash cycle in Norway is at about 1.04 kWh. In [18], several washing machines, programs etc. were tested and measured. There, 40$°C$ programs consumed about 0.6-0.8 kWh, and 0.6-1 kWh for 60$°C$.

A clothes dryer would use hot air to dry clothes, and therefore would have noticeable consumption related to heating the air. [19] includes a power consumption overview, with relatively constant load for each hour. The hourly energy consumption was at around 1.5-2 kWh/h.

## Space heating (SH)

SH is associated with heating the house to keep a stable and comfortable indoor temperature. This could include cooling, but this analysis only considers heating. During colder days, there is a need to supply heating to keep the indoor temperature appropriate. Suitable indoor temperatures for different rooms in an apartment was investigated in [20], where the average living room temperature was between 22-24.5$°C$. Work in [21] looked at outdoor temperature thresholds for when SH would be needed for each European country, finding the threshold for electric heating at 11.53$°C$ for Norway.

To find the thermal demand for heating purposes, several techniques can be applied to model the thermal system. Using linear state space models, the thermal system can be represented as an electrical network [22], but requires more knowledge on how the unique area responds to thermal inertia and losses. Another approach is using a regression model for heat load, based on indoor temperature and daily average outdoor temperature [23]. Having weighed parameters for each hour of the day, the daily variation in thermal demand is captured.

## Load profiles for electrical appliances

It is possible to make representative load profiles for the electrical appliances based on the performed literature study. This will serve as a basis for how these appliances will be used in the following case study.

The EV load demand is determined by the charging need for future travels. We assume that the charging demand covers each day of travelling. With a daily travel distance of 60 km, and average consumption of 0.20 kWh/km, the daily energy demand would be at 12 kWh. With a 90% charging efficiency, a 2.3 kW charger would take 6 hours to cover the demand, and 4 hours for a 3.7 kW charger.

The load profile for showering is related to the EWH rated capacity and the duration of the shower. Assuming a 2 kW EWH, and a shower consumption of 0.25 kWh/min, a 10-minute shower would take 2 hours to heat up the EWH, having full 2 kWh demand the first hour.

A washing machine based on the work in [18] could consume between 0.6-1 kWh per wash. Assuming a wash period of 1 hour, the consumption profile would be at 1 kWh for this hour. Drying is mostly associated with a washing period, with a consumption rate of around 2 kWh/h over two hours [19]. Therefore, a washing cycle with drying would be at 3 hours, with 1 kWh/h the first hour, and 2 kWh/h for the next 2 hours.

The load profile of SH is determined by the heating strategy of the end-user. By pre-heating or altering the indoor temperature, the demand can be shifted. For this case, we assume a strategy to keep the indoor temperature at 22$°C$. Using the estimations by [23] for an apartment building, with average outdoor temperature at -15$°C$, the daily heating demand is at around 30 kWh, with average hourly demand at 1.2 kWh/h.

# CASE STUDY

The load profiles for electrical appliances have been applied to a case study surrounding Norwegian households. We assume the households to have some baseload, and specific loads from the electrical appliances, explained beforehand, that can be shifted during the day. The baseload is from actual anonymized household hourly smart meter load data supplied by the Norwegian DSO, Lede [2]. To gather a baseload that is stripped of most thermal demand and other kind of electrical appliances, consumption for a small household for a day in August has been used. The average hourly consumption for this baseload lies around 0.4 kWh. The analysis period is for 24 hours, with hourly resolution.

The households investigated are split into two; one apartment assuming few residents, and a larger single-family house (SFH). Each of these households have different electrical appliances and overall electrical demand. Table 1 showcases the parameters that apply for these household types. The SFH has higher overall consumption, with double SH demand and double baseload compared to the apartment. Additionally, the multiple washes and showers are sequentially activated.

*Table 1: Specifications of electrical appliances for two households*

| Parameter\House | Apartment | SFH |
|---|---|---|
| Number of EVs | 1 | 2 |
| EV energy demand | 12 kWh | 12 kWh |
| EV charger capacity | 2.3 kW | 3.7 kW |
| Number of washing cycles | 1 | 2 |
| Number of showers | Morning: 1<br>Evening: 1 | Morning: 1<br>Evening: 2 |
| Daily SH demand | 30 kWh | 60 kWh |

## Case runs

This analysis will investigate how the electrical appliances can be shifted to avoid high peak-consumption for both the apartment and SFH case. To provide a reference case as to how shifting the electrical appliances provide value, two different strategies are derived: a passive and active way of shifting appliances. The passive strategy activates all evening appliances at 5 PM, when returning home. For the active strategy, the appliances are shiftable anywhere between 5-10 PM, except for the EVs which are shiftable from 5 PM to 7 AM. The morning shower is shiftable between 6-8 AM. When an electrical appliance is turned on, it must remain on until it has completed its purpose, so the only flexibility here is load shifting. Heating demand is covered for each hour, acting as part of the baseload.

The demand charge peak consumption steps in the grid tariff involved here are derived from [2]. 0-5, 5-10, 10-15 and 15-20 kWh/h are the ones both households could operate within for this analysis. Since only a single day is analyzed here, this alone would not cause a cost increase in the grid tariff. However, by assuming the trend to be kept, this would be the expected demand charge step.

# RESULTS

## Apartment building

The performance of the apartment building under a passive strategy is presented in Figure 1. Since all electrical appliances for the evening are activated at 5 PM, the high consumption pushes the highest peak during the day up to the 5-10 kW demand charge step. The highest peak consumption is at around 6.5-7 kWh/h. Given that the overall consumption profile is high in the evening, and flat elsewhere, it is apparent that the strategy is not making use of the room and flexibility to spread out the timing of the electrical appliances.

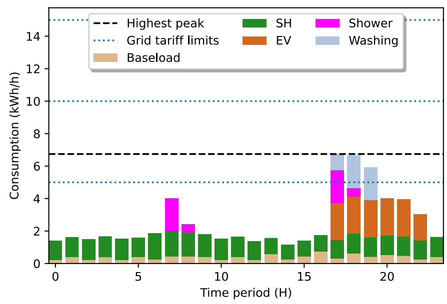


*Figure 1: Electricity consumption for apartment with a passive strategy*

The layout of the electrical appliances changes for the active strategy, shown in Figure 2. The electrical appliances are shifted to make use of the whole period. Since electrical appliances like showering and washing are limited during the evening, they are prioritized, letting the EV charge during the night. This causes the highest peak to be at 4 kWh/h, having reasonable buffer within the 0-5 kWh/h demand charge step.

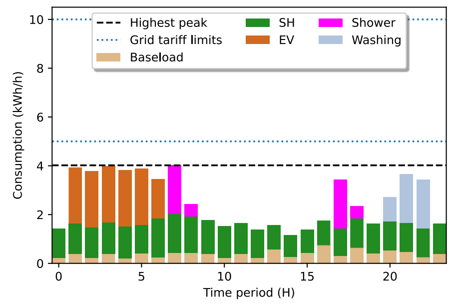


*Figure 2: Electricity consumption for apartment with an active strategy*

Within Figure 2, some distinct observations can be made. Firstly, the consumption profiles for showering and washing are quite similar in peak consumption. Therefore, it is not important which of those appliances would be turned on first or when they are on during the evening, as long as they are not turned on simultaneously. If they were activated together, this would likely push the consumption above the demand charge step.

Secondly, the EV charger makes use of the flexibility to charge during the night when other appliances cannot be active. This unique period gives room for the EV, but also ensures that the end-user can prioritize other appliances during the evening, as there are still hours during the evening where other appliances could have been activated. However, had the charger been rated at 3.7 kW, the consumption profile would be above 5 kWh/h during the night. By keeping it at 2.3 kW, the

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charging period is prolonged, but there is enough time. Therefore, the charging capacity plays an important role despite a standalone activation period.

## Single family house

Figure 3 showcases the performance for the SFH under the passive strategy, reaching a peak consumption level narrowly over 15 kWh/h. The baseload with SH have consumption up to 4 kWh/h, so the electrical appliances make up a high consumption profile during the evening. An apparent cause for this stem from the two EVs, totaling to 7.4 kW power output simultaneously.

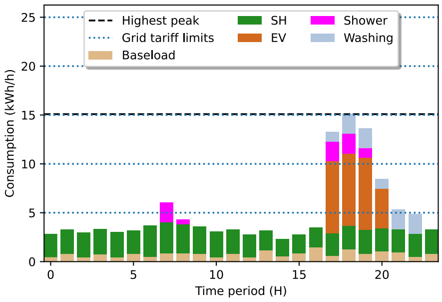


*Figure 3: Electricity consumption for SFH with a passive strategy*

Figure 4 presents the result of the active SFH strategy, where the distribution of the electrical appliances decreases peak consumption significantly. Ending at around 7-7.5 kWh/h, the strategic shifting of appliances enable the SFH to drop down two demand charge steps from the passive strategy. The EVs are shifted towards the night and charged sequentially. During the evening, the washing machine is activated for the whole duration, as two sequentially cycles are planned. With less room to shift the washing machine, the shower is activated alongside the washing machine. However, this does not cause any change in the demand charge step, since each electrical appliance individually pushes the load into the 5-10 kWh/h step, but none pushes it further.

An important observation is that the electrical appliances are evenly distributed over the whole evening and night, keeping a stable electricity consumption between 5-7.5 kWh for each hour. They never once reach up to the 10 kWh/h limit for this demand charge step. Since the baseload with space heating is at about 4 kWh, there is a room for up to 6 kWh/h consumption for the electrical appliances. Since the washing machine and shower consume individually around 2 kWh/h, both can be activated simultaneously, without the risk of increasing the peak charge. The EV charging benefits from the 3.7 kW charger, being able to charge both EVs during the night sequentially. 2.3 kW chargers could have been used without increasing the demand charge level, but this would result in the EVs charging simultaneously at some point. Therefore, the SFH has much room for using electrical appliances at the same time.

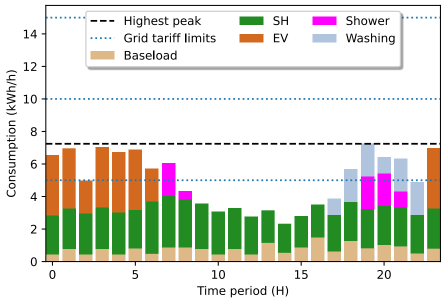


*Figure 4: Electricity consumption for SFH with an active strategy*

## Comparison of households

Comparing the apartment building and the SFH, one can see that both benefit from more strategic use of the electrical appliances. By load shifting, the peaks are kept under control, and both cases reduce their demand charge step. For the apartment building, the room for load shifting is narrower than for the SFH. With a baseload at around 2 kWh, the timing of the electrical appliances is more important than for the SFH. To stay within the 0-5 kWh/h step, the electrical appliances should be activated standalone, since multiple appliances could push the overall consumption too high. Additionally, the EV charger should be set at a level around the same as the other electrical appliances. Changing the EV charger from 2.3 to 3.7 kW for the apartment building would alone be enough to push the consumption above 5 kWh. Since there is only one EV being charged, it is better to slow charge at lower capacity longer, than rapidly charge.

For the SFH, there is more leeway for electrical appliances than for the apartment building. The baseload pushes it into the 5-10 kWh/h when any electrical appliance is activated. Therefore, multiple appliances can be activated simultaneously without provoking a demand charge step increase. At least two appliances can be activated together in this specific case. For the EVs, the 3.7 kW charger capacity enables them to charge during the night sequentially without charging together.

This analysis showcases that shifting the electrical appliances can keep the peak consumption low. The demand charge step to aim for is influenced by the baseload, and with increasing demand charge step, more electrical appliances can be used simultaneously. More care into what and when electrical appliances are activated is essential if aiming for the lowest charge. This is also coupled to what user behavior and time schedule the residents have, and their understanding of their baseload consumption. By having simple rules as to what step to aim for, like explained here, it should be possible to keep consumption at their desired demand charge step.

# CONCLUSION

Residential end-users will need to understand their electricity consumption in the future to be able to react to monthly demand charge grid tariffs. By having knowledge about their electrical appliances and how they influence the load profile, they can shift their consumption to mitigate the demand charge cost. This work has looked at the characteristics of several electrical appliances in households, their consumption profile, and put them into a case study covering two different households. The case study showed that by being strategic on shifting the activation of electrical appliances, the demand charge cost can be reduced. For smaller apartments aiming for the lower demand charge cost step, limiting simultaneous activation of appliances would enable this. For larger houses with higher expected demand charge cost step, there is a possibility to increase this to multiple appliances at the same time.

The study has found that there are benefits by being aware of their electrical appliances. This can have a positive effect on the demand charge cost if it leads to a planning of the timing of activation. This in turn can enable the end-users to make more effective use of their appliances to even out their consumption profile, which is the core idea surrounding the demand charge grid tariff.

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