Flexibility potential at Norwegian households – customer evaluations and system benefits

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***Abstract*—The peak load in electricity consumption is increasing among household customers, resulting in reduced utilization time of the distribution grid. Demand side flexibility can be a cost-efficient alternative to grid investments, but to achieve customers' involvement, knowledge about their willingness to change how they use electricity is important. Two surveys have been performed (in 2017 and 2020) to map the potential for flexible demand among Norwegian household customers. The surveys show that independent of cost savings, 61% are willing to accept remote load control of their electric water heater, as long as this do not affect their comfort (not cold water), and 7 out of 10 are willing to manually shift electrical appliances (washing machines, dishwashers, clothes dryers, …) in a period with limited grid capacity. 56-63% will accept remote load control and 63-64% will contribute with manual response if they save 200 Euros/year.**

***Index Terms*-- Demand Response, Electricity Energy Efficiency, Flexibility, Households**

I. INTRODUCTION

The amount of distributed generation from renewable energy sources (solar and wind) has increased in the power system – even on a customer level (households with solar panels on their roof). Due to new and more energy efficient appliances, the trend in the electricity consumption is a peak load increasing more than the energy consumption, resulting in reduced utilization time for the distribution grid. It is not a cost-efficient solution to increase the grid capacity to handle the increasing peak load and the new technology, and flexibility (demand response) has been evaluated as a cost-efficient alternative to grid investments, but to be able to realize the flexibility potential among the customers it is important to have the customers on board. Mapping the customers' willingness to be flexibility and change how they use electricity, is first step towards involving the customers, and this paper will give input to that.

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II. BACKGROUND

This section presents the background of this paper, related to introduction to demand side flexibility and the research project where this research has been performed.

A. Demand side flexibility

With demand response (DR) and demand side flexibility customers get the possibility to play a role in the operation of the power system. In [1] FERC has defined demand response as *changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.*

Demand side flexibility enables customers to become active in the market, and also to provide services to system operators, contributing to a more efficient grid operation [2]. The customer response can be either implicit or explicit. With *implicit response*, the customer reacts to a price signals (for example market price or a grid tariff), and with *explicit response* the response is dispatchable flexibility that can be traded on the different energy markets, such as whole sale, balancing, system support and reserve markets [3].

B. Research project

This paper presents results from two surveys performed within the research project "Modelling flexible resources in smart distribution grid - ModFlex" (2016-2020). The objective of the project is to develop dynamic models representing the consumption and production profiles for different flexible resources in the smart distribution grid, and address how such resources can be utilized to increase the flexibility in the grid – without introducing new peak load hours due to the rebound effect.

The surveys have been performed among a representative group of Norwegian with approximately 1000 respondents. The main objective of the surveys was to map the potential for

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demand side flexibility on household level – both implicit and explicit flexibility. The first survey was performed in 2017 with 1007 respondents, and a follow-up survey was performed in spring 2020, with 1006 respondents. Even if the surveys were performed among a representative group of Norwegian households, it was not the exact same respondents. The target group was households, age 25 years and older. This age level was set because the survey aimed for people that had experiences with receiving electricity bills and handle energy contracts. One challenge with this age limit, is that younger people that probably are more engaged in environmental issues (also including the willingness for demand flexibility) are left out.

This paper presents the results from the surveys, mapping the potential for demand side flexibility and the customers' willingness to change how they use electricity. The survey results are evaluated in the context of the Norwegian power system, to indicate the potential for demand side flexibility – both implicit and explicit.

III. Method

In the surveys the customers were asked about their willingness to reduce their consumption in peak load periods and to allow remote load control of specific appliances in their house (especially the water heater, which due to thermal capacity can be disconnected for a limited number of hours without any negative consequences for the customers). The surveys also wanted to map the trends in flexibility potential among residential customers and estimate how household customers valuate their contribution to flexibility (loss of comfort.

The surveys were web-based, and the questions had several predefined answers that the customers should choose between.

Survey-based methods such as stated preference methods (including contingent valuation and choice modelling) were used to estimate values non-market goods. This was used in the surveys to estimate the value the customers put on changing how they use electricity. With this approach the customers report their willingness to pay (WTP) for a specific good or their willingness to accept (WTA) to give up a good [4].

To map the potential for implicit and explicit flexibility, the customers were asked to evaluate different alternatives for demand side flexibility. The different alternatives should first be evaluated independent of any cost reductions, and then the customers were asked about their expected cost reductions (Euros/year) to contribute with different services.

Related to *explicit flexibility*, the customers were asked about their willingness for remote load control of specific electrical appliances. The results of this question give an indication if the respondents want to respond to an incentive by letting another party take control of their consumption.

Related to *implicit flexibility*, the customers were asked about their willingness for manually changing their electricity consumption. The results of this question give an indication if the respondents want to respond to an incentive, but still be in control.

The customers were also asked about their willingness to share the electricity with others in periods with limited grid capacity available. This was included in the survey, because an equal situation occurred in the northern part of the Norwegian power system in 2015 [5].

IV. Results

This section presents the results from the surveys performed, focusing on the electricity consumption of the households, electricity and economy, chargeable cars and flexibility in electricity consumption on special days.

A. Electricity consumption

Both surveys started with asking the households about their total yearly electricity consumption. The results are presented in Fig. 1. The columns represent the values from 2017, and the dots represent the values from 2020. The figure shows that for 3 out of 10 households (32%) the yearly electricity consumption is 10,001-20,000 kWh per year. This is on the same level as for the average electricity consumption of a Norwegian households, which according to official statistics in Norway use 16.000 kWh/year [6]. 16% of the households use 5,001-10,000 kWh/year and 18% uses 20,001-30,000 kWh/year. 28% did not know their yearly electricity consumption. In 2020 the category '10,001-20,000 kWh/year' was also largest, with the same value as in 2017.

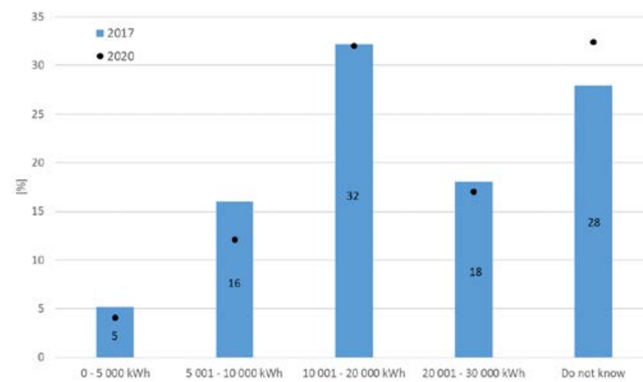

Figure 1 Yearly electricity consumption. Based on results from surveys in 2017 and 2020.

Since the objective of the survey was to map the potential for flexibility in electricity consumption among Norwegian household customers, the customers were asked on a general basis, if they could consider changing how they use electricity. The results are presented in Fig. 2. The columns represent the values from 2017, and the dots represent the values from 2020. The figure shows that in total 57% could consider changing how they use electricity ('Yes,definitely' and 'Yes, probably'), while 36% do not want to do this ('Probably not' and 'Definitely not'). 7% did not know if they would change their consumption. The values from 2020 are in line with the values from 2017. This result can indicate that approximately 3 out of 5 households possible could change their consumption pattern related to use of electricity.

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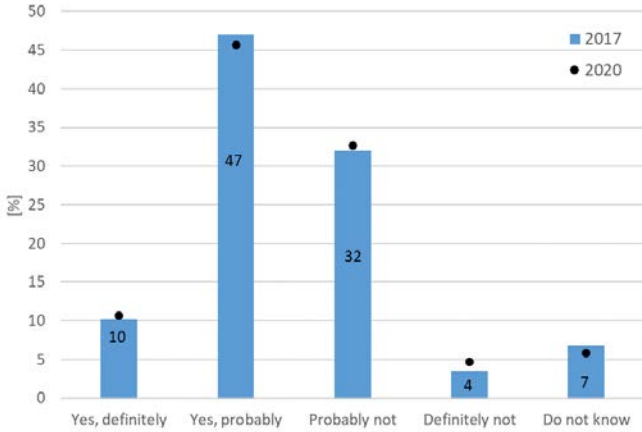

Figure 2 In general, could you consider changing how you use electricity? Based on results from surveys in 2017 and 2020.

This question was followed up by asking the respondents to evaluate different arguments for why they should change their consumption. The results from 2020 are presented in brackets. For 54.3% (66.4%) of the respondents, private economy was the main reason to change their consumption. 32.8% (17.2 %) would accept remote load control of their electricity consumption if their comfort were not affected, and 27.8% (34.2%) would change their consumption if they got information about environmental benefits related to this change. 10.6% (9.0%) said that they would not change their consumption.

Demand response can be achieved through changed habits for the households and/or by automatic control of appliances. Among the respondents in the first survey 71.5% (69.5%) did not have the possibility for automatic control of their electricity consumption, 12% (15.3%) had installed systems for controlling indoor temperature, 9.9% (13.0%) could turn appliances on/off and 0.9% (1.5%) had smart house. This shows that at present a limited potential for demand response as a result of automatic control, since 7 out of 10 do not have installed any technology for load control.

B. *Electricity and economy*

In the survey the households were informed that the electricity delivered to the electric water heater (EWH) could be disconnected for a limited number of hours (2-4 hours) without reducing the comfort for the customer. This is due to the thermal capacity of the water heater.

The survey included questions mapping the customers' willingness to accept (WTA) remote load control of their water heater for 2-4 hours in peak load period (no cold water), and to manually change how they use some electrical appliances (washing machine, dishwasher, clothes dryer etc.).

For each question, the respondents were divided into three groups of equal size, where each group was asked whether they wanted to save 50, 100 or 200 EUR/year. In total the results give an overview of what the households expect to save before they will accept any alternative of demand response. The results related to demand response via remote control, are presented in Fig. 3 and the results related to manual control of electrical appliances, are presented in Fig. 4. In each figure the unbroken line is showing the results from 2017, and the dotted line is showing result from 2020.

The share of customers willing to participate is increasing with increasing costs savings per year. The results are consistence with the Law of demand, where other factors being constant, price and quantity demand of any good and service are inversely related to each other [7]. This means that the willingness to pay is negatively correlated with costs – i.e. when the price of a product increases, the demand for the same product will fall. Equally, increased cost savings will contribute to increased interest for the service. The share is reduced with increased potential for cost savings for the customers answering 'No' or 'Do not know' on these two questions.

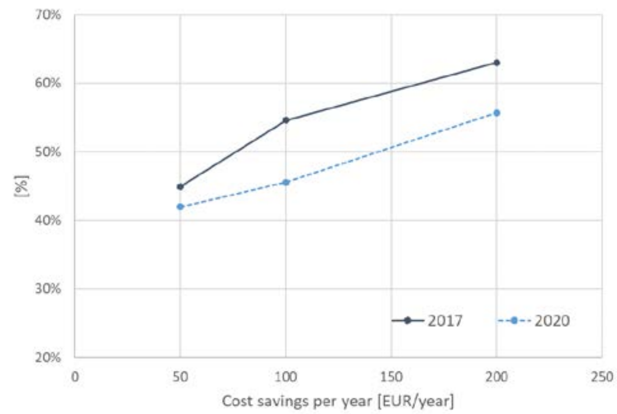

Figure 3 Customers' willingness to contribute with demand response via remote control, at different levels of savings (50 Euro / 100 Euro / 200 Euro)

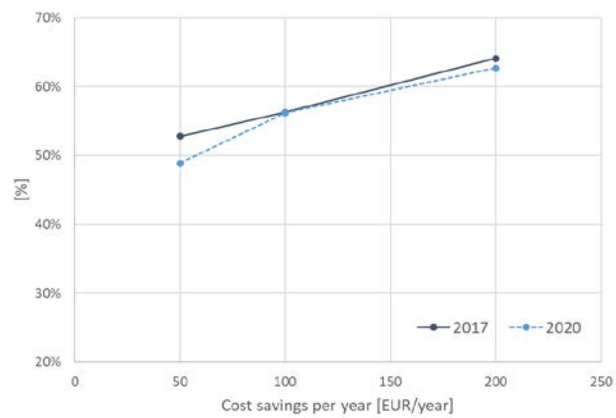

Figure 4 Customers' willingness to contribute with demand response via manually changes, at different levels of savings (50 Euro / 100 Euro / 200 Euro)

In general, the customers are more positive to manual control than remote control, meaning that the willingness is higher if the customers are in control (even if this means increased manual effort). The share of positive customers is increasing with increasing cost savings. For remote load the share of customers willing to participate was larger in 2017, compared to 2020. At a saving of 200 Euro/year 63% wanted to participate in 2017, but the result in 2020 was only 56%.

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For manual control of electrical appliances, the results from 2017 and 2020 are quite similar, increasing from 53% (49% in 2020) to 64% (63%) with the savings from 50 Euro/year to 200 Euro/year.

C. Chargeable car

The number of chargeable cars is large in Norway – both for electrical vehicles (EV) and plug-in hybrid cars (PHEV). Based on the public statistics for Norway out of 2,801,208 private cars in 2019 [8], there are 260,688 private EVs (%) and 115,178 PHEV [9]. When the survey was performed in 2017, 8.0 % had one or more EVs and 3.8% of the respondents had one or more PHEVs (in total: 110). The share of respondents with chargeable car had increased in the second survey (2020), where 14.1% of the respondents had one or more EVs, and 5.4% had one or more PHEV (291 in total). Characteristics related to use and charging of EVs and PHEVs, based on the surveys, are presented in Table I.

TABLE I. CHARACTERISTICS RELATED TO USE AND CHARGING OF EVS AND PHEVS

Characteristics	2017 [%]	2020 [%]
Daily driving distance 11 km or more	72.2	79.0
Home charging - single family house/row house	66.4	74.2
Home charging – housing cooperatives	12.7	11.7
Daily charging	60.0	57.2
Weekly charging	28.2	39.8

The table shows that that in addition to increased share of chargeable cars among the respondents, there is also an increase in the use of the cars, meaning that a larger share of the respondents are using the cars for longer distances. In total there are also a larger share of the respondents charging their car at home – increasing from 79.1% in 2017 to 85.9% in 2020. There is a shift in how often the cars are charging, reducing the share of daily charging from 60.0% to 57.2%, and increasing the share of weekly charging from 28.2% to 39.8%. This is typically related to technology improvement of the cars, with improved battery capacity.

D. Flexibility in electricity consumption on special days

If demand response should be evaluated as an available source in grid operation, it is important that the flexibility also is available in peak load periods, when the electricity consumption is close to available grid capacity. For the Norwegian power system this situation usually occurs on cold winter days.

Based on this, the customers were asked if they, on a cold winter day when the total electricity consumption is close to what the system can handle, would contribute with one of the following measures: 1) Delay the start of some electrical appliances.(washing machine, dishwasher etc.) and use the appliances at a later time, 2) Accept remote control of water heater (no cold water) and, 3) Share electricity with others, by manually reducing your own consumption. The results are presented in Table II.

TABLE II. MEASURES CONTRIBUTING WITH FLEXIBLE CONSUMPTION ON SPECIAL DAYS (COLD WINTER DAYS)

	Measures	Yes	No	Do not know
1	Manually delay start of el.app.	73.8	13.4	12.8
2	Remote control of EWH	61.0	22.8	16.2
3	Share electricity (manually response)	49.4	21.4	29.2

Table II. shows that the share of positive response are reduced from the three suggested measures. A large share (73.8%) is positive to reduce their consumption as long as they are in control (manually change the use of electrical appliances), and a lower share (61.0%) is positive if someone else is controlling their consumption (remote control). An even smaller share (49.4%) is positive if they should manually reduce their consumption and share the electricity (and grid capacity) with others.

The follow-up question was related to the customers' willingness to change their electricity consumption on holidays, with the Christmas Eve as an example. The customers were asked if they would accept remote control of EWH (and other thermal loads for space heating), without reduced comfort, for a shorter period on Christmas Eve. The remote control would not affect the use of other electrical appliances. The results are presented in Fig. 5.

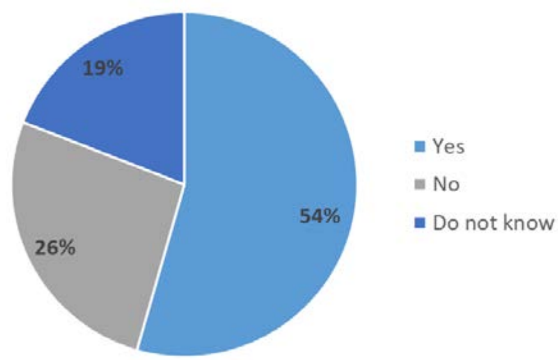

Figure 5 Potential for demand response on holidays (Christmas Eve)

The results show that more than half of the customers (54%) would accept remote control, 26% answers 'No' and 19% answers 'Do not know'. This is a lower share of positive response compared to remote load control on cold winter days (61.0%, line 2 in Table II).

V. DISCUSSION AND CONCLUSIONS

With demand side flexibility the customers can play an important role in the future power system, where flexibility can be a cost-efficient alternative to grid investments.

This paper presents the results from two surveys performed in 2017 and 2020 among a representative group of Norwegian households. The objective of both surveys was to map the potential for demand side flexibility and the customers' willingness to change how they use electricity, and evaluate this further in the context of the Norwegian power

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system, to indicate the potential for demand side flexibility – both implicit (manually, with the customer in control) and explicit (remote load control).

Implicit and explicit flexibility can be used for different purposes in the power system. Explicit flexibility can be used for purposes where the system operators have to rely on the flexibility, and implicit flexibility is general demand response based on a price incentives (for example a capacity based grid tariff).

In the Norwegian power system, it is estimated that grid investments costs will be approximately 13,5 billion Euros in the period 2018-2027 [10]. 27% of these investments are related to increased consumption. In the distribution grid the estimated investments are 5 billion Euros, where 54% are due to increased consumption (37% in new grids and 17% in reinvestments). Introducing demand side flexibility can contribute to a reduction in the expected investments.

In [11] it was estimated that remote load control of EWH would contribute to a reduction of 600 Wh/h per household in the hour 9, which also is the peak hour in the Nordic power system. With 2.5 mill households in Norway today (2020), and using the results from this survey, with 61.0% willing to contribute with remote load control of EWH (explicit response), the potential for demand side flexibility from remote load control of EWH will be 915 MW.

In 2018 the Norwegian Transmission System Operator performed a pilot project for fast frequency reserves, where different flexible resources (generation and consumption) participated [12]. The flexible resources should respond within 2 seconds, and the response duration should be at least 30 seconds. In this pilot a power retailer's portfolio of controllable EVs was included, and in a pre-qualification test it was verified that an aggregated response for a limited number of cars could be achieved within 2 seconds, but from a group of 80-90 cars the response was achieved from 1/3 of the cars. Further technology development related to control technologies would increase the potential for response. Based on the surveys described in this paper, there is a potential with EVs for demand side flexibility due to the frequently occurrence of home charging.

In Norway full scale deployment of smart meters was completed January 2019, and all customers have hourly metering of their electricity consumption. This technology is an enabler for hourly price signal to customers. Today, there is a discussion related to new distribution grid tariffs, where capacity-based grid tariffs are evaluated. The tariff model is not decided, but the objective is among other things to give customers an incentive to pay according to grid capacity they use, and also give them incentives to reduce their peak load. Based on the surveys a large share of the households (73.8% in 2017) are willing to manually reduce their consumption (implicit response), but 53% want to save 50 Euros/year or more to do these changes.

Based on the surveys performed, this paper has shown that there is a potential for demand side flexibility among household customers, both for implicit and explicit flexibility. To realise this, it is important with technology for remote control and information to the customer, and also to develop business models for stakeholders involved. The Distribution System Operator (DSO) can achieve implicit response via the planned capacity-based distribution grid tariff, but also explicit response via agreement for remote control. The response per household customer is limited, but the aggregated response including several resources from several customers can be an important resource to the power system.

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