Energy Model for Municipality Flexibility Investigation

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***Abstract*— Electrifying the energy system with heat pumps and electric vehicles is a strategy of many countries to reduce CO2 emissions. Large electrification, however, poses several new challenges for the electricity system, particularly in combination with a simultaneous substitution of nuclear power plants by volatile renewables such as photovoltaics. The increasing consumption of electricity and the growing number of installed photovoltaic systems are pushing the existing electrical grid to its limits. Today's grid must be expanded with smart controllers and their components regulated. For this purpose, an understanding of the flexible participants such as boilers, heat pumps and electric vehicles, but also of the new production facilities such as photovoltaic systems must be built up. The aim of this work is to develop an energy model in which the change of these components can be simulated and analysed. To achieve this, data such as weather data, installed boiler capacities, installed photovoltaic capacities, heat pump data and installed vehicle charging stations were collected over the entire municipality. Afterwards, a load profile generator was created, which is supposed to generate a suitable profile over a day for different weather conditions, weekdays and holidays.**

Keywords— Electric Boilers, Electric Vehicles, Flexibility, Heat Pumps, Photovoltaic systems

I. INTRODUCTION

Energy is a crucial basis of global economic and social development. In recent years, global energy consumption has continued to grow. Meanwhile, the energy structure is undergoing profound changes. The challenges from large-scale exploitation and utilisation of fossil energy severely threaten the development and even the very survival of humanity. The remaining exploitable reserves of coal, oil and natural gas can continue to be mined for the next 132, 50.9, and 50 years respectively [1]. In order to achieve the primary goal of the 2015 Paris Agreement [2] limiting the average global warming to less than 1.5°C, Switzerland and many other countries follow a strategy to mitigate greenhouse gas (GHG) emissions and global warming by a transition from a fossil-based to a renewable-based energy system [3]. Consequently, the energy sector is in severe transition:

The current Renewable Energy Sources (RES) (mainly photovoltaic (PV)) volume targets of the 2050 energy strategy are not aligned with the climate targets. The goals become more ambitious, by 2035 an increase from 11.4 to 26 TWh is announced; by 2050, a new goal of 45 TWh is to be striven for [4]. A recent study of the Swiss Federal Office of Environment (FOEN) confirms that the Swiss energy turnaround is feasible by increasing the number of PV installations until 82 TWh [5]. In combination with the existing hydropower (35 TWh) and other RES (especially wind), a 100% energy supply for Switzerland can be ensured by 2050, including replacement of nuclear power and fossil fuels (for mobility, heating). The growth of energy produced from RES, changes the nature of the world's power grids, shifting it from transmission level to medium voltage (MV) and low voltage (LV) levels [6]. The increasing distribution of power generation leads from presently unidirectional to a distributed and bi-directional power flow. This situation requires intelligence and security features at each level of the grid and its interfaces.

In addition to the increasing expansion of RES on the generation side, distribution system operators (DSOs) are facing new challenges on the load side due to the electrification of the energy system with heat pumps (HPs) and battery electric vehicles (EVs). In Switzerland, about 60% of all fossil CO2 emissions currently occur in the sectors of mobility and buildings [7]. Therefore, the substitution of fossil energy carriers in these two sectors by electricity-based technologies seems to be most effective. With respect to buildings, it applies primarily the substitution of fossil heaters and boilers operated on heating oil and natural gas by HPs [8]. With regard to mobility, it concerns primarily the substitution of internal combustion engines (ICE) running on fossil gasoline and diesel fuels by EVs [9]. The total additional electricity demand, due to the electrification, is expected to be 13.7 TWh, of which appoint 10 TWh (75% penetration of HPs) and 3.7 TWh (scenario with 20% EV share). Therefore, in relative terms, the additional electricity demand of HPs and EVs is 23% of the current Swiss electricity demand. Due to this development, electrical distribution grid problems and shortages are expected, especially for grid level 5-7 [10]. The violation of thermal loading limits and, especially in rural networks, of permissible voltage bands limit both the further diffusion of EVs and HPs as well as the functionality of the grids.

In order for the grids to be able to handle these changes, it is necessary to understand how the RES, EVs, HPs and boilers will behave under different conditions. To achieve that, a load profile generator is proposed in this work, to understand the influence of the behaviour from the customer and the meteorological changes during one day. For that, data was collected from

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different places and implemented in an Excel based energy model (EM) to generate different profiles for PV, HP, EV, boiler, household customers and industrial customers which are then summed up to an overall daily profile.

It will be shown how the load profiles of the different consumer groups are structured on the basis of flexible loads in low-voltage grids. Thus, various current and future scenarios can be generated in order to be able to check possible demand side management from the perspective of a DSO. This is becoming increasingly important for DSOs, as the rise of renewable energy sources is leading to higher fluctuations and such a model facilitates load planning, allowing these renewable energy sources to be integrated more efficiently in the future.

A similar approach was taken in 2011 by the Korean KEPCO research group, which instead of standard load profiles, grouped consumer points according to their consumption and from these created so-called typical load profiles. These were in turn divided into subgroups. It could be due to the fact that they had more accurate measurements and thus a bottom to top approach was made possible. This allows a more detailed analysis of different loads. Since the DSO only distinguishes flexibilities and the consumption points according to the standard load profiles, the distinction in the energy model of this paper is sufficient. [11]

The main sections are explained in the following: Section 1 defines the goals and structure of the paper. Section 2 introduces the used approach and methodology. Section 3 summarises the results of the EM. In section 4 Discussion and Outlook of results are being interpreted.

II. Approach and Methodology

This section describes the methodology and the approaches used to develop the profile generator. In general, it should be noted that no time shift is taken into account in the EM, but the time according to central European time (CET) has been chosen. In next subsections each component of the generated load profile shows its influence factors on the left side and the technical details, which were needed to calculate their capacities, on the right side.

A. Structure of the PV Section

The synthetically generated load profiles of the PV systems are calculated with the input parameters G_Gh (Global radiation on horizontal plane kW/m^2 15 min), G_Dh (Diffuse radiation on horizontal plane, kW/m^2 15 min), Ta (Air temperature, measured 2 m above Ground) from weather data set and further information from municipality about their already installed PV systems as shown in flowchart Fig. 1.

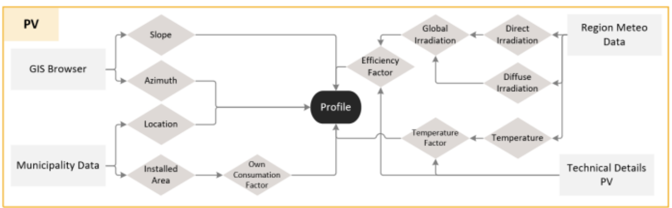


Fig. 1. Flowchart for PV profile generation: outside of the system (left side) and technical details (right side).

To develop the part for PV systems, in the EM, it was important to find out their orientation. To get this, the "Solarkataster"19 of the GIS-Browser from the canton of Zurich was used. In order to calculate the load profile in the EM, the installed area in m^2, the slope angle and the azimuth in degrees was needed.

The PV section needs following parameters as input information:

- Latitude of the municipality
- Longitude of the municipality
- Module Area
- Slope of the PV systems (Horizontal = 0°)
- Azimuth of the PV systems (North = 0°)
- Efficiency factor
- Self-consumption rate
- Temperature coefficient

Further assumptions had to be done, such as the value for the temperature coefficient, efficiency factor and self-consumption part of the PV production. According to EnerigeSchweiz [12] the self-consumption rate for private PV systems is smaller than 30% and for industrial PV systems, up to 50% of their produced energy can be used on site. For the remaining values, assumptions were made using a technical data sheet of the module type used in the municipality.

To convert the irradiation on a horizontal plane to any other slope and azimuth angle, the angle between the normal vector of the plane and the sun's irradiation vector was used according to the Klucher model [13].

B. Structure of the HP Section

For air HP no information from the canton nor municipality could be given, as non of the mentioned parties has any list saved. In order to be able to estimate performance nevertheless, the Swiss ratio of ground HP (GHP) to air HP (AHP) was used as a basis. In 2019, the ratio was 71% AHP to 28% GHP [14]. The remaining 1% is water HP, which are not considered in this work. This ratio was set in the generator regarding the capacities as a basic setting and can be changed by the user. Hot water is not taken into account, only the heating capacity for the building. A more detailed flowchart is given in Fig. 2, to depict the necessary input information.

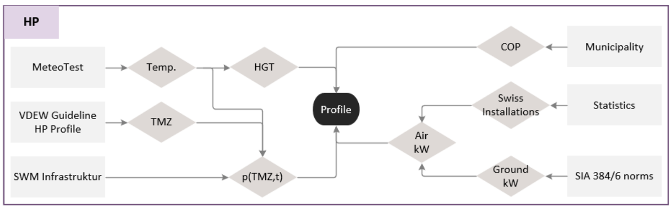


Fig. 2. Flowchart for HP profile generation: outside of the system (left side) and technical details (right side).

HP must reach at least a coefficient of performance (COP) of 3.1 for air and 4.3 for ground types [15]. It is therefore assumed that this represents the state of the art and can be used as a basic setting for the generator.

BDEW an organisation for grid distributers together with the university Cottbus published a guideline "load profiles for interruptible consumer systems". With liberalisation of the electricity market in Germany, a general practice about the estimation of load profile for interruptible consumer systems had to be provided. These profiles need to be made available to the public by every distribution operator in a normed form. For estimation and integration in EM, the following technique was adapted [16]:

The daily average of the outside temperature is determined according to the equation of 24 hourly air temperature measurements.

$$T_m = \frac{T_1+T_2+\cdots+T_{24}}{24} \quad (1)$$

where: Tm - average outside temperature [°C] and T1..24: air temperature [°C]

The guide states that the evaluated average as well as the temperature coefficient number, needs to be specified with one decimal place. The temperature coefficient number (Temperature Mass Index) is being calculated as followed:

$$TMZ = max(T_{Reference} - T_{m,eq}; K^2) \quad (2)$$

where: TReference - Reference temperature [°C], Tm,eq - Temperature of the relevant measuring point [°C]

The mentioned reference temperature is stated to be 17 °C if the distribution operator does not choose to change it. The result is rounded down. As for the constant K, Stadtwerke München (SWM) considers, that for profiles used concerning HPs the factor 1 is used if electric power is still used even when exceeding the limit temperature. But if no electric power is needed above the limit temperature then 0 is to be taken

Further, the temperature with the concerning relevant measuring point is calculated as followed [17]:

$$T_{m,eq} = 0.5 \cdot T_m(d) + 0.3 \cdot T_m(d-1) + 0.15 \cdot T_m(d-2) + 0.05 \cdot T_m(d-3) \quad (3)$$

where: Tm(d), Tm(d-1), Tm(d-2) and Tm(d-3) are daily mean outside temperatures.

The required load needs to be standardized to electric power of the interruptible systems and corresponding temperature coefficient number [16]:

$$p(t) = P(t, TMZ) \cdot \frac{\Sigma A}{TMZ} \quad (4)$$

where: p(t) - normed load profile of the distribution operator [K/h]; P(t,TMZ)- load profile of the interruptible systems [kW]; TMZ - temperature coefficient number [K]; A - electric power of the interruptible systems of all customers [kWh]. The normed load profile are given for every 1 °C step in 0.25h-time intervals.

DSOs provide any standardised tables, data from SWM was used as they cover a smaller area and are located in Munich which provides some sort of similar weather condition. If a larger DSO were to be used, which covers a larger area, the behaviour of the HP would be softened or certain fluctuations would no longer be made visible by averaging the measurements. In Fig. 3 the plotted data from SWM is illustrated in a line graph. With each decreasing degree the HP consumption of energy from the grid increases.

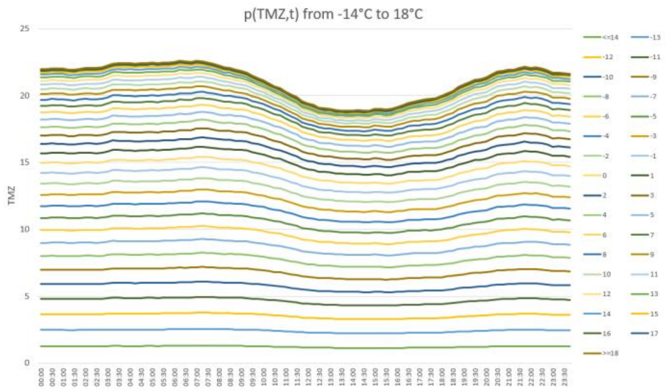


Fig. 3. TMZ table as published by SMW for a temperature range of minus -14 to plus 18 degrees.

As the generator is designed to generate profiles for at least a municipal sized population, another influence arises besides temperature. The heating behaviour is also influenced by the seasons. In cold winter, heating is used everywhere. Whereas in summer, only hot water is needed for heating, if no separate HP boiler is used. During the transitional periods of spring and autumn, however, there is a certain proportion of people who are ready to heat and some who are not.

This behaviour can be explained in more detail with the heating degree days. An internal temperature of 20 °C is usually assumed. The 12 °C represents the limit below which the heating is switched on. The Heating Degree Day (HGT) 20/12 is thus determined from the temperature difference between the average outside temperature and 20 degrees. The days which are below 12 degrees, are taken into account. [18]:

$$T_{HGT\,20/12} = T_b - T_{e,m} \quad (5)$$

where: Tb - is base temperature [°C], generally 12 °C is used; Te,m - daily average outdoor temperature [°C]

To determine the individual behaviour of switching the heating off and on, in relation to consumption, the behaviour of HGT and no HGT (0=If(day>12,0,20-day)). This assumption is shown in TABLE I. :

TABLE I. THE CALCULATED TMZ AND HGT FOR EACH MONTH IN ORDER TO EVALUATE THE LOAD PROFILE OF HPS

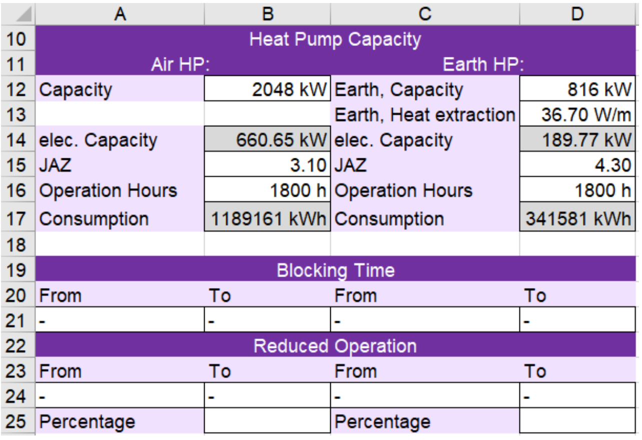
Month	TMZ	HGT 20/12 factor
January	539	1
February	402	1
March	332	1
April	258	0.73
May	224	0.68
June	41	0
July	31	0
August	37	0
September	87	0.17
October	182	0.52
November	363	0.97
December	426	1

In the EM, these calculation steps are executed step by step. First, the correct temperature curve is requested with the specified weather situation, time and month, which is then in a

second step converted to TMZ. With the given time and TMZ, the next step is to search for the corresponding power coefficient in the TMZ table. Through this, it is possible to determine the power for the HP. In the following lines, the influencing factors such as blocking times, reduced operation and heating degree days are taken into account for the effective performance.
The HP section needs following parameters as input information:

- Capacity of AHP
- Capacity of GHP
- Annual performance factor of AHP
- Annual performance factor of GHP
- Operation hours of AHP
- Operation hours of GHP
- Earth heat extraction

As seen in Fig. 4, the grey marked cells automatically calculate the missing information needed to evaluate the load profile. If desired by the user, up to two additional blocking times can be added by selecting the corresponding times from the drop-down list. There is also the option to add two reduced overall operation times besides the initial information needed, which limits the maximum power in the desired time interval.



	A	B	C	D
10	Heat Pump Capacity			
11	Air HP:		Earth HP:	
12	Capacity	2048 kW	Earth, Capacity	816 kW
13			Earth, Heat extraction	36.70 W/m
14	elec. Capacity	660.65 kW	elec. Capacity	189.77 kW
15	JAZ	3.10	JAZ	4.30
16	Operation Hours	1800 h	Operation Hours	1800 h
17	Consumption	1189161 kWh	Consumption	341581 kWh
18				
19	Blocking Time			
20	From	To	From	To
21	-	-	-	-
22	Reduced Operation			
23	From	To	From	To
24	-	-	-	-
25	Percentage		Percentage	

Fig. 4. Screenshot of the control panel in the HP Excel sheet.

C. *Structure of the EV Section*

An EV load profile generator developed in [19],[20] was used to develop a version in the EM by incorporating the probability densities for a specific municipality, as shown in Fig. 5.

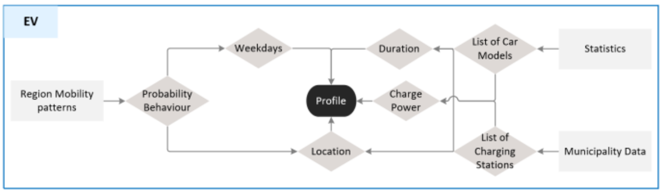


Fig. 5. Flowchart for EV profile generation: outside of the system (left side) and technical details (right side).

From the municipality, a list of charging stations with each nominal current power and EVs type is defined. It is highly possible that other charging stations are installed without a permit. Also possible is, that a location could have multiple stations but was not mentioned in the documents submitted for the authorisation. More common is also that EV owners plug their car into a socket outlet. As no further data, concerning the three mentioned types of charging, is known to the DSO, the official charging stations are used for the profile generator.

With the given information, about the car models and charging stations, a way of combining them according to their probability, can be done.

Each charging station ID is now given a car model, its technical details, a randomly created connection duration arrival time and average energy demand depending on what week day was chosen. In order to achieve a realistic profile for EVs, the probability for each time interval throughout the day and the corresponding location type (private, public, workplace) is calculated for the arrival time, energy demand per charging event and the connection duration per charging event. In a last step, each of the charging stations are summed up for each of the 15 min time intervals which concludes to the total power output.

D. *Structure of the Boiler Section*

In order to obtain the necessary data for the calculation of the boiler load profile, the municipality provides data on the installed capacity, minimum charging time and the number of boiler load groups. Most of the boilers are controlled with the ripple control device from the DSO itself, though there are some exceptions which can be controlled manually. As an example, different boiler groups are listed in TABLE II.

TABLE II. EIGHT LOAD GROUPS WITH DIFFERENT OPERATING HOURS AND ACCUMULATED POWER

Load Group	Installed Power [kW]	Minimal Loading Time [h]
Boiler 1	20	4
Boiler 2	600	4
Boiler 3	600	4
Boiler 4	100	6
Boiler 5	200	8
Boiler 6	100	8
Boiler 7	150	4
Boiler 8	400	4

For the information to process the data in the EM to calculate load profile, the model predictive controlled (MPC) principle from field experience was applied. Therefor many assumptions had to be made to define the loads of the boilers such as, • Every boiler is controlled with the ripple control device • Every Boiler switches on, when they get the release order • After the minimal loading time some boilers switches on again due to their thermal losses or water has already been drawn again. Flowchart of Boiler load profile generation is depicted in Fig. 6.

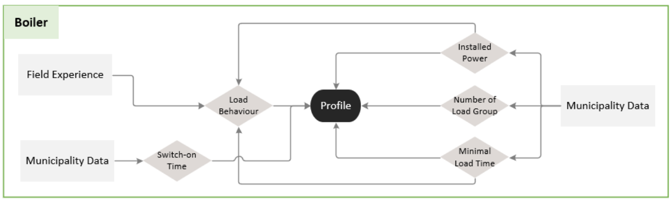


Fig. 6. Flowchart for Boiler profile generation: outside of the system (left side) and technical details (right side).

As can be seen in the Fig. 7, each boiler of a load group is switched on at the beginning and switched off one after the other until each boiler is finished after the minimum charging time.

Except for the ones which already lost some heat or hot water, was removed during the time.

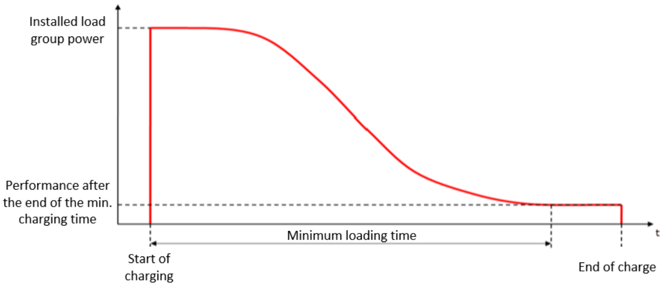


Fig. 7. S-curve to describe the behaviour of the boiler load groups. On the x-axis is the time and on the y-axis power in kW.

To calculate the load profile for the boilers the S-curve method was adapted in the EM. For this the distribution function, from the gaussian distribution, is needed. This equation is defined as:

$$F(x) = \frac{1}{\sigma * \sqrt{2 * \pi}} * \int_{-\infty}^{x} e^{-\frac{1}{2} * \left(\frac{u-\mu}{\sigma}\right)^2} du \qquad (6)$$

where: σ - standard deviation; μ - mean of the gaussian distribution

To get the S-shape of the curve, as shown in Fig. 7, the complementary function is needed. The Eq. 7 is in Excel already implemented with the syntax "Norm.Vert(x;mean;standard deviation;True)" what simplifies the code for the load profile.

$$F_2(x) = 1 - F(x) \qquad (7)$$

where: x - is the time of the day; σ - is a parameter which defines the detailed shape of the curve. This has to be defined with help of measurements; μ - is half of the minimum loading time in hours

With this information, it is possible to determine the needed parameters in an equation to calculate the S-curve for the boiler load groups:

$$P(x) = F_2(x) * (P_{inst} - z * P_{inst}) + P_{inst} * z \qquad (8)$$

where: z – a percentage of power that is consumed after the minimal time; Pinst - installed power of boiler load groups [kW]

For the boilers, there are few information needed to generate the right profile. This part of the EM is based on the fact that boilers are controlled with the ripple control device. For that, it is crucial to know when they switch on and at which hours the boilers are inaccessible. The cells to insert the time range for the release time is illustrated in Fig. 8. The numbers to the right of the release time, which can be seen in the same figure, describe the time step from the selected time, of the day. These numbers are determined by the EM itself and do not need to be adjusted by the user.

initial Information about boilers		
start release time	20.00 Uhr	80
end release time	7.00 Uhr	28

Fig. 8. Start and end time of the release time when the boiler group is allowed to switch on.

To feed the EM with the data about the individual boiler groups, the cells which can be seen in Fig. 9, have to be used. The first time defines the switch on time on workdays, if the boilers are available to switch also on Saturday and Sunday, it is needed to choose "yes" in the "Weekend Day Release" column. Afterwards, the switch on time for the weekend can be inserted in the last two columns. In the second column, the loading time of the boiler groups is needed in hours.

11	Initial Boilergroup Information						
12	ID	Heating Time	Installed Power	switch on tin	Weekend Day Release	Release Time Sa	Release Time Sun
13	1	4	20	22.00 Uhr	Yes	15.00 Uhr	11.00 Uhr
14	2	4	600	22.00 Uhr	No	12.00 Uhr	12.00 Uhr
15	3	4	600	0.00 Uhr	No	12.00 Uhr	12.00 Uhr
16	4	6	100	23.00 Uhr	No	12.00 Uhr	12.00 Uhr

Fig. 9. Table in the EM where the information about the boiler groups has to be inserted.

E. Structure of the Household and Industry Section

The "Representative VDEW - Load Profiles" is a guideline created by VDEW which explains the approach and documents various considerations that led to the proposed load profiles [21]. DSOs are therefore recommended to proceed according to this standardised method. Some publish their load data unprocessed with measurements throughout the year in 15min intervals. Others follow the guideline and provide their data in a standardised form. The data differs between the three categorised seasons and what type of weekday is affected: work day (WD), Saturday and Sunday [21]. Standard Load Profiles (SLP) values from ED Netze [22], a DSO active in the Freiburg region in Baden-Würtenberg, were used. For this work, the EM consists of "H0" group for households and "G0" for the industry were used to evaluate the load profile. The load generation flowchart is shown in Fig. 10.

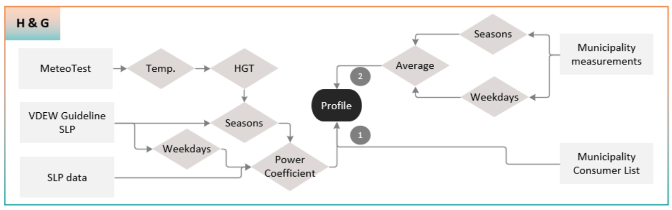


Fig. 10. Flowchart for Household and Industry profile generation: outside of the system (left side) and technical details (right side).

The main part of the overall load profile is taken by the two customer groups household and industry. In order to achieve the desired solution, two methodologies were carried out.

Municipalities tend to deviate more from the SLP. Smaller municipalities in particular are assumed to have an individual consumer profile for the industry group. The fewer measurements there are, the more individual their mean values are and the more fluctuations they show. In larger cities, deviations are compensated more quickly by the evaluation of the SLP.

Therefore, it was decided to consider also the second method in EM and evaluate a second methodology by calculating the average value for each month and WD type. Holidays are attributed to Sundays. Factors and values used to evaluate the average are shown in Eq. 9.

$$Average\ Power(Month,\ Type\ of\ Day,\ Time)\ [kWh] = \frac{\Sigma\ Power(Type\ of\ Day,\ Time)\ [kWh]}{Number\ of\ affected\ Days} \qquad (9)$$

Average measurements of each month and the three subcategories: WD, Saturday and Sunday are derived according to the historical measurements from the municipality.

For the methodology of SPL an allocation of the time intervals to their season according to the guideline from VDEW. As it is not possible to allocate specific dates in the model, a simplification by months was made. The calculations of HGT, as shown in TABLE I. , present that the seasons do not behave as indicated in the guideline [21] with regard to their temperatures. For example, according to the heating degree days, September is still considered summer and not half of it is already a transitional period as described by the VDEW in 1999. March, on the other hand, is largely attributed to winter, but in the model the month was assigned to the transitional periods, as a reduction in HGT is already evident. In TABLE III. the allocation to the three season types by VDEW and for the model is shown.

TABLE III. ALLOCATION OF THE CALENDRICAL FACTORS INFLUENCES THE MONTHS AND DAYS OF THE WEEK

Season	Type of Day	VDEW Allocation	Adaptation Model
Winter	Workday Saturday, Sunday	01.11. to 20.03	December, January, February
Summer	Workday Saturday, Sunday	15.05 to 14.09	June, July, August September
Transitional Period	Workday Saturday, Sunday	21.03 to 14.05 15.09 to 31.10	March, April, October, November

It is assumed that these distinctions have been caused by climate change in the last 20 years.

Depending on which methodology to be carried out, different changes need to be made by the user. In the case of the SLP the user enters the consumption of the individual consumer group in kWh of the wanted year. If the second methodology is used, then the user will need to evaluate each average of every month and type of day beforehand and values are then defined in a special EM table.

III. Results

In the following section, the results from the EM are presented. They are shown for each sheet, except for the industrial and household profiles which are described together. Finally, there are also the results shown from the overall daily profile of the EM.

A. *PV Profiles*

The results of the PV section are shown in Fig. 11. For each weather condition, there is one graph. The figure shows the calculated PV production for the month of June and since there was no snowing at all in this month, Fig. 11f represents snowing from the month of January.

Fig. 11 reveals that the produced power of the PV systems can change at any time. Just one cloud for a few minutes can make a difference in the production of about 300 kW, as illustrated in (c). It is also possible to see the seasonal differences if one looks at the time when the first production takes place in (f). The weather condition has a crucial influence on the production of PV systems. As one can see, the peak at (a) is over 1100 kW, (b) just over 1,000 kW, at (c) just under 1,000 kW, at (d) already under 600 kW, at (e) the production is low on average but once it rises above 800kW after morning rain and at (f) it remains under 200 kW all day.

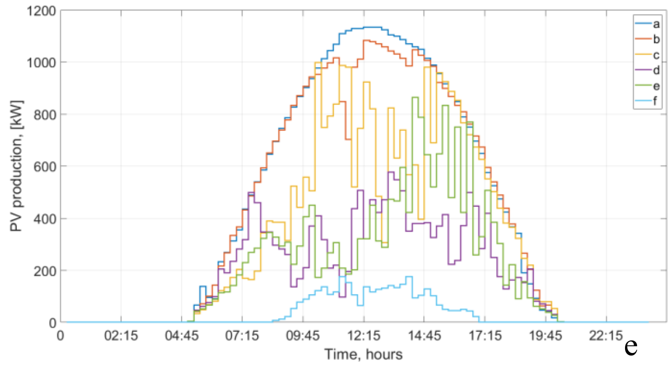


Fig. 11. Simulated profile of the total amount of PV production from the EM. For each weather one profile starting with sunny (a), partly sunny (b), partly cloudy (c), cloudy (d), rain (e) and snowing (f)

B. *HP Profiles*

The results of the HP section are illustrated in Fig. 12. Two weather situations and two WDs are compared with each other. In addition, the functions "Blocking" and "Reduced Operation Time" are examined. The latter, both the transitional period and the summer, are presented and analysed.

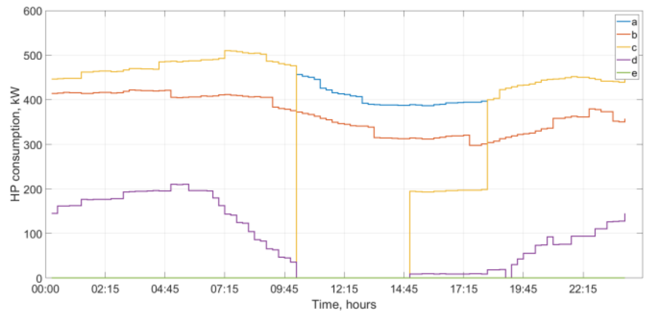


Fig. 12. Simulated profile of the amount of HP load from the EM. (a) illustrates January on WD with sunny weather whereas (b) with snowy weather. (c) uses the blocking and reduced operation time, (d) shows a transitional period and (e) summer.

Fig. 12 reveals that the consumed power of HPs differs depending on weather, WD, month and the influence from the DSO by blocking or reducing the HPs in the power grid. Since HPs are influenced by temperature changes, the weather and the temperature changes, that come with it, have an indirect influence. This is shown by (a) with a sunny and (b) with a snowy WD in January. Different WDs do not influence the heating system as there are no changes between. By influencing specific blocking times throughout the day, with reduced operation of the HP in the power grid, the maximum used power by the flexibility can be limited or even entirely deactivated as shown in (c). Blocking time is shown to be from 10 to 15 o'clock and reduced operation time by 50% from 15 to 19 o'clock. Larger fluctuations in consumption caused by temperature changes can be seen in (d). April is regarded as a transitional period and therefore also shows greater temperature fluctuations during the course of a day. Thus, a heating load is still required during the night, but during the day this can sometimes even disappear completely, as shown at around 13 o'clock. In (e) summer is being simulated with August as chosen month. As there are no heating degree days in summer no consumption from HP occurs either.

C. EV Profiles

By using the probability behaviour of the EVs each time Excel refreshed the given commands a new profile is automatically generated. Thus, a momentary behaviour is represented and not average values, which only change when an influencing factor changes. In Fig. 13 are therefore two charging events depicted.

In Fig. 13a a WD load profile of all charging stations (it is assumed 10 electric vehicle supply equipment (EVSEs) per charging point) in a municipality is depicted. Throughout the day there are charging events, only between 2 and 10 o'clock seems no EV charging to be needed. A power peak of 330 kW at around 11 to 12 o'clock is visible. By analysing the individual charging behaviour, visible under (c), it becomes clear that the greatest demand for power is at 22 kW, which is equivalent to the most powerful charging station. However, the majority of the time, 11 kW of power is drawn from the grid.

On Sundays, as shown in (b), a higher consumption density in a shorter time interval than on a Workday, is depicted. A power peak of 370 kW at around 20 to 21 o'clock is reached. As seen in (d), the charging events for each charging station is gathered in a tighter group between 12 to 24 o'clock. No charging events are generated in the early to late morning.

D. Boiler Profiles

To generate the load profile, the right switch on times had to be inserted in the EM. According to the data, which was provided by the municipality, it was possible to identify the times when the ripple control device sends the release order. Fig. 14 shows that the load profile during the night hours is for all three WD types. The only differences are seen on Saturday and Sunday when the groups "Boiler 1" and "Boiler 6" are allowed to switch on during the day, otherwise, the consumed power of the boilers is always 0 kW between 7:00 and 20:00.

E. Industrial and Household Profiles

In Fig. 15 and Fig. 16 the two methods are being compared. For both the household profile and the industrial profile, winter (January) and summer (July) were set in the EM. The household profile does not subtract the boiler and EV profile. Because these consumers are part of the household and not so far defined as separate consumers by VDEW. Only HPs are being separated from the average measurements.

Discrepancies between the two methods can be seen across all four counts. With regard to the household profile, in addition to the different results from the methods, a different behaviour with regard to the seasons is also evident. In winter, the SLP in the time window from 6 to 21 o'clock exceeds the curve of the mean value. The difference between the two varies from about minus 400 kW to plus 800 kW. In summer, on the other hand, the SLP falls below the curve of the mean value throughout the day with a difference of at least 400 to a maximum of 2,000 kW.

With regard to the industry profile, significantly greater differences can be found. In both winter and summer, the curve of the mean values is clearly above that of the SLP, with differences of up to more than 3,000 kW. Only the ratios and thus the curves show similarities, both in winter and summer.

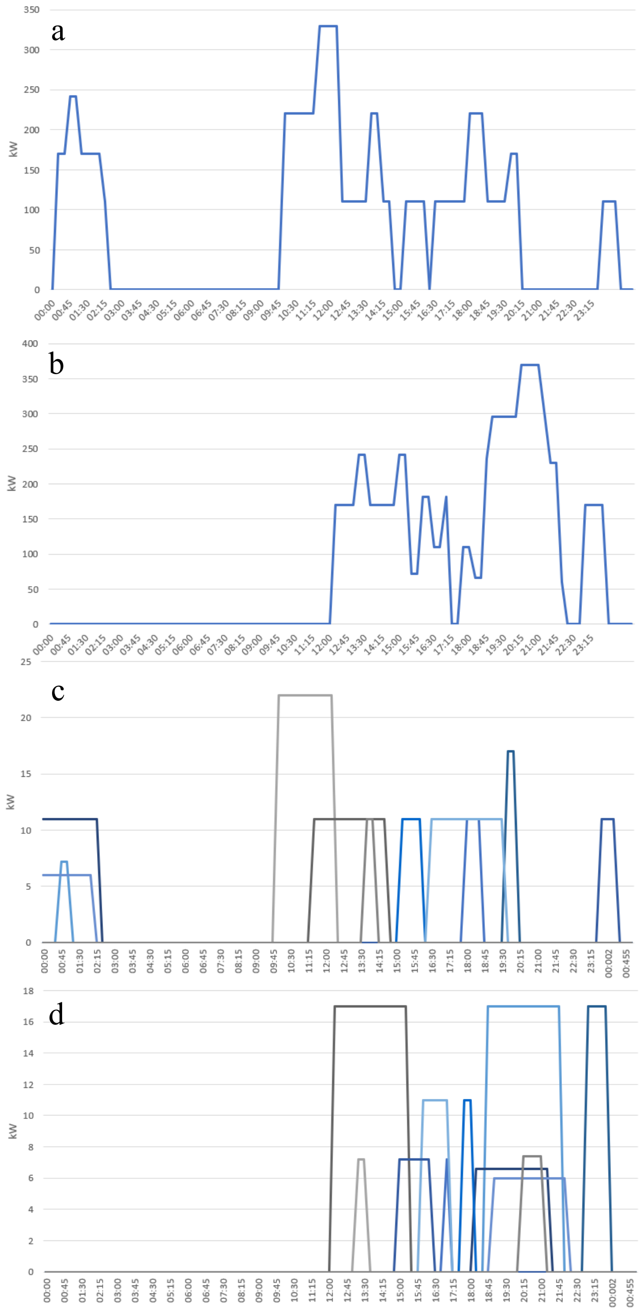


Fig. 13. Two simulations of EVs shows the difference in WD (a) and Weekend (b) in a total charging profile and in (c) and (d) are each charging station individually

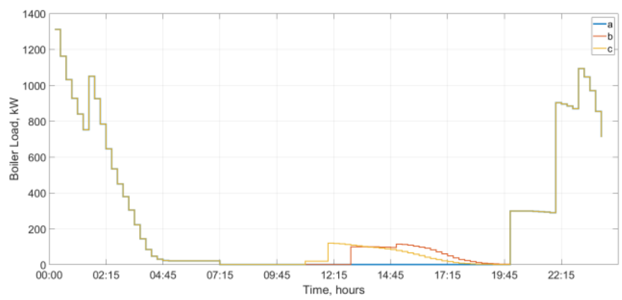


Fig. 14. The simulated profiles for the boilers. First in (a) is the load profile for WD, in (b) for Saturday and in (c) for a Sunday

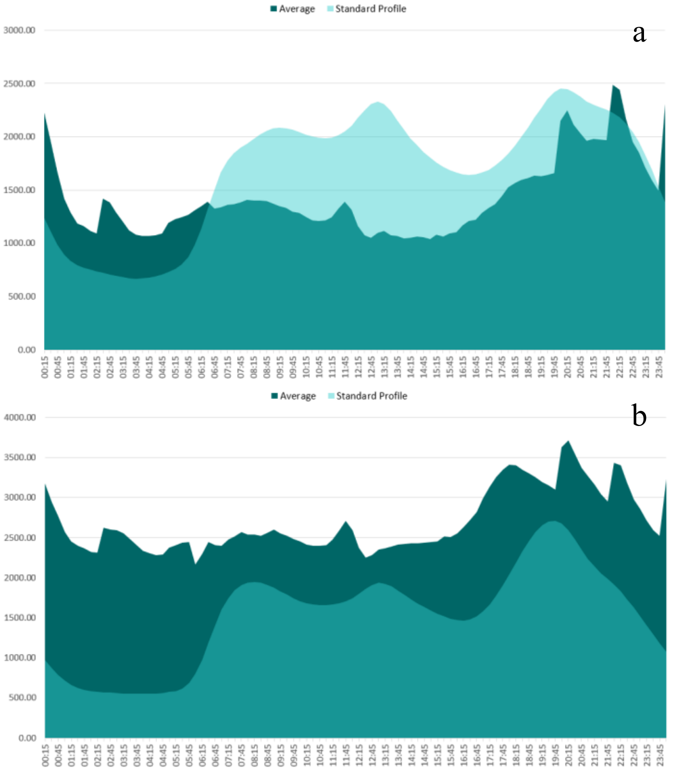


Fig. 15. The two methods in comparison to each other by comparing the households consumer in winter (a) and summer (b)

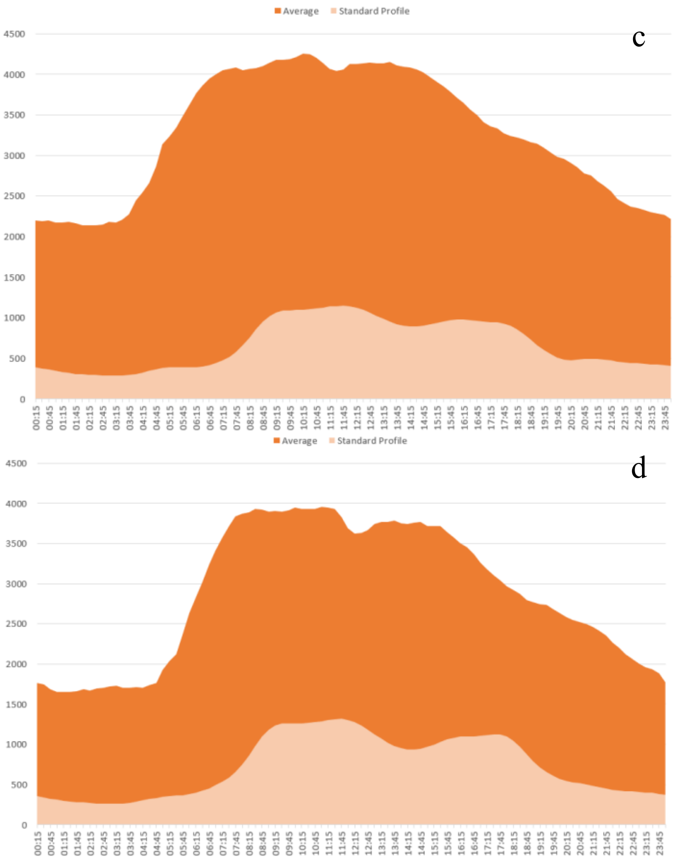


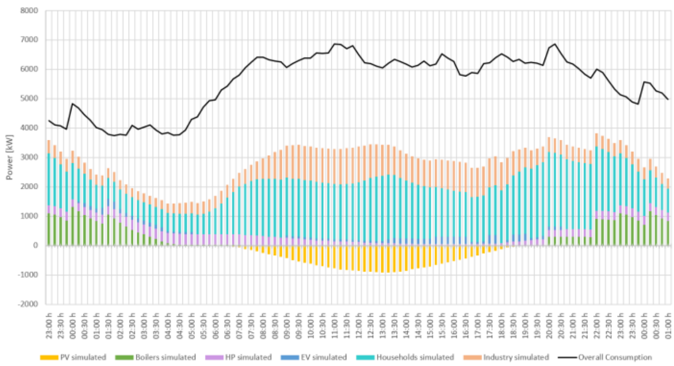
Fig. 16. The two methods in comparison to each other by comparing the industrial consumers in winter (c) and summer (d)

F. Overall Daily Profile

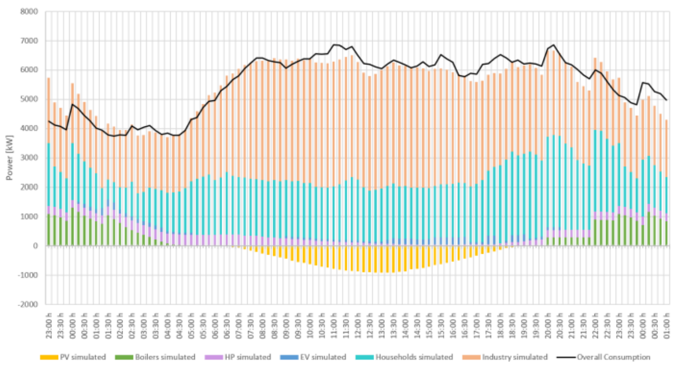
As already mentioned in Sec. E, the calculation for the household and the industrial section has two different methods which lead to different results. As the graphs in Fig. 17 reveal, there are significant differences between the used methods. Fig. 17a leaves a big gap between the simulated curve and the measurements of the municipality.

In Fig. 17b shows the difference between the measurements and the calculations, there are deviations but not as many as can be seen in Fig. 17a. In both graphs is the low amount of EVs in the profile. In general, the flexibilities are just a small amount of the overall consumption next to the households and industrial consumers. To find out what share the flexibilities have in the total consumption, the "ratio of flexibilities from measured Power" is integrated into the EM, as can be seen in TABLE IV. From each calculation, the min/max are derived.

The ratio of flexibilities is calculated with the amount of EV, HP and boilers. The fluctuation of the minimum amount, which is in the winter months, never undercuts 0%. It also seems that the HPs are one possible reason for this behaviour. The PV production grows as expected until June and then decreases again. Due to the made assumptions to calculate the boilers, they have no significant fluctuation of the peak during the whole year.



(a) SLP method.



(b) Average method.

Fig. 17. Overall load profile with the overall consumption (line graph) and the simulated profiles (bar graphs). The upper (a) shows the simulated profile with normal SLP and the lower (b) shows the average calculated profiles.

TABLE IV. THE RATIO OF FLEXIBILITIES FROM MEASURED POWER

Month	Min	Max	PV [kW]	HP [kW]	Boiler [kW]	EV [kW]
January	6%	36%	370	510	1,310	566
February	3%	35%	618	426	1,310	584
March	2%	37%	914	370	1,310	522
April	1%	45%	1,000	210	1,310	346
May	0%	45%	1,108	168	1,310	330
June	0%	37%	1,134	0	1,310	584
July	0%	37%	1,060	0	1,310	790
August	0%	39%	1,034	0	1,310	450
September	0%	39%	894	38	1,310	500
October	1%	40%	625	148	1,310	560
November	3%	39%	374	367	1,310	340
December	9%	44%	349	460	1,310	390

IV. DISCUSSION AND CONCLUSION

In the following section, each EM section group is being individually discussed. Problems are addressed, suggestions for improvement are made and expected future changes in the respective load group are discussed. The main open questions addressed are: Which information is missing that a DSO would have to deal with in the future? Are there any processes within the municipality which are not yet carried out?

A. Discussion

PV Section: To improve the accuracy of the EM, it is necessary to gather more details about all installed PV systems in the municipality, such as installed technology, area, installed power, slope and azimuth of the modules and how high the feed-in is.

HP Section: Although there was almost no information about HPs from the municipality or the DSO, it is possible to develop a simulation model using known methods, such as the TMZ in Germany, and generally known technical details. Since the authorisation of HPs, both AHP and GHP go through the municipality, it is recommended that the municipalities follow this up from now on. A ratio between the two technologies alone would make the load curve in the simulation appear more realistic. If, in addition, the COP of each HP is also tracked, the COP could be adjusted more specifically to the municipality.

With the opening of the electricity market, the HPs should also be made accessible to the public in each DSO in the near future. Whether this is done via the TMZ or only the load curve in a 15 min cycle should not make much difference. This will allow more accurate profiles to be generated.

EV Section: Since all the calculations are based on probability densities, to be able to generate a more realistic load profile, several calculation runs would be necessary. In this way, a more general profile could be generated that is not based on a momentary load or on events generated once with the discrete function. Since the simulation model is based on probabilities, a change in these factors is to be expected over time. Due to the increasing consumption of EVs with more and more registrations, the implementation of smart grids, and the release of new technologies and new car models, a constant change in the probabilities can be expected. A more flexible method is therefore needed for the EM, similar to the SLPs (for households and industry), the TMZ (for HPs) or the direct obtaining of consumption measurement values (average method in H and G).

As EV bidirectional capabilities (charging/discharging) became possible, it will also be necessary in the future to have a tariff group for EVs in terms of consumption and feed-in. Although Germany, with its open electricity grid, already offers transparency of the DSOs, this has not yet been implemented by them either. However, since Switzerland is only in the transition phase, it is possible to set up a structured load group allocation from the very beginning. With the later complete opening of the electricity market, the transparency of EV consumption will also become clear. Finally, the load profiles can be evaluated at specific DSOs, regionally or nationwide.

Boiler Section: The implementation of the boiler section has shown that there was a gap of data in the installed capacities. It was not possible to get more proper data about their state of the art in the municipality. The assumptions made are based on behaviour experience of a boiler load group. By the comparison of the simulated load profile with the measured overall load profile, one can see that the peaks almost fit with the measurements. To align them perfectly, further data about the hot water consumption of the customer, the installed power of the boilers and at which time each one of them can switch on (even those that have exceptions) to be turned on manually or during the day. These findings suggest that in general more measured data, about water and energy consumption to heat up the boilers, are needed to make more precise statements.

Industrial and Household Section: If the two methods for the evaluation of household and industrial consumption are examined more closely, the SLP method shows clear differences from the real load profile. Furthermore, they generally overlap only slightly or not at all. The biggest differences lie in the consumer group industry. Different factors can be assumed for these results. One factor could be related to the selected SLP G0. The behaviour of the individual consumers is so different that a more precise division of their data into the categories G1 to G6 would be necessary.

One quarter of the electricity consumed by the municipality comes from industry. It is therefore possible that the differences are due to the behaviour that the SLP does not take into account or even dampens. Because of the relatively small size of the municipality with a relatively large share of industry, a different behaviour than that of the standard solution can be expected.

Depending on which information is given beforehand, the user can choose between the two options. The first one follows as mentioned the guideline from Germany and determines standardized results. Whereas the second option is tailor-made for the electricity utility under investigation. However, it requires that the user has the load data in a time interval of 15 minutes over a whole year and prepares them according to the EM, so that only the average values have to be adapted. Especially depending on the size and load behaviour, found in the municipality to be analysed, the second option can lead to more realistic load simulations as seen in Fig. 17.

By choosing one of the two options, the overall load profile is drastically changed and can lead to different results. If the focus lies on the flexibilities, no simulation of the consumer groups households and industry is needed. Therefore, less data needs to be processed beforehand by the user itself. But does the user need a realistic result, the average method is recommended to be used.

B. Conclusion

The main goal of this work was to develop and present an Energy Model which can be used to analyse the grid structure in municipalities. Due to the current data situation, only conditional statements can be made with the EM, there is a degree of uncertainty in the simulations. Nevertheless, with the available data, it was possible to implement a generator in Excel that simulates specifically the consumption of the municipality under investigation. If it's desired to use it for other municipalities, a few assimilations have to be made. These findings contribute in several ways to our understanding of flexibilities and provide a basis for the grid studies in the next step.

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