Prototype for estimation and forecasting of the future demand and generation from households in selected European countries

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***Abstract*—New smart grid technologies, such as solar panels and electric vehicles, are increasing in popularity, but there is uncertain how this will affect the load profile for households, and how the Distribution System Operators should incorporate these changes in their grid planning. In this paper, a prototype for estimation and forecasting of the electricity demand (active power) for households is presented. The tool uses hourly data for load, temperature and irradiation as input to create a 24-hour load profile based on season and day type, as seen from the connection point to the grid. It is possible to add a solar panel, charging of electric vehicles or demand response, to see how these smart grid technologies may alter the profile. The tool is, in addition to Norwegian data, further tested on data from Germany and the UK. The results show the calculated profiles for households with solar panels in Norway, Germany and the UK, in both winter and summer time. Further, it becomes obvious that charging of electric vehicles has a profound impact on the load profile of a household.**

Keywords—Smart Grids, photovoltaic, prosumers, load, distributed generation, Renewable energy sources

I. INTRODUCTION

There is an increasing interest in smart grid technology for household customers, such as roof-mounted solar panels, electrical vehicle (EV) charging and demand response. The paper presents a prototype developed for the estimation and forecasting of the demand and generation from households, based on hourly smart meter data from existing customers. The prototype also enables calculation of an updated profile for households that have invested in one of these new technologies. This methodology can improve today's practices related to planning and operation of the distribution grid, and information about how the increased number of prosumers (households with solar panels) might affect the distribution grid.

A. Energy and climate goals in EU focus

A great share of Renewable Energy Sources (RES) will be integrated in existing energy distribution systems all over Europe to cope with the climate and energy targets of the European Union (EU). Therefore, the power system is changing from a centralized system with large power plants and one-way transmission of electricity to the customers, and into a system with multi-directional power flow, and distributed generation also installed at the customer level.

Within EU there is a large focus on the transition towards a low carbon economy, and the Renewable Energy Directive sets a binding target of 20% final energy consumption from renewable sources by 2020 [1]. Based on this each EU member has committed to reach their own national renewable targets, ranging from 10% in Malta to 49% in Sweden [1]. As part of the EU's energy and climate goals for 2030 the EU members have agreed upon a new renewable energy target of at least 27% final energy consumption from renewable sources [2]. Additional targets for 2030 are a 40% cut in greenhouse gas emission compared to 1990 levels and at least 27% energy savings compared with the business as usual scenario.

B. Energy structure in Norway, Germany and UK

In this section the energy generation and consumption for the countries in question (Norway, Germany and UK) are presented, focusing on energy sources used for producing electricity and on household customers.

1) Norway

In Norway nearly all electricity is produced with use of hydro plants, most of them with large reservoirs. At the end of 2016 the hydro installed generation capacity was 31,500 MW [3], and approx. 96% of the produced electric energy was from hydro plants.

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For households' energy consumption electricity is the main source for both space heating and heating of tap water, resulting in an average electricity consumption for a household of 16,000 kWh per year [4]. Other energy sources such as wood-firing is also in use. Systems for district heating are only available to some extent in the largest cities.

In total there are approx. 5.2m people living in Norway, and 2.4m private households [4]. Smart meters will be deployed by 1st January 2019 to all customers connected to the grid – in total 2.9m meters [5]. According to the requirements these new meters should be able to meter both consumption and generation on an hourly basis [6].

2) Germany

In Germany, RES already have a significant share in the installed generation capacity. Fig. 1 shows the distribution among technologies in 2016.

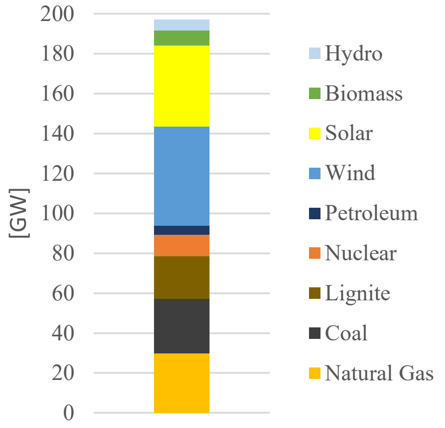

Fig. 1. Installed capacity [GW] in Germany 2016 [7]

The greatest share of the produced energy is based on wind and photovoltaic (PV). This is shown in Fig. 2.

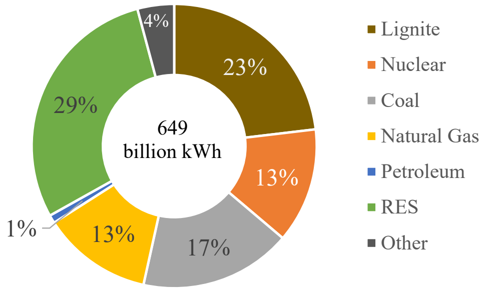

Fig. 2. Generation of electrical energy in Germany 2016 [8]

In total as of 2016 there are 40.96m domestic households [9] with an average energy consumption of approx. 3,000 kWh [10]. The amount varies with the use of electrical heating (mainly storage heating) as well as electric water heating.

Smart meters have to be deployed for the following cases: Since 2017 for domestic households with a consumption above 10,000 kWh as well as prosumers (customers who are both consuming and generating electricity) with decentralised energy resources installed with a rated power above 7 kW. Starting in 2020 also households with a consumption above 6,000 kWh must be equipped with smart meters. In the remaining cases the deployment is optional. However, the deployment will not start until there are at least three certified smart meters available on the market, which is expected to happen during 2018 [11].

3) United Kingdom (UK)

The UK has a total annual electricity demand (2016) of 304 TWh, met by an installed generation capacity of 78.3 GW. Electricity demand is met by a mixed portfolio of sources, with 5% met by interconnector imports. Omitting interconnector imports, the 2016 generation mix consisted of Gas (42%), Nuclear (21%), Coal (9%), and Renewables (28%) [12].

There are approximately 65.6m people living in the UK, in 27.8m domestic households. Domestic electricity consumption sits at 108 TWh, 35% of total electricity consumption [12]. The average electricity consumption in the domestic sector is 3,889 kWh. Space and water heating accounts for the majority of energy consumption, which is mostly provided by gas. Approximately 2/3 of electrical consumption is associated with lighting and appliances, with 1/3 associated with space heating, hot water, and cooking [13].

Smart meters will be deployed to all domestic and small commercial consumers by the end of 2020, led by electricity suppliers. Latest statistics show that 8.5m smart meters have been installed in domestic properties [14]. Smart meters will provide energy suppliers with half-hourly readings of electricity consumption. This information is not immediately available to Distribution System Operators (DSOs).

C. Development of prosumers – Norway, Germany and UK

1) Norway

The first regulations for prosumers were introduced in March 2010, when the Norwegian Regulator (NVE) approved a simplified system for all the DSOs to accept prosumers. This was not a mandatory arrangement before regulations were updated in January 2017 [15].

In the new regulations the Regulator defined the prosumers as: *A prosumer is a customer with both consumption and generation behind the connection point to the grid, where the electricity fed into the grid should not exceed 100 kW. A prosumer cannot have an installation subject to a concession behind the connection point, or a sale of electricity behind the connection point that require concession.*

According to the updated arrangements the grid tariff should not include more than an energy part for the electricity fed to the grid – independent of which DSO they are connected to, and the prosumers are responsible for finding a power retailer interesting in both buying the excess power from the prosumer and selling power to the prosumer when needed.

The development of installed PV capacity in Norway is presented in Fig. 3. Until 2013 the Norwegian market for PV panels was mainly characterised by isolated installations (off grid). The total installed capacity has increased during the last years, and at the end of 2016 there was 26.7 MWp installed in total. 11.4 MWp was installed in 2016, an increase of 366%

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compared to the volume installed in 2015. At the end of 2017 there were approx. 1,000 prosumers in Norway in total. For household customers the average PV panels are roof-mounted.

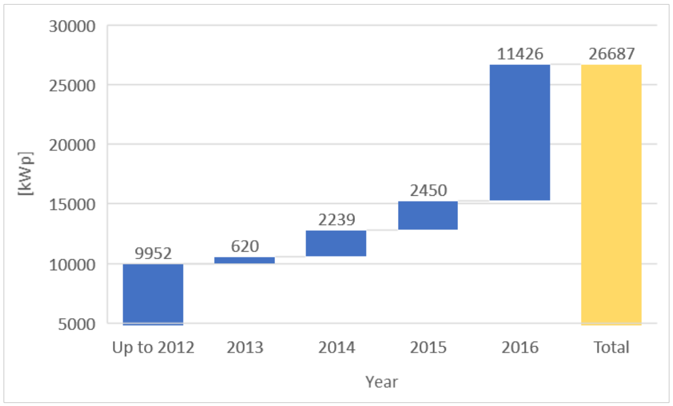

Fig. 3. Installed capacity of PV panels (Norway) [16]

2) *Germany*

In the early 2000s, the German Federal Government started a system of financial incentives to increase the share of RES in the German energy mix. There are different kinds of national directives active to promote RES. The system of financial incentives was adapted over the years as investment costs fell and include fixed Feed-In-Tariffs (FITs), direct marketing at the stock exchange with bonuses to cover extra costs, as well as public tenders. The resulting growth in PV installations is shown in Fig. 4.

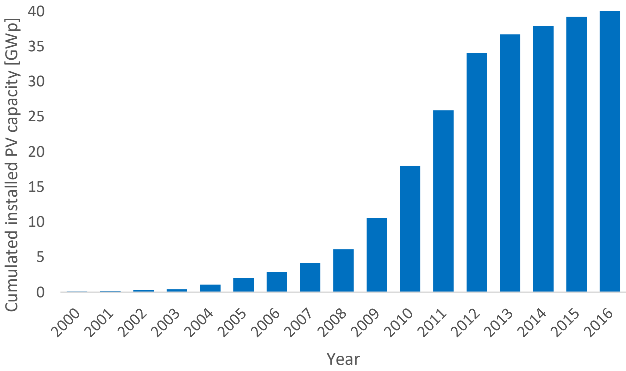

Fig. 4. Development of PV installations in Germany [17]

At the end of 2017 approximately 1.6m PV plants and panels are installed in Germany [18]. 73% of the installed capacity is roof-mounted, which amounts to 29.8 GWp [19]. The average installed power of PV panels in the group below 30 kWp is 10.1 kWp [20].

DSOs are obliged to connect RES to the grid if no other grid is economically or technically more suitable. They are required to do so with priority and without delay. The connection point in the grid must be suitable regarding the voltage level and in closest distance (beeline) to the generator [21].

3) *UK*

Domestic-level generation development, effectively creating domestic prosumers, was accelerated in the UK through the introduction of the FIT in 2010. FITs are awarded to generators smaller than 5 MW, offering fixed £/kWh rates that vary depending on the rated capacity and generation technology.

Between April 2010 and March 2018, approx. 2.5 GW of sub-10kW PV connected through the FIT scheme, across approx. 780,000 sites [22]. Following a revision to the FIT rates, reflecting the falling cost of PV panels, the installation rate of domestic PV fell from 2016 onwards.

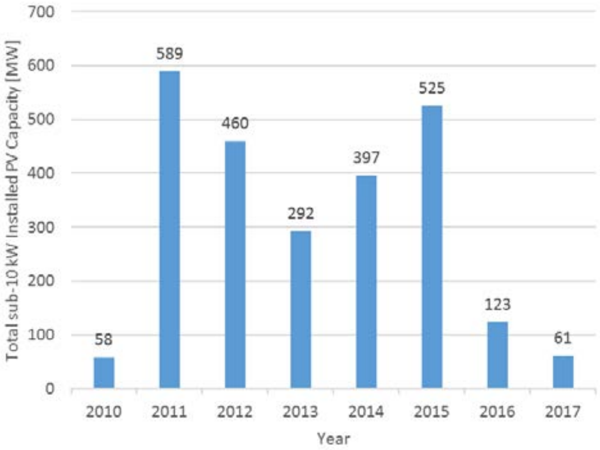

Fig. 5. Yearly growth in UK domestic (<10kW) PV installation [22]

D. *"SmartGuide" research project*

The SmartGuide project (ERA-Net SG+) focuses on the development of improved and generalised planning and operating guidelines for European smart grids, considering RES and the demand that arise from smart market applications (e.g. demand response, frequency control and reserves management).

The project is executed by various research institutes and DSOs from Germany (Bergische Universität Wuppertal), Portugal (INESC Porto), Norway (SINTEF Energy Research, Skagerak Nett) and Scotland (Smarter Grid Solutions).

The work is split into six Work Packages (WPs) that will lead to the global objective of the project of defining guidelines for future DSO planning and operation activities, supported by an adequate regulatory framework.

The WP3 "Advancing Smart Grid Planning Methods and Tools", is one of the focal WPs of the SmartGuide-project. The work starts with identifying today's practice related to network planning, as well as missing planning methods and tools for each country and their specific smart grid technologies, separately. Because of the different requirements for the planning process for grids with these technologies, there will be different tools developed by the different partners.

The prototype developed for Norway is based on today's methodology for grid planning with typical profiles for different customer types. To evaluate the prototype tool developed for Norwegian conditions, it has been tested based on data of active power from Germany and UK, and the results are presented in this paper.

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II. METHODOLOGY – STRUCTURE OF THE TOOL

The objective of the tool presented in this paper is to display a 24-hour load profile of a household as seen from the connection point to the distribution grid. This load profile is calculated based on hourly metering data given as input by the user. If metering data is not available, it is also possible to use general profiles based on meter data from several households, however, this is not discussed further in this paper.

The input data is listed below:

- Date and hour of data, defining time span
- Hourly temperature data for time span, $T_{series,h}$ [°C]
- Hourly load data for time span, $P_{input,h}$ [kWh/h]
- Hourly irradiation data for time span, G_h [W/m^2]

The typical load profiles are calculated for weekdays and weekends (day types), as well as summer and winter (seasons). Winter is here defined as the months from October to March, leaving the remaining months as summer.

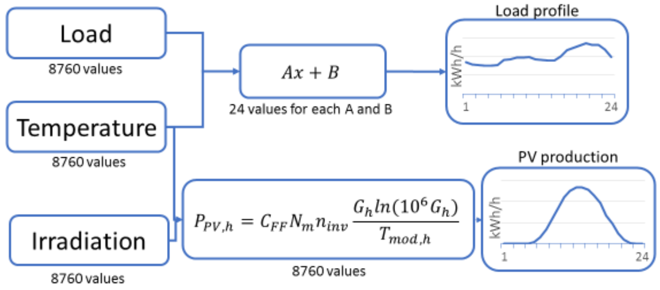

Fig. 6. Flowchart of calculation of load and PV production

Fig. 6 shows how the tool uses the input data to calculate the load and production profile from a solar panel. Linear regression is used on the hourly load and temperature data, to create four sets of dependent variables A (dependant on temperature), and four sets of constant variables B. There are four sets since there are two day types for two types of seasons. Each set has 24 values, one for each hour of the day. The user can specify a day temperature, season and day type, which gives a 24-hour load profile.

Hourly temperature and irradiation data is used as input to calculate the PV production from a given solar panel, from Eq. (3). These values are then averaged depending on season and hour, giving two sets of 24 values. Specifying the season will then give a 24-hour production profile as shown in the flowchart. The net load then equals the load profile subtracted by the PV production profile.

In addition to PV production, it is also possible to add an electrical vehicle (EV) charging profile and/or demand response.

For the load profile, the following variables are calculated from the linear regression on basis of the input data:

- A set of dependent variables, $A^{D,S}{}_h$
- A set of constant variables, $B^{D,S}{}_h$

where D = {Weekend, Weekday}, S = {Winter, Summer} and h = {1, …, 24}.

Further, the user needs to specify:

- Temperature of the day to calculate for, T_{day} (°C)
- Yearly energy consumption of household, E_{input} (kWh)
- Day type (weekend/weekday), D
- Season (winter/summer), S

Eq. (1) shows the calculation of hour h of the final load profile:

$$P_{profile,h} = \left(A^{D,S}{}_h \cdot T_{day} + B^{D,S}{}_h\right) \frac{E_{input}}{E_{calc}} + P_{EV,h} - P_{PV,h} - \Delta P_{DR,h} \tag{1}$$

where

$$E_{calc} = \sum_{h=1}^{8760} P_{input,h} \tag{2}$$

E_{calc} is the yearly energy consumption calculated from the load input, in kWh. $\Delta P_{DR,h}$ is the change in load for hour h if demand response is used, in kWh/h. This is not considered in this paper and is therefore set to 0.

$P_{EV,h}$ is the load in hour h of the EV charger, in kWh/h. The load is calculated based on inputs from the user regarding battery capacity, state of charge, charging power and at what time the battery should start to charge or be fully charged. It is assumed that the battery is charged at constant power (limited by the capacity in the charging point, e.g. 16 A), with a duration calculated according to the energy needed to fill the battery.

$P_{PV,h}$ is the production from a solar panel for hour h, in kWh/h. A Mitsubishi Electric PV_MLU255HC solar panel is used, with 12 modules of 255 Wp. In addition to the specs given in Ref. [25], it is assumed that the inverter efficiency, n_{inv}, is 0,9. The production is calculated from the irradiation and temperature data given as input by the user, as done in Ref. [26]:

$$P_{PV,h} = C_{FF} N_m n_{inv} \frac{G_h ln(10^6 G_h)}{T_{mod,h}} \tag{3}$$

where N_m is the number of modules, $T_{mod,h}$ is the temperature of the PV module at hour h, and C_{FF} is a fill factor model constant. The reader is encouraged to see Ref. [26] for more details.

III. SCENARIOS – WITH USE OF THE PROTOTYPE TOOL

The tool is used with input data from Norway, Germany and UK. All results shown are for D = Weekday. For summer, T_{day} is set to 20 °C, for winter T_{day} is set to -15 °C. The input data used for each country is specified below. For error values present in the datasets, irradiation values were set to 0, while temperature values were set equal to the temperature of the previous hour. The yearly energy consumption is decided based on the average values for each country, described in Section II.B.

Fig. 7 and Fig. 8 show the output of the tool when using average hourly metering data from 100 houses in Central Norway. The data is collected for 2015, along with measured temperature data [23] for that area, with and without adding a solar panel. Irradiation data is used for Mære weather station, 2015 [24]. E_{input} is set to 16,000 kWh.

At present, Norway is the largest market in the world for EVs compared to the total number of vehicles sold. In total there are 140.000 private EVs, representing approx. 5.6% of a total of 2.5 mill. private cars [27]. The target for non-emission transport will result in 1.5 mill. private EVs in 2030, resulting in an energy need of 4 TWh (3% increase in the Norwegian electricity consumption) [28]. The increased number of EVs will not be an energy problem, but it can become a capacity related problem in the distribution grid. Therefore, Fig. 7 and Fig. 8 also show how an EV will affect the profile. The modelled EV has a battery capacity of 27 kWh and charging power of 3.68 kW, set to be fully charged at 6am, with a state of charge at zero.

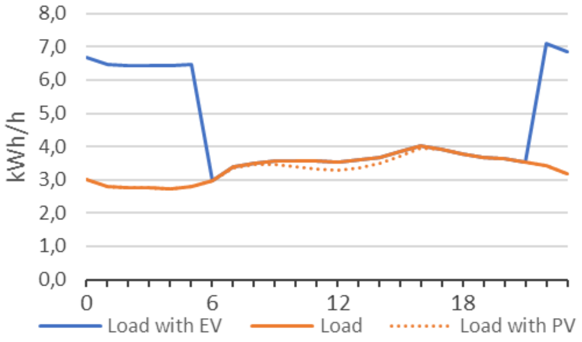

Fig. 7. Load profile for Norway, with PV and EV, S=Winter

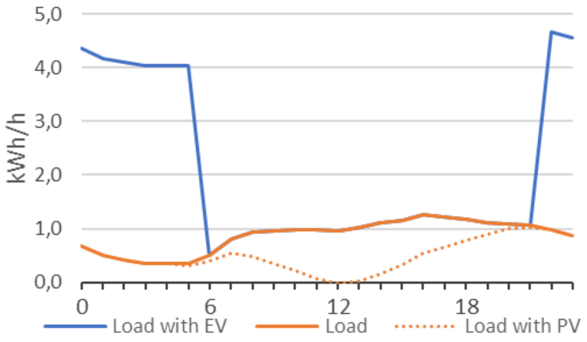

Fig. 8. Load profile for Norway, with PV and EV, S=Summer

As shown in Fig. 7, the Norwegian winter load is in some hours increased by over 100% when adding an EV with a charging power of 3.68 kW. From Fig. 8, it is shown how a household in Norway with a solar panel, in addition to an EV charging at night, could get a substantial difference in load over a 24-hour time span: hardly producing any watts at noon, but consuming over 4.5 kW around 11pm.

Fig. 9 and Fig. 10 show a comparison of Norway, Germany and the UK for summer and winter, respectively. The figures show the load profile for each country, along with the load profile when a solar panel is added.

For Germany, hourly temperature and irradiation data for 2017 is obtained from Deutscher Wetterdienst [29][30], for Leipzig weather station [31]. Load data input is a general load profile from Mitnetz [32]. E_{input} is set to 3,000 kWh. For UK, temperature and irradiation data for 2013 is obtained from the Met Office Integrated Data Archive System [33], for Heathrow weather station. The load data is an average load profile from 53 customers from 2013, collected from the Low Carbon London project [34]. E_{input} is set to 3,800 kWh.

For comparison purposes, all country profiles are calculated with the same season temperatures, e.g. the temperature used for winter is -15°C. In the data sets used, the lowest winter temperature is -14.2°C, -10.9°C and -4.2°C, for Norway, Germany and UK, respectively. This must be kept in mind when considering the profiles, for instance the load profile for UK in winter will be a conservative estimate.

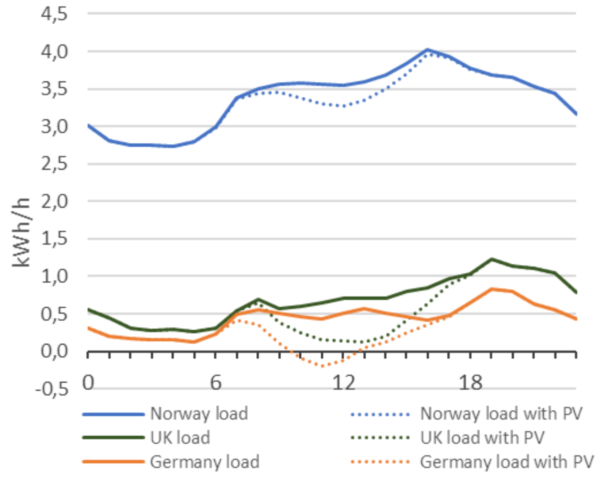

Fig. 9. Load profiles all countries with PV, S=Winter

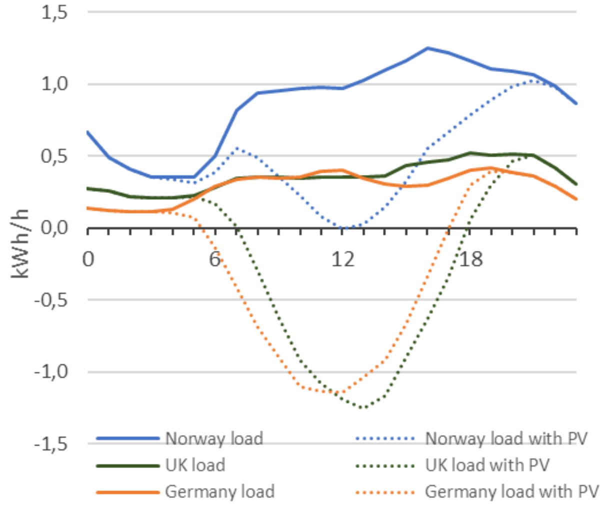

Fig. 10. Load profiles all countries with PV, S=Summer

Fig. 9 shows that the winter load profiles for Germany and UK have a similar shape: a small peak at 9am, and a notably higher peak around 8pm. Norway's winter demand is much higher and peaking around 5pm. Fig. 10 shows that also the summer profiles for Germany and UK have a similar shape: a quite flat profile with a small peak around 7pm. Norway's summer profile resembles more the winter profiles of the other two countries, in both magnitude and shape, although the peak is earlier, around 5pm. A household in UK and Germany produces approx. the same in summer time, while in Norway the net production is lower, due to both a higher load and lower

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irradiation. Since the different countries have different yearly energy, this will naturally affect the load and net production. Norway is, as mentioned earlier, producing little energy in winter time, while Germany has a net production in winter time.

IV. CONCLUDING REMARKS

The prototype tool presented in this paper has shown that by using historical hourly load, irradiation and temperature data, a general 24-hour load profile based on season and day type can be created, showing the demand for households in different countries. The effect a solar panel has on the general household profile for Norway, Germany and UK is also illustrated for summer and winter, along with the effect an EV has on a load profile in Norway.

Further work/improvements on the prototype tool includes displaying a lower and upper bound on the load profile, calculating the profile based on months instead of seasons, as well as using linear regression on the irradiation data to calculate the PV production.

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