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VALIDATION REPORT OF THE AUTARKY RATE TOOL & THE CHECKLIST

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Content

1. Introduction

This document contains the validation and evaluation report of the Autarky Rate Tool. The Autarky Rate Tool is a simple but very useful online tool which is available for everyone who is interested in the installation of electrical storage solutions in combination with renewable energy sources. By adding only a few numbers, the user will get an evaluation of the

- technical,
- economical and
- ecological

effects of the chosen system configuration. The main output is of course the autarky rate, which is a figure for the independency of the public grid. If the autarky rate is high, this means, that the user is able to self-supply major parts of his energy demand. As the economical perspective is always a substantial fact for every investment decision, the energy cost savings as well as a rough estimation of the amortisation period are shown too, to give the user an idea if this configuration is economically feasible or not. To evaluate the ecological impact, the CO2 savings, based on the national electricity mix are calculated.

Another major part of the tool is the so-called checklist, which can be created as pdf-file. On the one hand, the idea of the checklist is to give the user a possibility to save the calculation results, and on the other hand, it should serve as a further explanation how to make results understandable. The tool results are valid in general and not only for historical urban buildings. For the users who are planning the integration of a storage in a historical urban centre (HUC), a further page is added, which provides them with additional information and advices from the Store4HUC project.

The tool does of course not replace an individual technical configuration assessment, but it gives a good overview what positive influence the installation of a storage solution in combination with renewable energy sources might have and will possibly motivate more people to consider such installations on their own. The tool is available in English, German, Italian, Slovenian and Croatian on: https://store4huc-autarky.4wardenergy.at.

The report is structured in two parts. The first part contains a summary of different validation and evaluation measures which were carried out in the last months. The tool was presented at several events and feedback as well as recommendations for improvements were collected from the project partners and from external stakeholders. Some of these measures have already been implemented, others are discussed and have not (yet) been implemented for different reasons. Moreover, the monitoring data of the pilot plants in Croatia and Italy have been used to validate the Autarky Rate Tool.

The second part of the deliverable contains background information of the Autarky Rate Tool, as several stakeholders have asked for such a document. This part is linked to the Autarky Rate Tool and is already available online. Moreover, a short introduction video was recorded to facilitates the usage of the tool.

2. Internal validation and evaluation

The first steps of the validation and evaluation have already been set during the development phase of the Autarky Rate Tool. The current status of the tool was presented periodically to the project partners and their feedback was used to improve the tool. Due to this procedure the originally idea to develop Microsoft Excel based tool which is available online for download was reconsidered and real online tool was developed. After the completion of the tool, the final (beta) version was presented to all project partners at the Train the Trainers workshop, and they were asked to test the tool on their own in the following three weeks.

There feedback and recommendations have been collected and a final revision was carried out before the tool was launched for the public.

The general feedback from the Train the Trainers workshop was very good. The proper functioning of the tool was approved, and the attractive design was highlighted. Some minor adjustments to make the explanations in the information boxes clearer have been carried out and some additional funding possibilities have been included in the checklist. Moreover, it was decided to translate the Autarky Rate Tool to all four partner languages.

Following that, the results of the Autarky Rate Tool have been compared with the results of the Optimal Sizing Calculator as well as with the monitoring results of the two pilots with an electrical storage, the Bračak Castle in Croatia and the Slope Elevator in Italy.

2.1. Validation/comparison with the Optimal Sizing Calculator

Due to the reason, that no monitoring data of the pilot plants was available at the time when the Autarky Rate Tool (ART) was finalized, the tool was validated/compared with the Optimal Sizing Calculator (OSC) in a first step. Two examples based on the pilot in Bračak, one with and one without a storage, have been calculated. By using the same load profiles, it was ensured that the results of both tools are comparable with each other. However, as the two tools are developed for different purposes, different calculation approaches have been used which leads to different results for some of the KPIs.

2.1.1. Example 1: without storage

<u>Inputs Optimal Sizing Calculator:</u>

- Basic parameters
  - Country: Croatia
    - Electricity cost: 12.66 cent/kWh
    - Peak power cost: 5.13 €/kWh
    - Feed-in: 6.66 cent/kWh
    - CO_2 emissions: 131 g/kWh
  - Consumer: Bračak manor
  - Peak power billing: yes
  - Yearly consumption: 17 320 kWh
  - Investment payoff period: 20 years
  - Investment limit: No
  - Optimality criterion: Yearly cost of the energy
- BESS parameters
  - Number of cycles: 2000
  - Depth of discharge: 0.8
  - (dis)charging efficiency: 0.9
  - Lifetime of power converter: 25 years
  - Price of battery pack: 770 €/kWh

  - Price of power converter: 660 €/kW
- PV system parameters
  - Maximal possible peak power: 10 kWp
  - Orientation: southwest
  - Inclination: 15°
  - Lifetime of PV system: 25 years
  - Price of PV system: 1050 €/kWp (no subsidies)

Results Optimal Sizing Calculator:

- Battery size: 0 kWh
- Power converter: 0 kW
- PV size: 10 kWp

The same scenario was calculated with the ART (see inputs below). The electricity prices (electricity cost, peak power cost, etc.), which are background numbers and can therefore not be entered by the user, are also chosen the same in both tools. However, there are also some differences in the calculation procedure of the two tools. For example, the ART calculates the storage losses based on the relation between the actual charging/discharging capacity and the maximum charging/discharging capacity, while in the OSC the storage losses are an input parameter. Moreover, the ART also considers funding possibilities of the investment cost for the calculation of the amortization period which are not considered in the OSC (at least not in example 1). And finally, the OSC is resampling the data of the demand and production profiles before the calculation while the ART is not. These differences must be kept in mind when comparing the results of the two tools.

Input Autarky Rate Tool:

- Type of power generation
  - Type: Photovoltaics
  - Peak Power: 10 kWp
  - Orientation: southwest
  - Inclination: 15°
- Consumer Characteristics
  - Consumption: 17320 kWh/year
  - Consumer Type: Castle (Bračak manor)
  - Country: Croatia
- Storage Parameter
  - Useful Capacity of storge: 0 kWh
  - Charging capacity: 0 kW
- Evaluation Period: whole year

Comparison of the results:

Table 1: Comparison of the calculation results without storage

	Autarky Rate Tool	Optimal Sizing Calculator	Comment
Autarky Rate	26 %	26.6 %%	-
Own Consumption Rate	55.0 %	53.8 %	-
CO_2-Emission Savings	590 kg	604 kg	-
Energy costs (100 % grid) - first year	3176€/year	2854 €/year	Note: The ART shows as result the mean value of the costs within the next 15 year considering an increase of the electricity costs of 2 % per year (=3176 €/year), while the OSC shows the results of the first year. If the results of the first year would be compared the output would be the same for both tools (=2854 €/year)
Energy costs with PV-system - first year	2005 €/year	1817 €/year	The deviation is caused due to the resampling of the data in the OSC*. If the resampling is deactivated the result of the OSC for the energy costs with PV - system in the first year would be 2004 €/year.
Savings - first year	849 €/year	1036 €/year	Differences due to results from the energy costs with PV-system in the first year (see above).
Amortization period	5 years	17 years	As the ART considers funding opportunities and the OSC does not, the results cannot be compared. However, a calculation with the ART removing the funding opportunities leads also to an amortization period of greater than 15 years (max. value of the ART).

* Resampling: Upon the initial implementation of the OSC it was noted that the computational requirements for running the tool were too large, i.e. a regular laptop or a PC would not be able to run the tool. Therefore, changes were made in the mathematical operation of the OSC to make it available for broader public. Electricity consumption profiles and the PV generation profile were recorded with sampling time of 15 min, but then they were resampled with sampling time of 1 h which makes the profiles 4 times smaller than the original ones and saves memory at the expense of the accuracy. The exact mathematical explanation is provided in deliverable D.T3.1.3 Finalized software tools for energy management in HUC.

Conclusion: The technical and ecological outputs of the ART & the OSC are similar, while the economic outputs are different. The different economic evaluation results come, on the one hand from different calculation procedures (resampling of the data in OSC - see above), and on the other hand from different assumptions. While the ART considers funding opportunities, the OSC (in this example) does not. As shown in Table 1 this has a significant effect on the amortization period. However, it is up to the user to also consider the funding opportunities in the OSC as shown in the example 2. If the same investment costs are used for the calculation and the resampling is deactivated, the results of both tools would be approximately the same.

2.1.2. Example 2: with storage

In example 2, the funding opportunities are considered in the OSC too. The lower investment costs lead to the recommendation of installing a storage with a capacity of approximately 10 kWh.

Inputs Optimal Sizing Calculator

Same as Example 1 except for the price of the PV-system:

- Price of PV system: 420 €/kWp (1050 € – 60% subsidies)

Results Optimal Sizing Calculator:

- Battery size: 9.47 kWh
- Power converter: 4.39 kW
- PV size: 10 kWp

Input Autarky Rate Tool

Same as Example 1 except for the Storage parameters:

- Storage Parameter
  - Useful Capacity of storge: 9.47 kWh
  - Charging capacity: 4.39 kW

Comparison of the results

Table 2: Comparison of the calculation results with storage

	Autarky Rate Tool	Optimal Sizing Calculator	Comment
Autarky Rate	32.3 %	27.32 %	Difference due to different operation modes of the storage (see below)
Own Consumption Rate	70.8 %	56.4 %	Difference due to different operation modes of the storage (see below)
CO_2-Emission Savings	732 kg	620 kg	Difference due to different operation modes of the storage (see below)
Energy costs (100 % grid) - first year	3176 €/year	2854 €/year	Note: The ART shows as result the mean value of the costs within the next 15 year considering an increase of the electricity costs of 2 % per year (=3176 €/year), while the OSC shows the results of the first year. If the results of the first year would be compared the output would be the same for both tools (=2854 €/year)
Energy costs with PV-system - first year	1961 €/year	1723 €/year	Difference because of the resampling (see example 1) and the different operation modes of the storage
Savings - first year	893 €/year	1130 €/year	Difference because of the resampling (see example 1) and the different operation modes of the storage
Amortization period	15 years	19 years	In both tools the funding opportunities are considered, however as the results above are different, the amortization period is too.

Conclusion: The differences of the technical outputs are caused by the implementation of different operation modes of the storage. The OSC simulates a full year of the storage performance and chooses the optimal values for charging and discharging the storage at every timestamp. It takes into account the storage degradation with every charging and discharging, which hinders the use of the storage. Also, aging of the power converter and the PV system are considered as maintenance cost. In contrast, the ART charges and discharges the storage based on the energy balances. The storage losses are calculated as result, but they are not part of the decision making. In other word, when a PV-surplus is available, and the storage is not already fully charged, the ART will always charge the storage first while the OSC could decide to feed-in the surplus in the public grid. Therefore, in the ART, own consumption rate, CO2 savings and autarky rate are higher, while the amortization period is lower. Moreover, the resampling in the OSC (see example 1) has still an influence on the economic results.

As the tools are developed for different purposes, different approaches have been used which leads to different results. However, it is clear where the differences come from, and it could be ensured that both tools work as intended. For the users of the tools, it is important to consider that the operation mode of the storage has also an influence on the optimal storage dimensions and the size of the PV-system.

2.2. Validation with the Croatian pilot (Bracak castle)

In course of the validation with the Croatian pilot, the calculation results of the Autarky Rate Tool have been compared with the already available monitoring that. At the time the report was written, monitoring data was available for August and September 2021. As shown in Table 3, the total energy demand and the total PV-production were measured for this period and the own consumption rate was known. Information about which share of the PV-production was used directly and which share was buffered in the storage was not known. Moreover, there was no information about the actual storage efficiency available at the time the report was created, which means that there was a bit of impreciseness in the calculation of the autarky rate from the monitoring data.

Table 3: Measurement data of the Croatian pilot

	August	September
Total energy demand [kWh]	1356	1065
Total PV-Production [kWh]	905	1220
Own consumption rate	90 %	85 %

The main parameters of the Croatian pilot are shown in Table 4. These parameters as well as the measurement data of the total energy demand (Table 3) have been used for the calculation with the Autarky Rate Tool. The comparison between the monitoring data and the results of the Autarky Rate tool are shown in Table 5.

Table 4: Parameter of the Croatian pilot

Peak power of the PV-system	10.8 kWp
Orientation	southeast
Inclination	15°
useful capacity of the storage	8 kWh
charging capacity of the storage	3.4 kWh

It was shown that the actual autarky rate and the actual own consumption rate were a bit higher than in the calculation of the Autarky Rate Tool. The difference of the own consumption rate is similar in both months with about 6 percentage points. The difference of the autarky rate amounts to 7 percentage points in August and 4 percentage points in September. A part of this difference can come from the calculation of the storage losses as the Autarky Rate Tool uses data from a lithium-ion battery, but a saltwater battery was installed in Croatia. However, as described above, there was a certain impreciseness in the monitoring results. Moreover, only a short period of time was available for the validation and the weather as well as the electricity demand profile will always differ a bit over the years. Therefore, the deviation between the monitoring data and the calculation results of the Autarky Rate Tool are within an expected range of tolerance. If the trend, that the results of the Autarky Rate Tool are lower than the actual monitoring data, would continue over a longer period, an adjustment of the data in the Autarky Rate Tool for Croatia/Bracak castle could be considered.

Table 5: Comparison of the calculation results with the monitoring data of the Croatian pilot

		Monitoring Data	Autarky Rate Tool
August	Autarky Rate	~ 52 %	45 %
	Own Consumption Rate	~ 90 %	84 %
September	Autarky Rate	~ 41 %	37 %
	Own Consumption Rate	~ 85 %	79 %
August - September	Autarky Rate	~ 47 %	41 %
	Own Consumption Rate	~ 88 %	82 %

2.3. Validation with the Italian pilot (Slope elevator)

When the report was created, measurement data was only available for about one month for the Italian pilot, divided in two measurement periods. All data for an exact determination of the autarky rate and the own consumption rate were available for this period. A detailed evaluation of the Italian monitoring data is available in *D.T 2.2.3: Final report of the HUC pilot action in Cuneo (IT)*.

The main parameters of the Italian pilot are shown in Table 6. These parameters have been used for the calculation with the Autarky Rate Tool. The comparison between the monitoring data and the results of the Autarky Rate tool are shown in Table 7.

Table 6: Parameter of the Italian pilot

Parameter	Value
Peak power of the PV-system	9.38 kWp
Orientation	south (-20°)
Inclination	70°
useful capacity of the storage	19.32 kWh
charging capacity of the storage	8.33 kWh

A look at the results of the autarky rate shows, that there is a larger difference between the monitoring results and the calculation results of the Autarky Rate Tool for the first period of time (20.10 – 06.11.2021), while the results are very similar for the second period of time (07.11. – 20.11.2021). The actual pv-production in the first period was with about 423 kWh much higher than assumed by the Autarky Rate Tool (218 kWh). The global radiation profile, which was used in the Autarky Rate Tool, was expecting more cloudy/rainy days, as there actually has been in 2021. However, as the results of the second period fits very well, it can be assumed, that the first period is not representative for the general quality of the calculation results. There will always be some periods, when the calculation results are different from the actual measurement data as the weather is varying from year to year. The smaller the chosen period for the calculation is, the larger this effect will be.

Table 7: Comparison of the calculation results with the monitoring data of the Italian pilot

		Monitoring Data	Autarky Rate Tool
20.10 – 06.11.2021	Autarky Rate	41 %	24.7 %
	Own Consumption Rate	86 %	100 %
07.11 – 20.11.2021	Autarky Rate	21 %	21.3 %
	Own Consumption Rate	88 %	100 %
20.10 – 20.11.2021	Autarky Rate	32 %	23.2 %
	Own Consumption Rate	86 %	100 %

Moreover, it was shown that the Autarky Rate Tool expects an own consumption of 100 %, while the actual own consumption is between 85 % and 90 %. A look at the measurement data shows, that there are peaks up to 12 kW in the monitoring data, which are higher than maximum power of the pv-inverter (8 kW) and the maximum discharging capacity of the storage. Therefore, these peaks cannot be covered with self-production only. In the used demand profile in the Autarky Rate Tool there are no peaks which are higher than 8 kW. Therefore, an own consumption rate of 100 % is possible in the Autarky Rate Tool. The currently used profile of the slope elevator was created generically based on measurement data of a short period only (see *D.T 3.1.3: Finalized software tools for energy management in HUC*). It is therefore recommended to exchange the currently used demand profile with the measured profile of the monitoring data as soon as a longer period of measurement data is available to increase the accuracy of the calculation results of the Autarky Rate Tool for the slope elevator.

3. External validation and evaluation

The goal of the external validation and evaluation was to ensure a good suitability and usability of the Autarky Rate Tool for the addressed stakeholder groups. This kind of validation was very important as the tool was developed to be generally applicable by non-experienced users like private household owners and should not be limited to the use within the Store4HUC pilot plants. The external validation and evaluation were carried out at the workshop with partners and members of the deployment desk (D.T 3.3.3) which was combined in some countries with the third deployment desk meeting (D.T 1.1.4). The Autarky Rate Tool was presented within the workshops, and the feedback of the stakeholders was collected. Moreover, the stakeholders have been asked to try out the tool on their own and provide a second feedback and recommendations for improvements at a later stage.

3.1. Austria

In Austria the Autarky Rate Tool was presented at the third deployment desk meeting and very positive feedback was collected. The participants agree that the Autarky Rate Tool can be very useful for showing the potential of electrical storages and to get more information about storages in general. Most of them are interested to use the tool and would sign the Memorandum. The training itself was interesting to get an introduction to the tool even if most of them agreed that they could also easily use the tool without the training. There have not been any recommendations for improvements yet.

3.2. Slovenia

In Slovenia the workshop with partners and members of the deployment desk, where they Autarky Rate Tool was presented, was carried out as an own meeting. The feedback for the Autarky Rate tool was also very good: "*the tool is excellent, very easy to use but still give a lot of data and information*". The tool will be used in the future as it is very concrete and actually useful. Certainly, everyone would sign a Letter of Intent. The training was fine, although the tool is pretty much self-explanatory, and they could start using it even without the training. There were no recommendations for improvements.

3.3. Croatia

Feedback in Croatia will be collected in the framework of the D.T 3.3.4 in the upcoming months.

3.4. Italy

During the 3rd deployment desk meeting in Italy the tools have been briefly presented and a survey was carried out. The questions were meant to understand the interest of the respondents in using the tools in the future and in attending the specific event planned for training of their use. Both questions got very good responses, being the 80 % of respondents interested in both. The workshop on using the tools was independently organized on the 1st of July as an online meeting. Detailed feedback will be collected in the framework of the D.T 3.3.4 in the upcoming months.

3.5. Germany

In Germany the Autarky Rate Tool was presented at the Zukunftsforum in Kassel Germany (online). The event was summarized by Michael Heidenreich as follows:

On 17.11.2020 between 9.00 and 10.30am an online event took place hosted by the Store4HUC partner Climate Alliance (PP10) and entitled with "Zukunftsforum Energie & Klima, F7: Energiespeicherung in historischen urbanen Gebäuden" and presented in German language. Responses on the following queries have been given by the presenters: "What potential do energy storage systems in buildings or urban districts offer and how can energy efficiency measures be implemented in listed buildings of historical value? Using the example of the Basilica in Weizberg, Austria, and with the help of a special online tool, we will discuss the opportunities and challenges of energy storage in historic buildings." In the following you may find some impressions of Michael Heidenreich (PP5) about the dialogue between the audience given in written in the chat room and orally answered by the presenters: Andrea Dornhofer (PP3) presented the integration of a thermal energy storage system into the existing Weizberg biomass heating system to increase flexibility and energy efficiency to be fully and seamlessly integrated as part of the regional climate and energy targets. Questions from the audience have been given mainly in regard to the degree of innovation of this pilot application and to the interaction with interconnected building storage facilities that allow a duplex operation of heat energy supply and injection of the sur-plus heat energy from the building to the grid via corresponding sub-stations. Robert Pratter (PP4) presented results of ad-hoc implemented data on the shown dashboard calculated via the Autarky Rate Tool based on average consumer behaviours. The constraints of the inputs have been discussed between the audience and the presenter and some valuable inputs of what would be nice to have in addition as input for the online tool published after its completion at a later stage.

Following questions regarding the Autarky Rate Tool has been asked:

- Is it possible to add an own demand profile?

No, it is not possible to add own demand profiles, but there are a lot of different load profile included. You have to choose the type of profile which would fit best. However, if you sent us your profile within the next weeks, we can still include it (remark: the profile was not sent)

- Can the tool be used for wind power plants?

  Yes, the tool can be used for photovoltaics, wind power plants and small-scale hydro power plants. But remember that amortisation period is only an estimation and the uncertainty for wind power plants and small-scale hydro power plants is larger than for photovoltaic system as these kind of power plants are normally made individually which results in a larger spread of the investment costs.

- Is the tool able to calculate the optimal storage size?
  - The optimal storage size can be found by trying out different scenarios, but the tool does no optimization on its own. However, the second tool which is developed in the Store4HUC project (Optimal Sizing Calculator) exactly does this. As such an optimization can last for some hours and needs a lot of calculation power, such on optimization would be against the idea of the Autarky Rate Tool which should be easy to use and able to provide fast results (calculation time lower than five seconds)
- Will the values like the electricity costs be updated time by time?
  - The tool will be updated at least once per year for at least six years.
- Is it possible to see which (cost) values are used for the calculation?
  - A document with background information of the most important values of the calculation will be published on the project website (see chapter 4).
- Is it possible to insert own cost values?
  - No that is not possible. We decided to make the tool easy usable for everyone who is interested in installing storage solutions in combination with renewable energy sources. That is why we have minimised the necessary input variables. However, an “Advanced mode” where such things are possible would be an interesting idea for future improvements of the tool.

4. Background information

This chapter is indented to provide the user with background information like the used load profiles, the used energy and investment costs or the considered funding opportunities and is directly linked to the Autarky Rate Tool.

4.1. Producer

To be able to reach a certain degree of autarky, an (renewable) energy source must be available. Nowadays, this source is mostly a photovoltaic system (PV-system), which is installed at the roof of a building or somewhere around (open space system). But also, wind energy stations and small-scale hydropower plants are included in the Autarky Rate Tool. This gives the user a bright variety of different application possibilities.

The inputs for the producers are shown in Table 8. The information about the orientation and the inclination is only necessary if a PV-system is chosen as producer.

Table 8: User input for the producer

	Input type	Options	Unit
Type	Drop down	PV, Wind or Water power	-
Peak power	input field	positive number	kW
Orientation (PV only)	Drop down	compass direction (S, SW, W, etc.)	-
Inclination (PV-only)	input field	number between 0 and 90	Degree

4.1.1. Wind power station

If a wind power station is chosen, a characteristic production profile is used, which is scaled with the user input of the peak power generation. The data for the profile was measured at a wind power station in Neusiedel am See in Austria in 2018. The course of the power generation for one year is shown in Figure 1. The power generation during summer is a bit lower and also in February, there are some days without wind, but generally there is a good production all year around. In Figure 2, one week is shown in detail. Normally there is a good production during day hours but no/less production in the night. This is of course one wind power station and the situation can be different for other stations at other locations or even for the same station in another year. However, it was considered accurately enough to enable the Autarky Rate Tool to make a good estimation how the autarky rate in combination with a wind power station can look like.

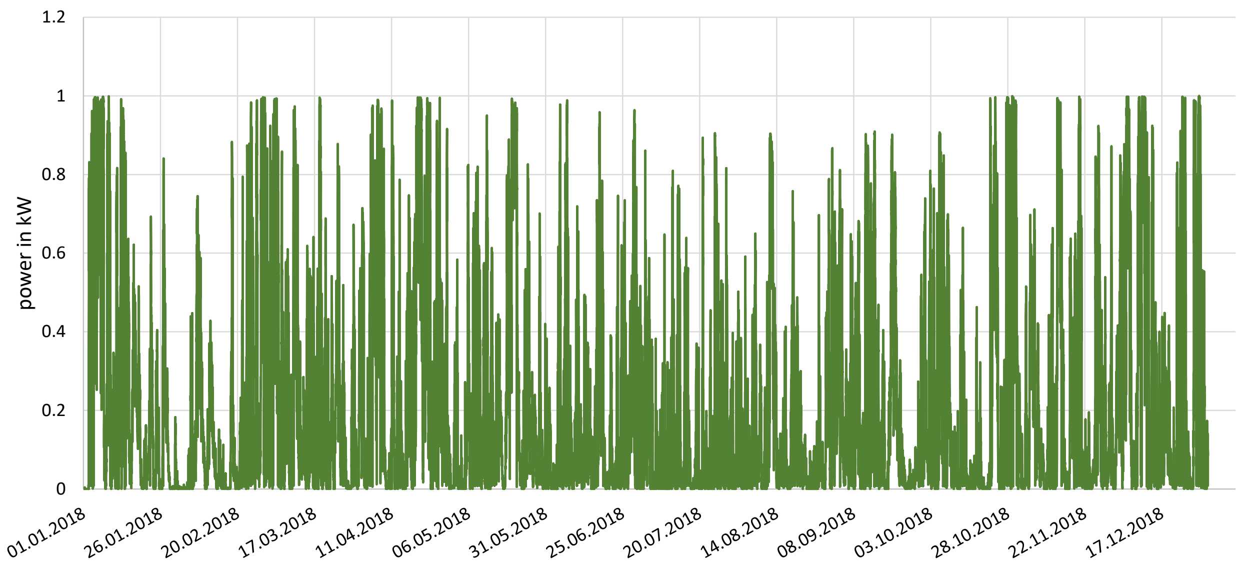

Figure 1: Production profile for the wind power station for one year

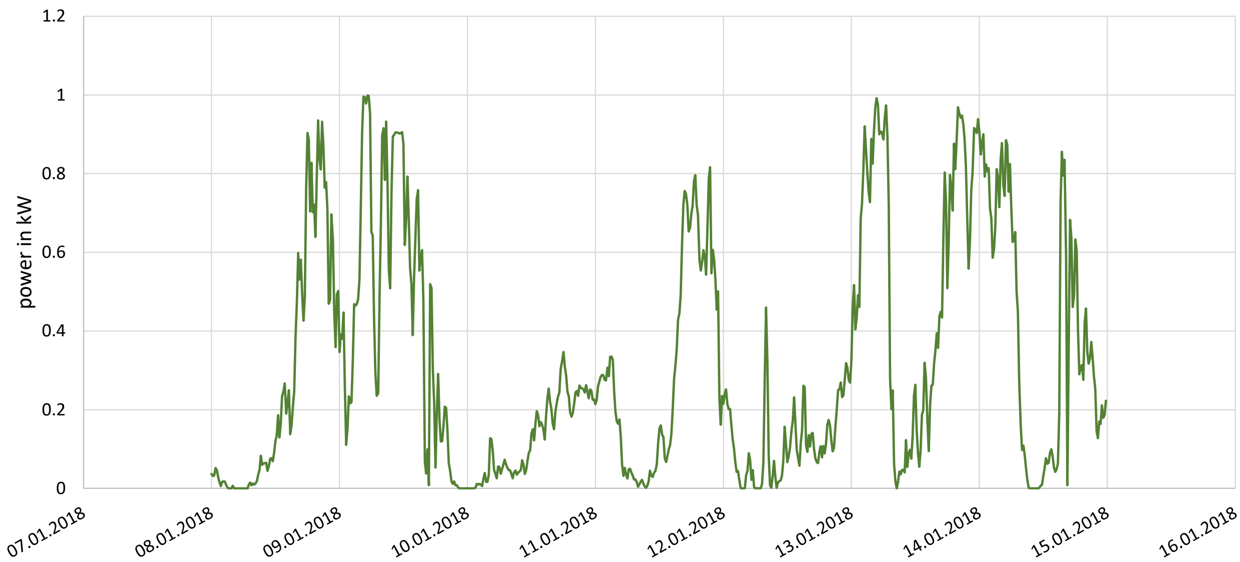

Figure 2: Production profile for the wind power station for one week

4.1.2. Small scale hydropower station

The same procedure was used for the small-scale hydropower station. A characteristic production profile is used, which is scaled with the user input of the peak power generation. The production profile is shown in Figure 3. The profile is based on measurement data for a smaller hydropower station in Austria. As the measurement data was only available for a short period of time and the data did not show major differences over the year, the same weekly profile was used in the calculation for the whole year.

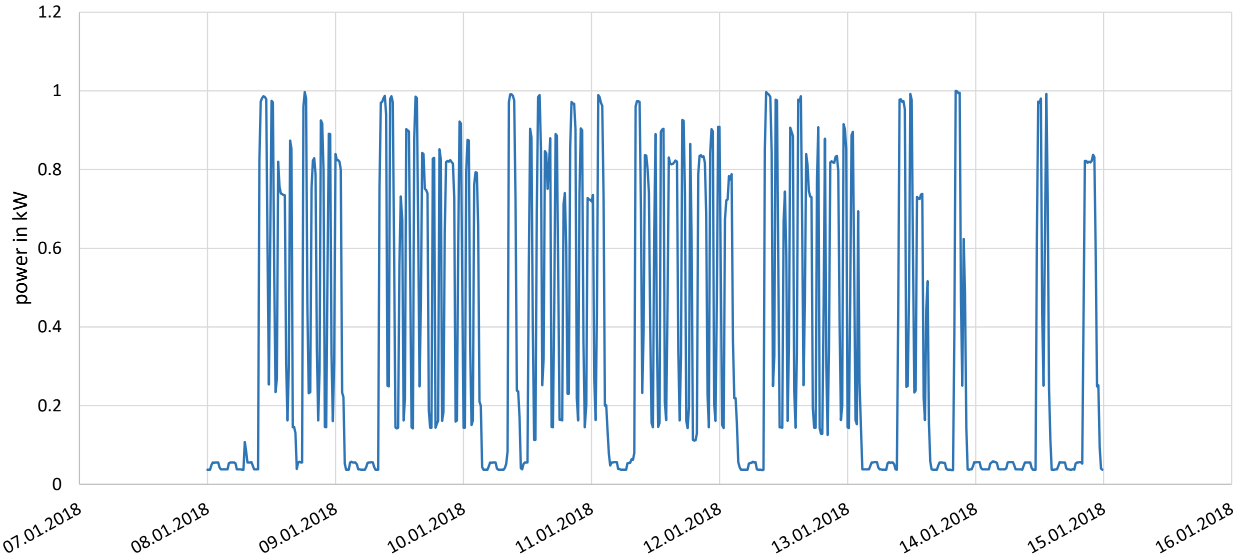

Figure 3: Production profile for the small-scale hydropower station for one week

4.1.3. PV-system

The calculation of the PV-production is a bit more complex than for the wind or hydropower station. The orientation (compass direction) and the inclination angle can be inserted by the user. With this information the global radiation on the inclined surface can be calculated from the profile of the global radiation on the horizontal surface and the information of the geographical location (course of the sun). If the global radiation on the inclined surface is known, the PV-production can be calculated by using the efficiency factor of a merchantable PV-system. The global radiation which is used for the calculation is shown in Figure 4. This data was measured in Neulengbach in Austria in 2016.

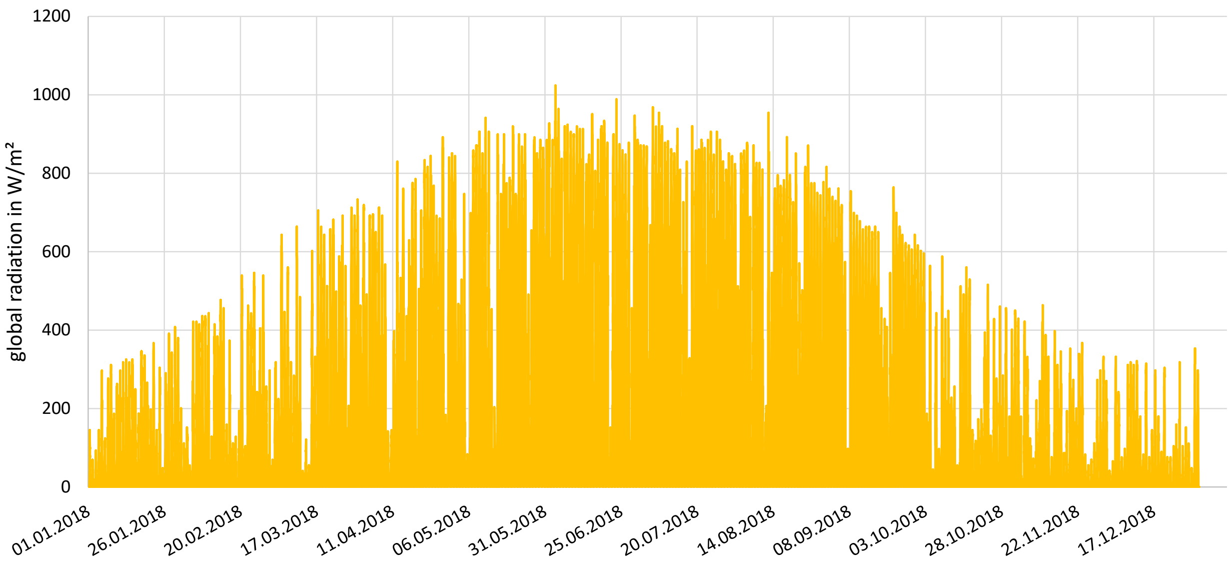

Figure 4: Profile of the global radiation

4.2. Storage

To specify the electrical storage, the useful capacity and the maximum charging capacity is necessary. These inputs are open to the user. The useful capacity indicates the energy amount of electric energy that can be stored in the storage in kWh. If the storage is full, the energy surplus has to be feed-in into the public grid. The maximum charging capacity indicates the maximum power in kW the storage can be charged and discharged with the electrical storage. If the power of the energy source is higher than the charging capacity, the surplus energy has also to be feed-in into the public grid, even if the storage is not completely charged. If for example, the maximum charging capacity is 2 kW and the RES minus current consumption would give a 3 kW surplus, 1 kW has to be feed-in into the grid. Moreover, this value has a large impact on the storage efficiency. The larger the deviation between the maximum charging capacity and the actual charging capacity, the higher are the storage losses (see also formulas in proceedings of IEA-PVPS)[1].

Note: In course of the project Store4HUC a second tool, which is able to calculate the optimal storage parameters, was developed.

Table 9: User input for the storage

	Input type	Options	Unit
Useful capacity	input field	positive number	kWh
Charging capacity	input field	positive number	kW

4.3. Consumer

The user is able to choose between different consumption profiles. For example, between different types of households (family household, single household with work, single household for someone who is retired, etc.), some types of industrial consumers or even a slope elevator profile. For each consumer a characteristic consumption profile is used. The household profiles are generated with the so called “Load Profile Generator”[2]. The Load Profile Generator is a modelling tool for residential energy consumption. It performs a full behaviour simulation of the people in a household and uses that to generate load curves. It is possible to choose between a wide range of predefined households or to model an own one.

For the industrial consumers standard profiles are used.[3] The profile of the slope elevator is based on measurement data of the elevator in Cuneo. To scale up the profiles, the user has also to enter the annual consumption or the consumption of the period if a shorter period is chosen.

Table 10: User input for the consumer specification

	Input type	Options	Unit
Type	Drop down	“Single household”, “Family household”, “Industry”, etc.	-
Annual consumption	input field	positive number	kWh/period

[1] https://iea-pvps.org/wp-content/uploads/2020/01/rep2_03.pdf

[2] Pflugradt Noah, Modellierung von Wasser und Energieverbräuchen in Haushalten (Load Profile Generator), Technische Universität Chemnitz, 2016

[3] APCS – Power Clearing & Settlement, Synthetische Lastprofile (online), https://www.apcs.at, 2020

A list of all implemented consumer profiles is shown in Table 11. As they are scaled by the user input, the important difference between them is the frequency and the points of time when energy is needed. For example, a household with employed workers consumes energymostly in the morning and in the evening, while a household with retired inhabitants does not show such a characteristic. Especially for the (direct) use of PV-energy this can make a big difference. Therefore, many different consumption profiles are implemented, to be able to cover different use cases.

Table 11: Consumer profiles

Profile	Type
Single household (working)	non-industrial profile
Single household (retiree)	non-industrial profile
Double household (1 working, 1 at home)	non-industrial profile
Double household (both working)	non-industrial profile
Double household (retiree)	non-industrial profile
Family household one child	non-industrial profile
Family household two children	non-industrial profile
Family household three children	non-industrial profile
Industry 24h working	industrial profile
Industry 8-18 weekdays	industrial profile
Shop	industrial profile
Agriculture	non-industrial profile
Slope Elevator	industrial profile
Castle (Bracak Manor)	industrial profile

In the following figures some of the profiles are displayed in detail to show the differences. The figures of the other profiles can be found in the appendix. In Figure 5, for example, a consumer profile of a single household of someone, who is working during daytime, is shown. In this profile the main consumption peaks occur in the morning and in the evening when the person is at home. During daytime only a smaller amount of energy is needed to cover the base load e.g. for the fridge, the freezer or devices in standby mode. There is a difference between the working days, but the main characteristic of the profile stays the same. The last two days (13.01 and 14.01) are Saturday and Sunday. For these two days the profile shows a different characteristic. On Saturday, for example, there is a high consumption until noon followed by a low consumption for the rest of the day. This could be because the tool assumes that the person leaves at noon and comes back lately. On Sunday, on the other hand, there is a higher consumption during the whole day. It has to be mentioned at this point that the profiles of the weekend are very different during the year depending on if the load profile generator assumes the resident stays at home this weekend or not. The characteristic of the weekday in contrast stays the same for the whole year except of a few weeks when the tool assumes that the resident is on holiday.

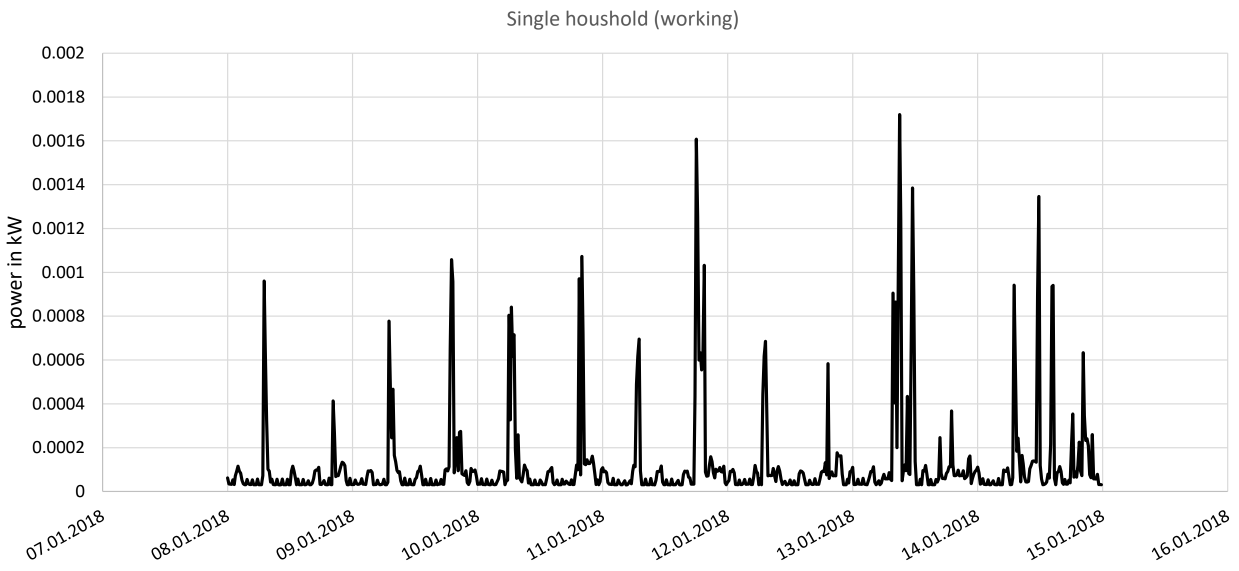

Figure 5: Consumer profile of a single household of someone who is working

In contrast to Figure 5 a typical consumption profile of someone who is already retired is shown in Figure 6. In this case there is no big difference between weekdays and the weekends. Moreover, there are also significant peak demands during the day and not only in the morning and in the evening hours.

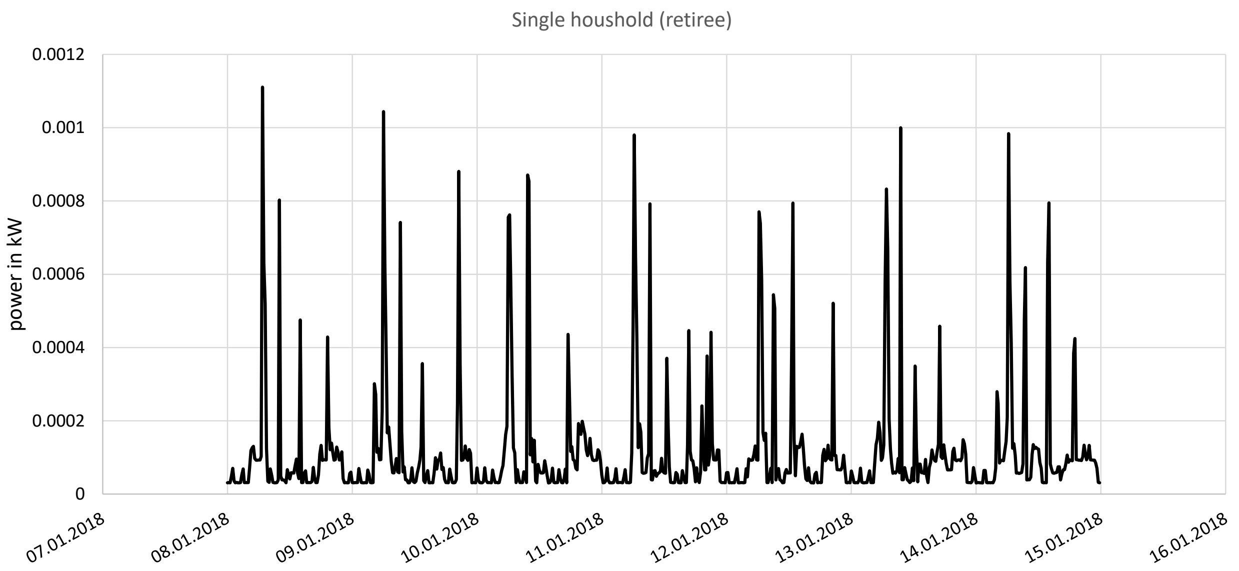

Figure 6: Consumer profile of a single household of someone who is retired

Figure 7 shows a typical consumption profile of a family household with three children. In this case there are also significant peak loads during the day and also the ground load is much higher than for a single person household. The reason why the peaks seem lower than in the previously described profiles is because all profiles are scaled to the same energy amount. It can be estimated that a family household with three children will have a higher yearly energy demand than a single household what will result in higher peak loads for this consumption profile after scaling it. On some days there is a higher energy demand than on others, but it is not clearly a weekday/weekend issue here.

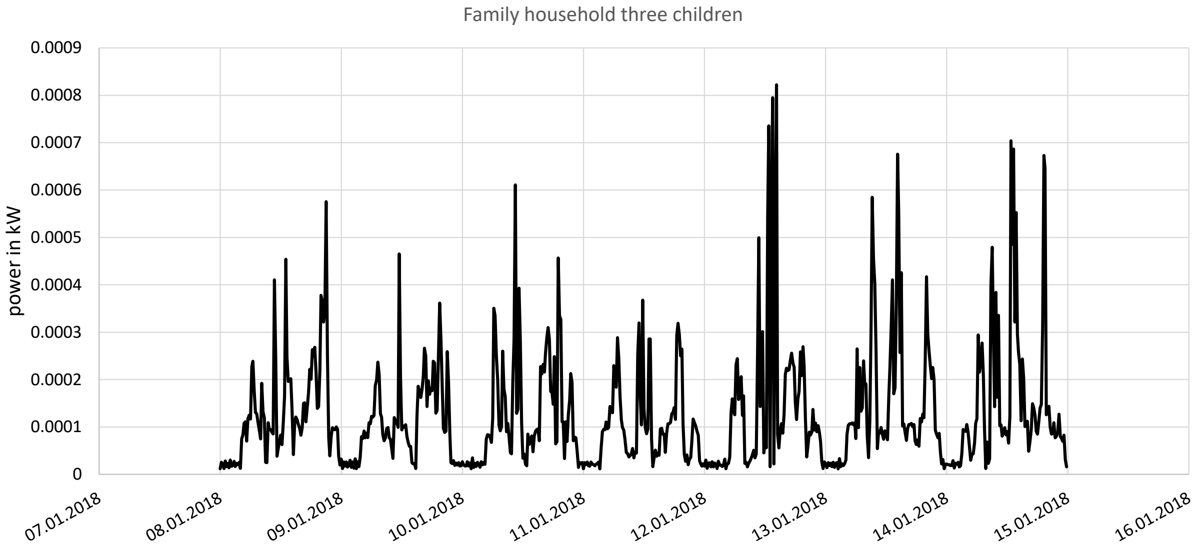

Figure 7: Consumer profile of a family household with three children

Figure 8 to Figure 10 show the consumption profiles for industrial consumers. These profiles are standard profiles and every week looks exactly the same. Figure 8 represents a profile for an industrial company which works for 24 hours. That means that there is always a significant energy demand needed. However, the energy demand is assumed to be lower during night times and on Sundays.

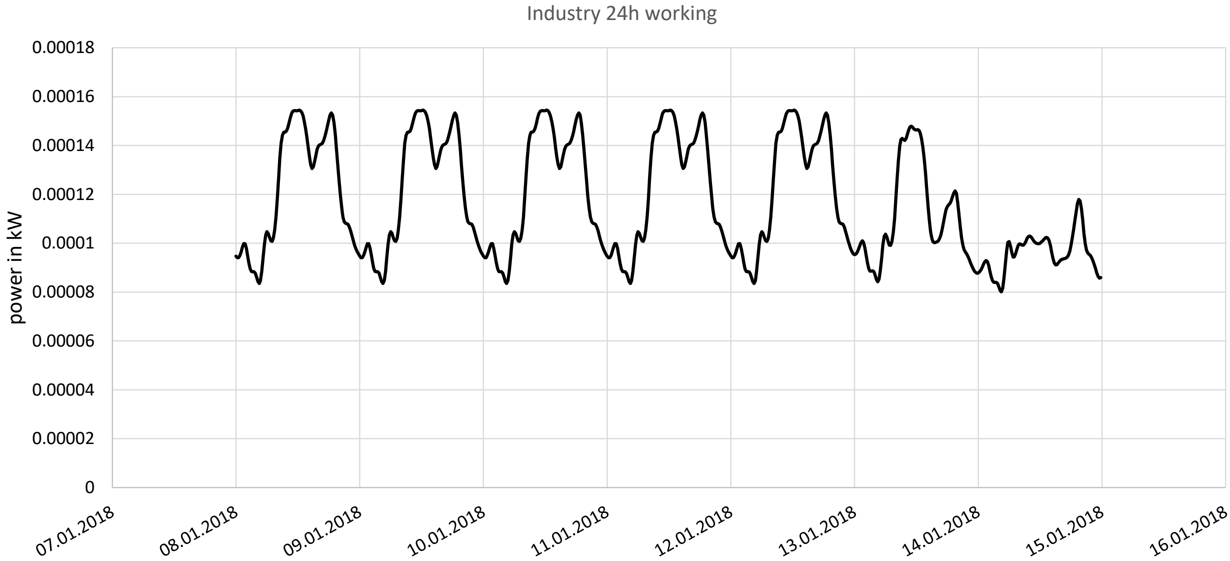

Figure 8: Consumer profile of an industrial company which is working for 24 hours

In contrast to that, Figure 9 shows the consumption profile for a typical industrial company with a working time between 8 am and 6 pm. During this time the company has a high energy demand. During night times and on the weekends only smaller load demands occur.

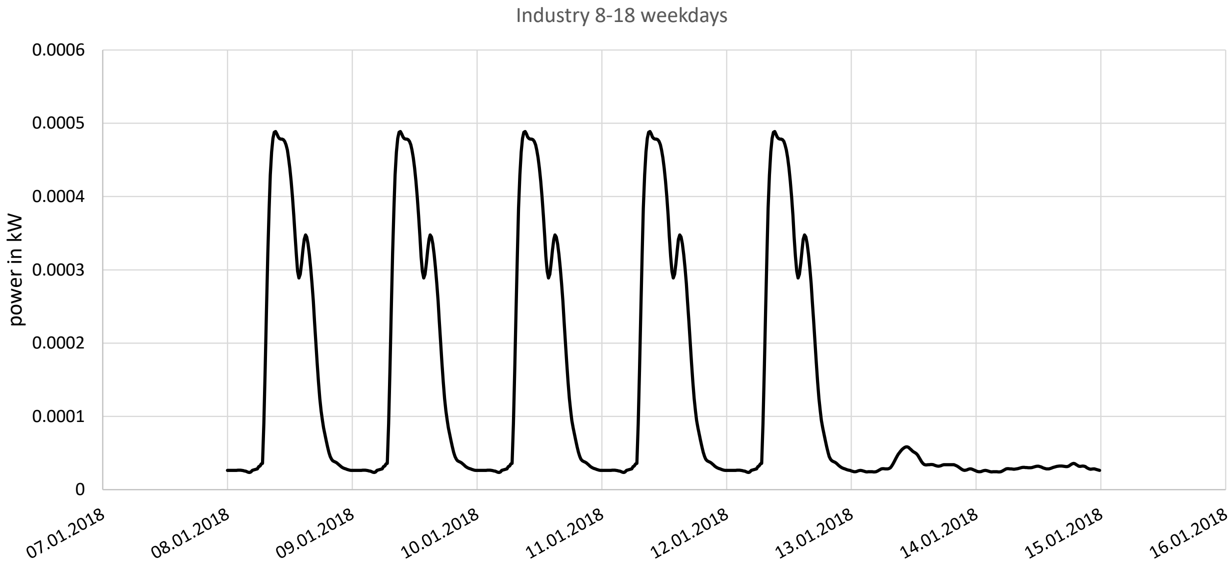

Figure 9: Consumer profile of an industrial company which is working on weekdays from 8 am until 6 pm

In Figure 10 a typical consumer profile of a shop is shown. The energy demand is considered the same for all weekdays. The most energy is of course needed during opening hours although lower loads are assumed at lunchtime. On Saturday shorter opening hours are assumed and no lunch break is considered. On Sunday there is only a low energy demand because the shop is closed.

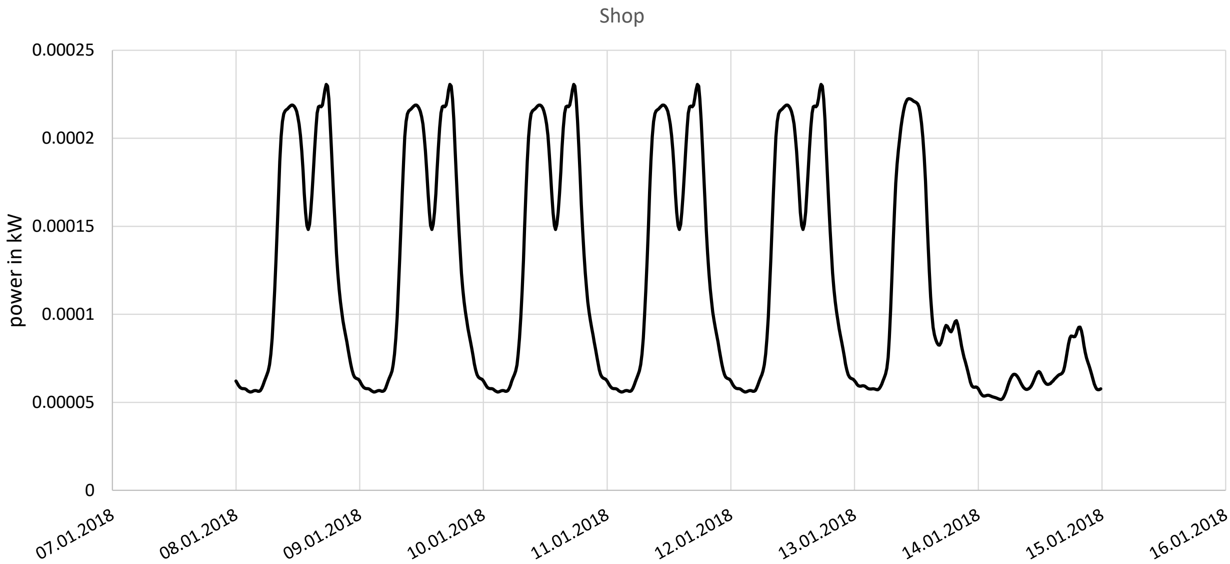

Figure 10: Consumer profile of a shop

4.4. Economic values (Country)

The selection of the country is used for the economic and ecological evaluation, as the average electricity costs, the feed-in tariffs and the share of CO_2 in the electricity mix are different in every country. These values have not to be entered by the user, only the country has to be selected. This approach was chosen, to simplify the use of the tool and to keep the number of necessary input variables reasonable.

It can be chosen between all participating countries (Slovenia, Croatia, Italy, Germany and Austria). The tool differentiates between industrial and non-industrial (private) users, depending on the chosen consumer profile (see Table 11). For industrial user peak power pricing and other electricity cost tariff (€/kWh) are considered. Based on the electricity costs (€/kWh), the peak power prices (€/kW) if an industrial profile is chosen, and the feed-in remuneration, the operational costs are calculated. For the reference case it is assumed, that the whole electricity demand must be purchased from the public grid (no production and no storage).

The investment costs consist of two parts, the costs for the production unit (€/kW) and the costs for the storage unit (€/kWh). Moreover, funding opportunities are also considered for photovoltaic and storage units. The funding opportunities are based on the mean funding amount per country, which can be expected. The investment costs and the actual funding amount can of course vary from case to case. Therefore, the calculated amortisation time can be only a rough estimation to be able to classify the selected scenario. The tool does not replace any individual technical configuration assessment.

The numbers which are currently used for the calculation are shown below. These numbers will be updated frequently in updated versions of the tool.

4.4.1. Electricity costs (non-industrial consumer)

For Austria and Slovenia, the electricity costs are considered depending on the annual electricity consumption. The tariff for Austria starts with 35.8 Cent/kWh for very low demands (<1000 kWh/year) and goes down to 16 Cent/kWh for demands >10 MW/year as shown in Figure 11. The tariff in Slovenia, see Figure 12, starts with 19.2 Cent/kWh for low demands and decreases down to 12.6 Cent for very large demands.

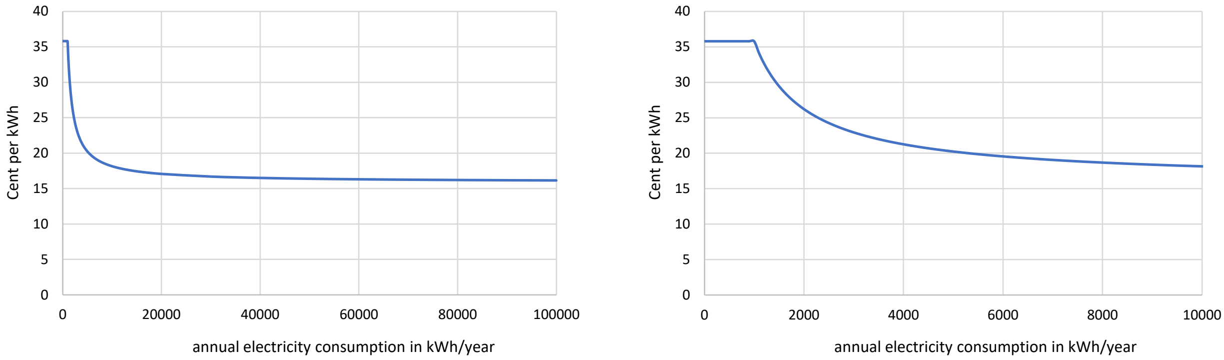

Figure 11: Electricity costs in relation to the annual electricity consumption for Austria (left: larger area 0 – 100 MW, right: detail between 0 and 10 MW)[4]

[4] Based on information from E-Control, requested 11.2020, https://www.e-control.at/statistik/strom/marktstatistik/preisentwicklung

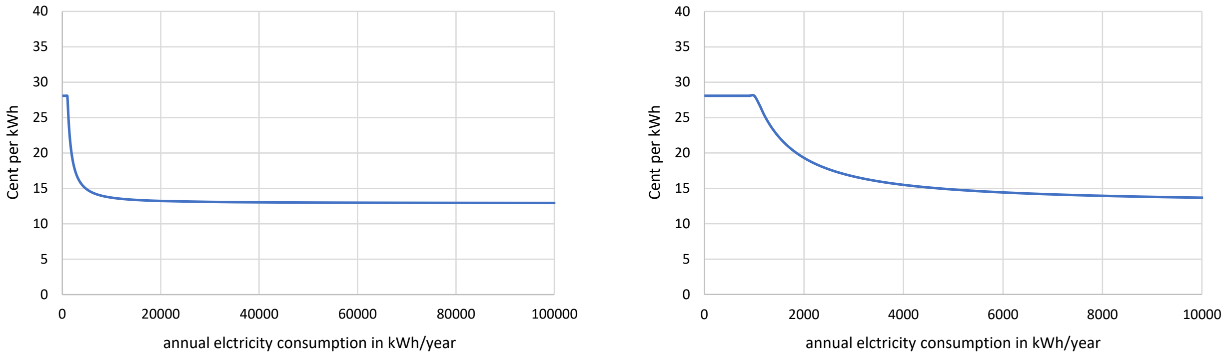

Figure 12: Electricity costs in relation to the annual electricity consumption for Slovenia (left: larger area 0 – 100 MW, right: detail between 0 and 10 MW)[5]

For Germany, Croatia and Italy constant electricity tariffs have been chosen, which are valid for average households:

- Germany: 30.88 Cent/kWh[6]
- Croatia: 13.11 Cent/kWh[7]
- Italy: 18 Cent/kWh

[5] Based on https://www.energetika-portal.si/statistika/statisticna-podrocja/elektricna-energija-cene/

[6] Based on https://www.destatis.de/...

[7] Based on https://www.hep.hr/elektra/kucanstvo/tarifne-stavke-cijene/1547

4.4.2. Electricity costs (industrial consumer)

For Austria and Slovenia, the electricity costs are considered depending on the annual electricity consumption. The tariff for Austria starts with 19.2 Cent/kWh for lower demands (<10 000 kWh/year) and goes down to 12.9 Cent/kWh for demands >1000 MW/year as shown in Figure 13. The tariff in Slovenia, see Figure 14, starts with 17.54 Cent/kWh for low demands and decreases down to 12.6 Cent for very large demands.

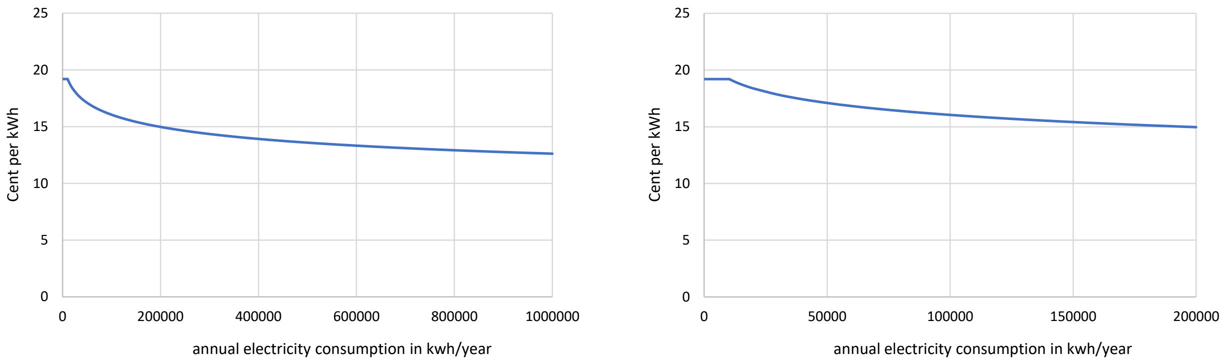

Figure 13: Electricity costs for industrial consumer in relation to the annual electricity consumption for Austria (left: larger area 0 – 1000 MW, right: detail between 0 and 200 MW)[8]

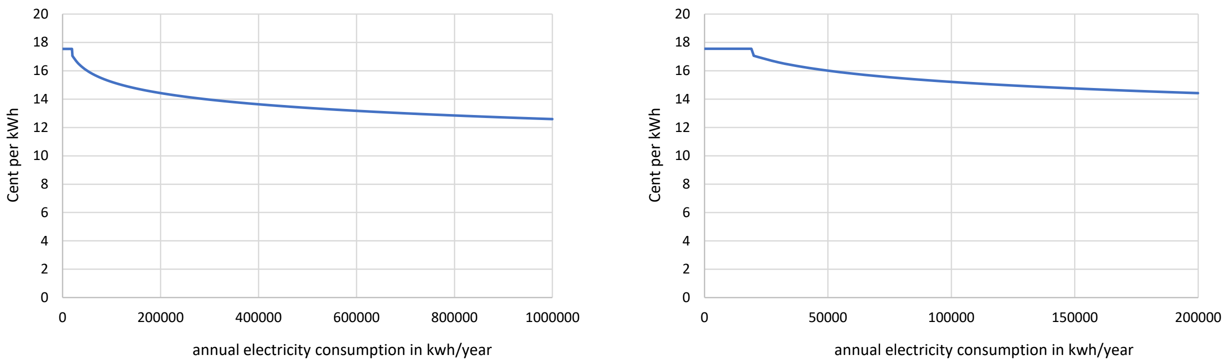

Figure 14: Electricity costs for industrial consumer in relation to the annual electricity consumption for Slovenia (left: larger area 0 – 1000 MW, right: detail between 0 and 200 MW)[9]

For Germany, Croatia and Italy constant electricity tariffs have been chosen which are valid for average households:

- Germany: 13.11 Cent/kWh[10]
- Croatia: 12.66 Cent/kWh[11]
- Italy: 19 Cent/kWh

[8] Based on information from E-Control, requested 11.2020, https://www.e-control.at/...

[9] Based on https://www.energetika-portal.si/statistika/statisticna-podrocja/elektricna-energija-cene/

[10] Based on https://www.destatis.de/...

[11] Based on https://www.hep.hr/elektra/poduzetnistvo/tarifne-stavke-cijene-1578/1578

4.4.3. Peak power prices

The peak power prices are only considered if an industrial consumer (see Table 11) is chosen. In this case, the electricity price is composed of the energy price (section 4.4.2 Electricity costs (industrial consumer)) and the price for the peak power shown below:

- Austria: 3.3 €/kW[12]
- Slovenia: 3.0 €/kW
- Italy: 4.925 €/kW
- Croatia: 5.13 €/kW[13]
- Germany: 15 €/kW[14]

The peak power costs are calculated monthly, by multiplying the peak power prices with the maximum power demand (kW) per month. The total costs result by summing up all monthly costs within the chosen calculation period.

4.4.4. Feed-in remuneration

The feed-in remuneration is the money the consumer gets for selling the production surplus to the public grid. In Austria, Slovenia and Germany the tariffs are chosen constant:

- Austria: 4.5 Cent/kWh[15]
- Slovenia: 5.1 Cent/kWh[16]
- Germany: 9.44 Cent/kWh[17]

For Croatia, the feed-in remuneration is calculated on a monthly base according to equation (1)[18]. The annual feed-in remuneration is the sum of all months within the chosen calculation period.

$$Feedin\ remuneration = min\left[E_t * 0.0666;\ E_f * 0.0666\right] \tag{1}$$

E_t = energy taken from the grid [kWh/year]

E_f = energy fed into the grid [kWh/year]

For Italy, the annual feed-in remuneration paid by the electricity grid operator for the exchanged energy is defined by the following equation (2):

[12] Based on https://www.ris.bka.gv.at/..., requested 11.2020
[13] Based on https://www.hep.hr/elektra/poduzetnistvo/tarifne-stavke-cijene-1578/1578
[14] Based on https://iam.westnetz.de/..., requested 10.2020
[15] Based on https://www.pvaustria.at/strom-verkaufen/, requested 11.2020
[16] Based on https://www.pocenielektrika.si/za-dom/cene-in-tarife/cenik/, requested 05.2020
[17] Based on https://www.solaranlage.eu/photovoltaik/..., requested 04.2020
[18] Based on https://www.hep.hr/ods/korisnici/kupac-s-vlastitom-proizvodnjom/29

$$Feedin\ remuneration = min[E_t * 0.08;\ E_f * 0.07] + min[E_t; E_f] * 0.06 \quad (2)$$

E_t = energy taken from the grid [kWh/year]

E_f = energy fed into the grid [kWh/year]

Another challenge of the electricity storage is related to auxiliary services in case of black-outs or performing efficiently by limiting the purchase from the grid.

4.4.5. Investment costs

The investment costs for photovoltaic units are shown in Figure 10. For Austria and Italy, the same data is used. In these two countries, small systems can cost up to 2125 €/kWp, larger systems cost about 1000 €/kWp.[19] In Croatia, the prices can be assumed to be a bit cheaper between 1250 €/kWp and 810 €/kWp[20]. For Germany (1280 €/kWp[21]) and Slovenia (1090 €/kWp[22]) constant mean prices have been used for the calculation.

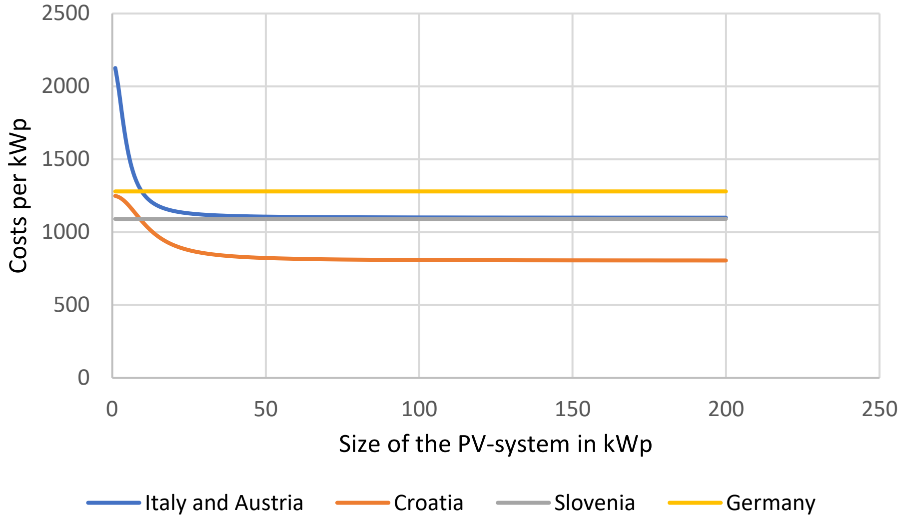

Figure 15: Investment costs for photovoltaic systems per kWp

The prices for wind energy and small-scale hydropower plants have been assumed the same for all countries. The prices are valid for smaller systems:

- Wind energy: 3800 €/kW[23]
- Hydropower: 7300 €/kW[24]

[19] Biermayr P. et al, Innovative Energietechnologien in Österreich Marktentwicklung 2019, Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (BMK), Wien, 2020

[20] https://www.solarno.hr/katalog/proizvod/ongrid4/huawei-solar-solarne-elektrane-cjenik

[21] https://www.ise.fraunhofer.de/...

[22] https://www.varcevanje-energije.si/...

[23] Based on: https://www.24ur.com/cas-za-zemljo/vetrne-elektrarne.html

[24] Based i.a. on Veh M., Steinbacher F. Effizienzsteigerung und Optimierungspotenzial bei bestehenden Wasserkraftanlagen, Steinbacher-Consult IngenieurgmbH&Co. KG (Link) and Nachtnebel H.P., Wasserwirtschaftliche Planungsmethoden, Institut für Wasserwirtschaft, Hydrologie und konstruktiver Wasserbau, BOKU, Wien (Link)

The investment costs of storages are depending on the storage type, the charging cycles, the efficiency, and of course the size of the storage. There is a certain bandwidth of possible storage costs. The differences between the countries however have turned out to be rather small. That is why the investment costs have been assumed the same for all five countries. Moreover, the prices for the most common lithium-ion storages are used for the calculation, which leads to a mean price of 1100 €/kWh.

4.4.6. Subsidies

In many countries there are lucrative funding opportunities for storages and photovoltaic systems available, which can reduce the costs of such systems significantly. To get a realistic assumption of the amortisation time, the funding opportunities of these technologies are also considered in the calculation.

For wind energy and small-scale hydropower no general funding opportunities are considered. It is common that grants for these technologies have to be evaluated individually.

- In Austria, a funding amount of 250 €/kWp for photovoltaic system smaller than 100 kWp can be expected. For systems between 250 kWp and 500 kWp, the funding amount is a bit lower with about 200 €/kWp. For larger systems (>500 kWp) no general funding opportunities are available. In addition, a storage funding of 200 €/kWh is considered in the calculation. This funding opportunity is limited with a total amount of 10 000 € for storages larger than 50 kWh.[25]
- In Slovenia, the funding for photovoltaic systems is considered with 180 €/kWp. For storages no additional grants have been taken into account.[26]
- In Croatia the subsidies on photovoltaic systems amount up to 60 % of the investment with a maximum funding amount of 7250 €.[27]
- In Germany and Italy there are no national subsidies. Every federal state has its own funding opportunities. As the tool is currently not able to deal with different situation within one country, the decision was made to not consider subsidies in Italy and Germany at all.

4.4.7. Amortisation period

For the calculation of the amortisation period, a pricing interest rate of 0.1 % and a useful lifetime of 15 years are assumed. Moreover, an increase of the electricity price of 2 % per year and an increase of the feed-in tariff of 1 % per year are taken into account.

4.5. Ecological values

The yearly CO_2 emission abatement (KPI_3) depend on the CO_2 emission factor of the applied energy source and the electrical energy consumption of the pilot system, which is supplied by an external source and is calculated as follows:

$$CO_2\ savings = E_{c\_tot} * EF \tag{3}$$

[25] Photovoltaik Austria, requested 11.2020, https://www.pvaustria.at/forderungen/
[26] https://www.ekosklad.si/...
[27] http://energetska-obnova.hr/

E_{c_tot}	Total electrical energy consumption of the pilot system, supplied by external sources for one year in kWh
EF	CO_2 emission factor to be applied to the energy source in t_{CO2}/kWh

Following CO_2 emission factors are used for the calculation:

- Austria: 85 g/kWh[28]
- Slovenia: 480 g/kWh[29]
- Italy: 298.2 g/kWh
- Croatia: 131 g/kWh[30]
- Germany: 474 g/kWh[31]

4.6. Period

The input of the "period of time" gives the user the possibility to calculate the results also for a smaller period of time. Therefore, it is possible to calculate the autarky rate, for example, only for the summer or the winter months and see how it is changing. Or if the energy consumption is only known for a certain time period and not for a whole year, the particular time period can also be chosen for the calculation. However, if the calculation of the amortisation period is the goal, it is recommended to choose a whole year as calculation period.

[28] E-Control Stromkennzeichnung Österreich, requested 11.2020, https://www.e-control.at/...

[29] https://ceu.ijs.si/izpusti-co2-tgp-na-enoto-elektricne-energije/

[30] https://hep.hr/opskrba/electricity-market/eletricity-market/electricity-sources/1474

[31] https://www.umweltbundesamt.de/...

Appendix

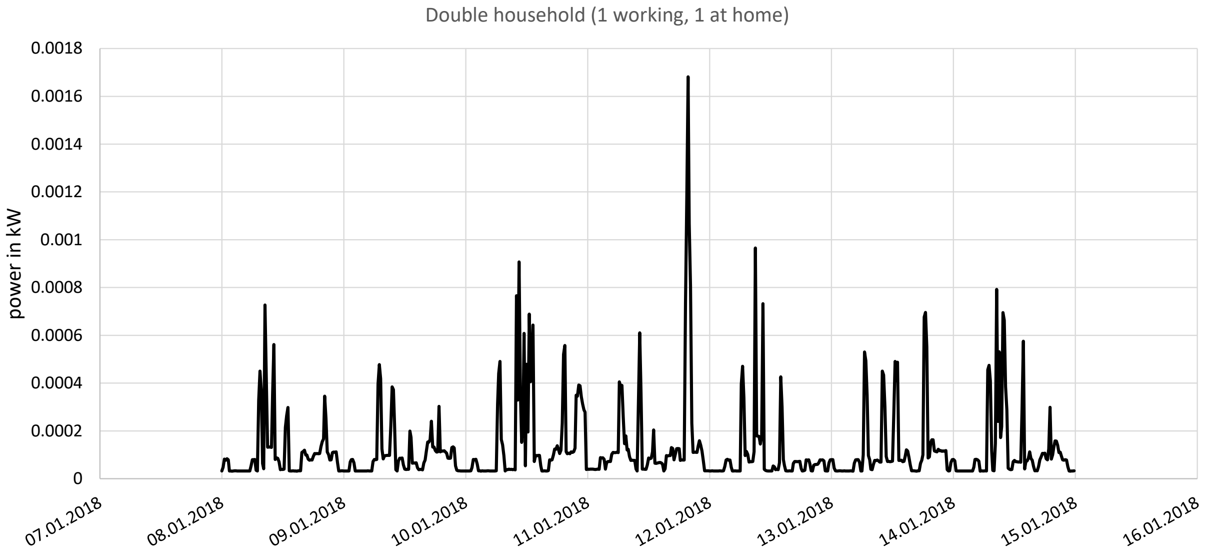

Figure 16: Consumer profile of a double household (1 working, 1 at home)

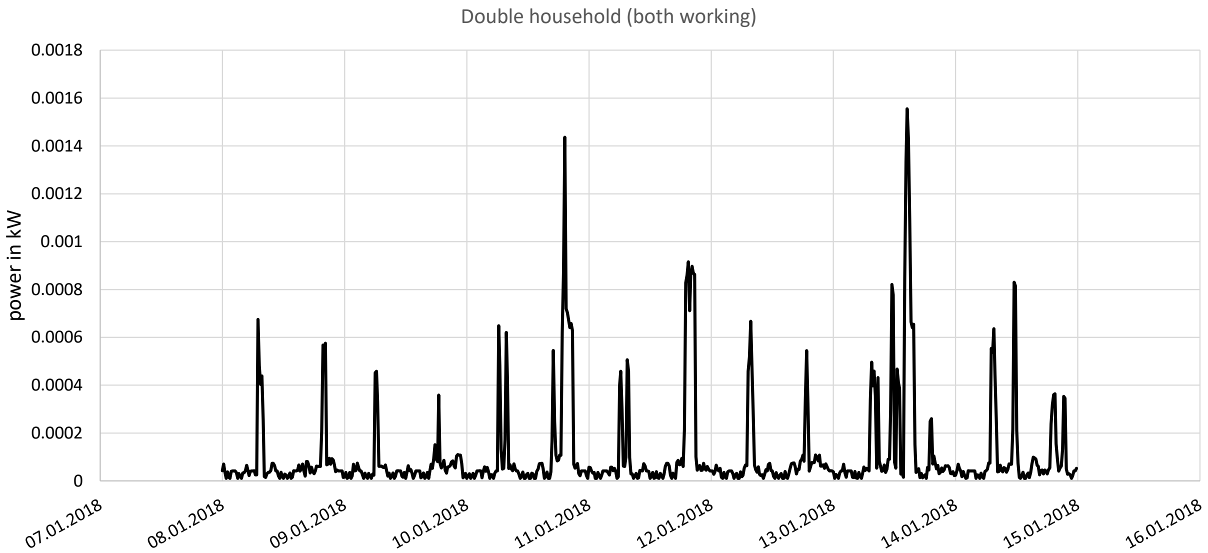

Figure 17: Consumer profile of a double household (both working)

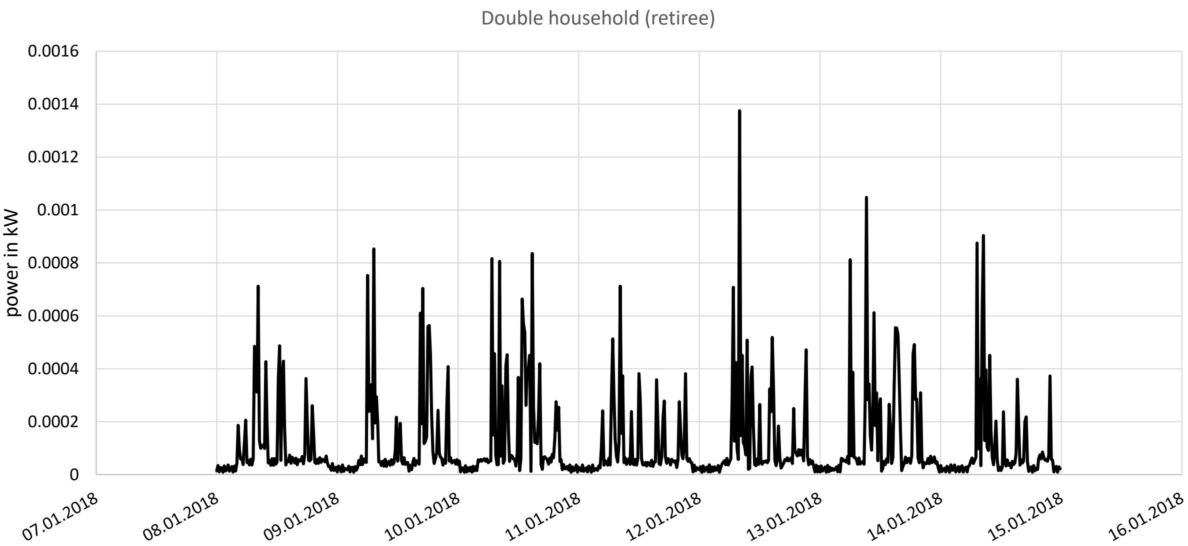

Figure 18: Consumer profile of a double household (both at home)

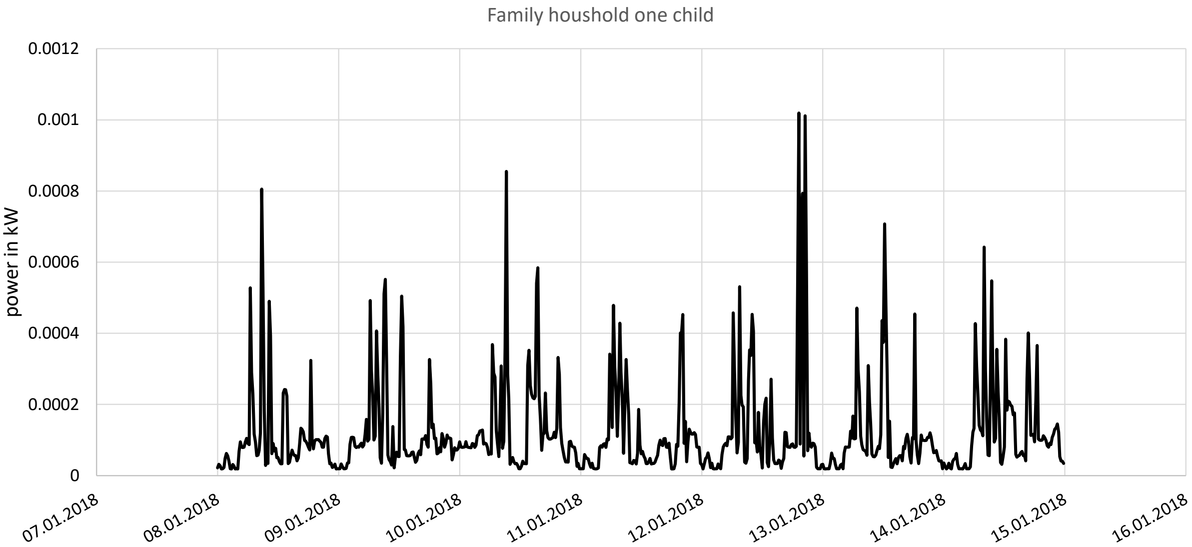

Figure 19: Consumer profile of a family household with one child

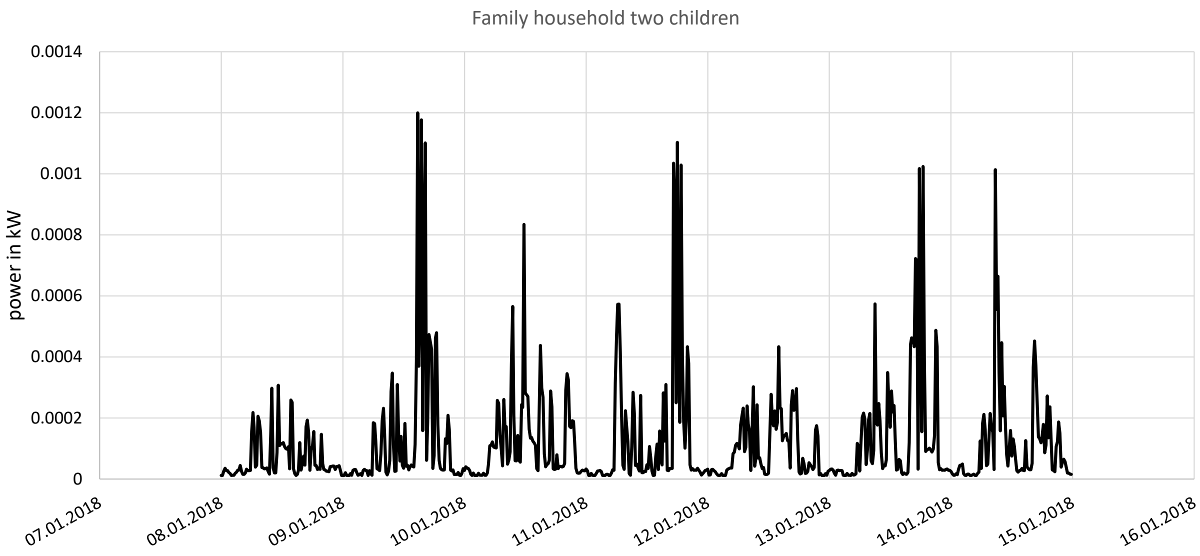

Figure 20: Consumer profile of a family household with two children

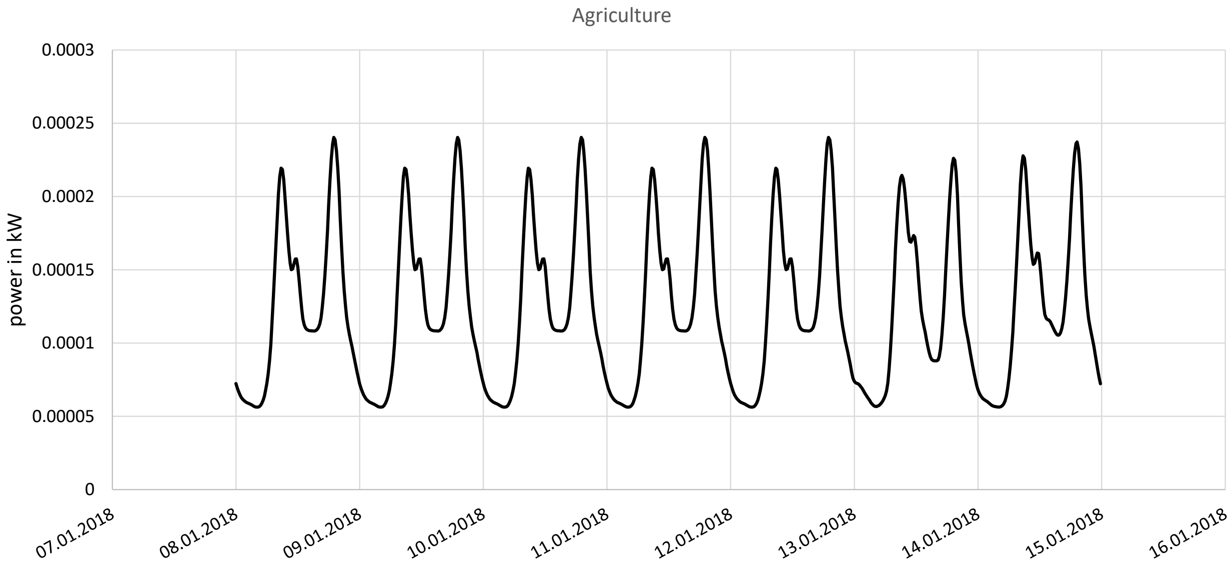

Figure 21: Consumer profile of an agriculture holding

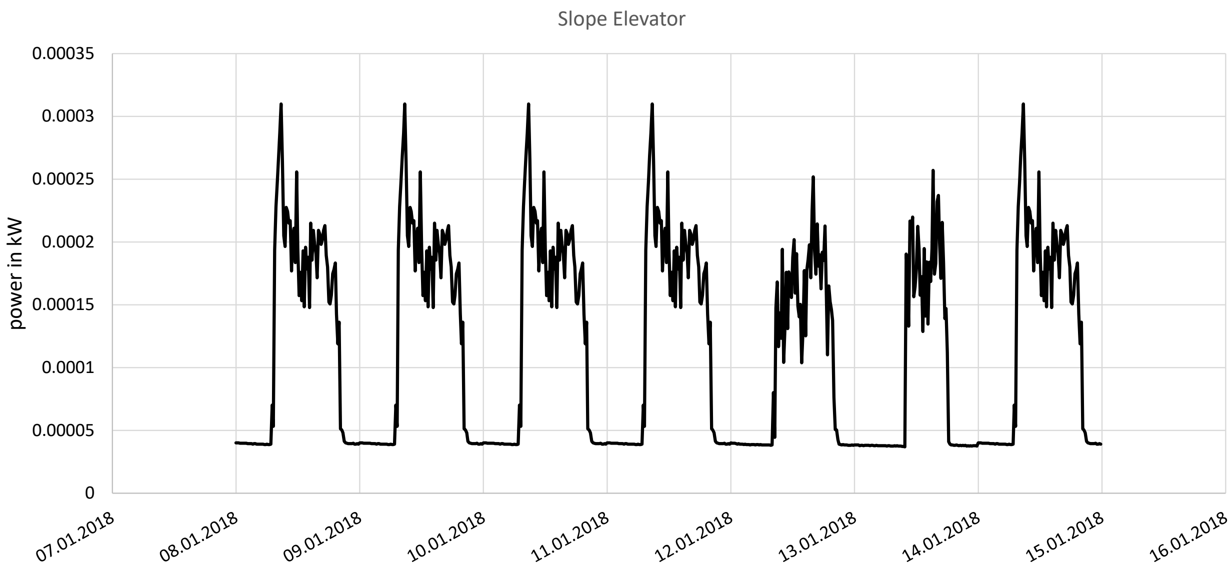

Figure 22: Consumer profile of a slope elevator[32]

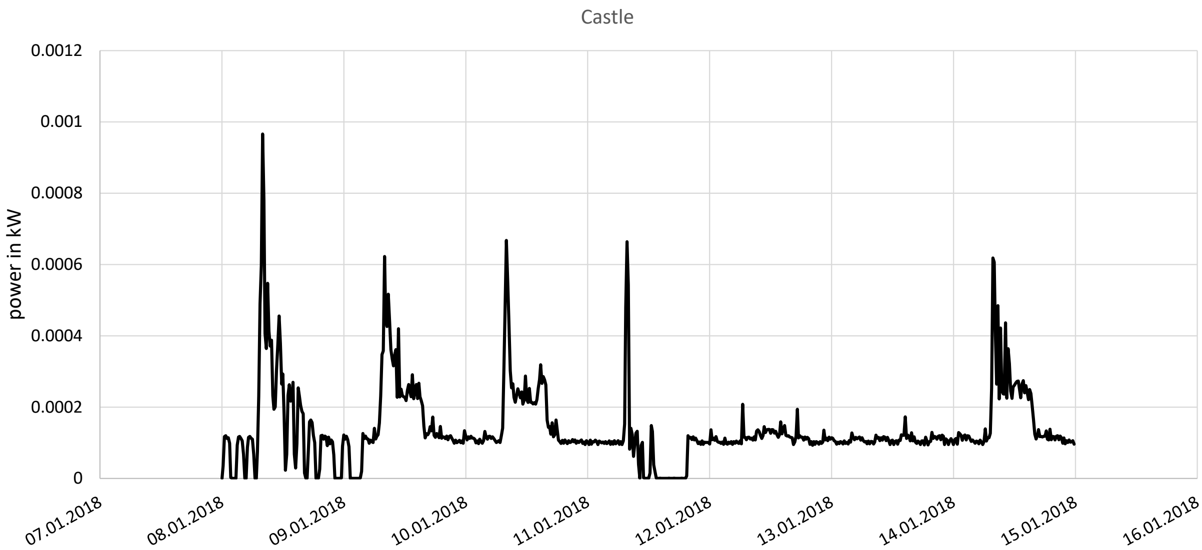

Figure 23: Consumer profile of a castle (Bracak Manor)[33]

[32] Information about the slope elevator pilot in Cuneo is available in the Deliverable D.T 2.1.2

[33] Information about the Bracak Manor pilot in Croatia is available in the Deliverable D.T 2.1.3