FP7 Collaborative Project
no 608806

Project duration:
October 2013 – September 2016

Coodinator:
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Strategic objective:
6.4 Optimizing Energy Systems for Smart Cities

Website:
www.cossmic.eu

D6.2 Report on collected, analyzed and evaluated measurement data

VERSION/STATUS	**DUE DATE**	**DELIVERY DATE**
1.1/External proposed(2)	2016-12-31	2017-04-06
DELIVERABLE NATURE	**DISSEMINATION LEVEL**	**NUMBER OF PAGES:**
R=Report	PU=Public	65

EDITOR

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ABSTRACT

This deliverable documents the data collected during the trials, and the evaluation of the data w.r.t. the KPIs defined in D6.1. CoSSMic evaluation includes early evaluation based on user centred design and involvement, and final evaluation using experiments and simulations based on trials on two trial neighbourhoods in Germany and Italy, respectively. The final evaluation follows the method also defined in D6.1, and includes computer simulations based on the collected data.

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CITE AS

CoSSMic deliverable D6.2, Report on collected, analyzed and evaluated measurement data, 2016

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Document history

VERSION	DATE	VERSION DESCRIPTION
0.1	2016-11-30	PCOS proposed (Planned COntent and Structure)
0.2	2016-11-30	PCOS approved
0.3	2016-11-30	Intermediate proposed (editor considers about 50% complete)
0.4	2016-12-16	Intermediate approved
1.0	2017-03-02	External proposed (proposed for external release)
1.1	2017-04-06	2nd External proposed (addressing reviewers' comments)

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1 About this Document

1.1 Role of the deliverable

The main goal of this deliverable is to describe how the CoSSMic concept and implementation is evaluated. The DoW already states that the evaluation will be based on data collected from field trials where the implemented system is installed in a number of households and used regularly by their inhabitants over a one year period. The one year duration of the trial period was chosen to capture the seasonal variation in insolation and outside temperature.

In this deliverable we refer to and apply the establish KPIs as introduced and described in D6.1 to evaluate the system, which data we need to collect in order to compute them and how the data will be collected.

Since both the number and diversity of trial households are rather limited due to budget, regulatory and organisational constraints, the project has decided that the analysis of the collected data will be complemented with simulations where user behaviours observed during the trials are replayed in a simulated context. In the simulations we can simulate phenomena that we were not able to realise in the trials, and also investigate how the system scales with increasing number of households and devices in a neighbourhood.

This deliverable also includes a justification and plan for the evaluation of the system and data by the carried out simulations.

1.2 Relationship to other CoSSMic deliverables

This deliverable reports on the evaluation based on the support and outcome of the deliverables D6.1, D6.3 and D6.4, for the evaluation design of measurement data, the habits of the integrated users and the implementation of simulations and the evolved feedback with the measured data.

This deliverable refers also to D2.4. D2.4 describes the energy related data measured, processed, logged and visualised through the GUI acting as the interactive interface between the CoSSMic system and the trial users.

In D3.3 are described all integrated data models and their data formats for PV production, weather forecast, device load profiles, tasks and schedules as logged and processed in EmonCMS[1].

References are also drawn to D5.1 which describes the involved buildings, systems, equipment and users of the trials and to D5.3 which **r**eports on the completed configuration of the software and hardware installations at the trial user sites, which is the infrastructure for the data acquisition.

1.3 Structure of this document

Chapter 2 gives an overview of the evaluation methodology and the objectives and suggests the need of the evaluation of the measured data by simulation support.

Chapter 3 describes the origin of the measured data.

Chapter 4 describes the data analysis and selection for evaluation and simulation.

Chapter 5 presents the evaluation of the data with respect to the key performance indicators (KPIs) as defined in D6.1.

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[1] https://bitbucket.org/cossmic/developer-guide/wiki/Complete%20integrated%20version%20of%20the%20software

Finally chapter 6 concludes the work and is followed by an appendix.

2 Methodology for evaluation

The evaluation of the CoSSMic concept has included several kinds of activities:

- Early evaluation and feedback based on user-centred design principles[2] and user involvement.
- Final evaluation based on field trials with the implemented prototype.
- Simulation based on data collected during the trials, using the simulation tool presented and documented in D6.4.

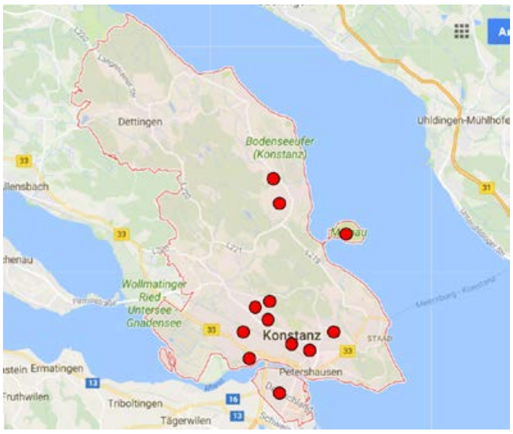
During early evaluation user requirements have been collected and validated by means of interviews and workshops with potential trial users at the two trial sites in Germany and Italy. Furthermore, the GUI has been designed following user-centred approach, and the concepts have been co-developed and validated with stakeholders and users in user centred design workshops[3, 4]. Both paper prototypes and mockups of the user interface were used during this phase of the evaluation, as well as early versions of the developed system with only partial functionality.

One important feedback was that users were generally unwilling to spend time on inputting additional information on a smart phone or pad each time they started a potentially flexible task. Therefore, we introduced user defined default rules and automatic detection of the start of single-run devices. If the user just switches on the device without entering specific constraints the system will automatically recognise that the device has been started, assume the default rules for load shifting and schedule the task accordingly.

For the final evaluation based on field trials two trial neighbourhoods has been set up, one in the City of Konstanz (Germany) with 12 households and one in the Province of Caserta (Italy) with 5 households. The trial neighbourhoods include private households, industrial buildings, schools, and a swimming pool, thus ensuring varied usage patterns and needs.

The following two maps show both trial sites, Caserta and Konstanz, where data were collected from.

Trial site “Province od Caserta”, Italy



Trial site “City of Konstanz”, Germany

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[2] Kubie, J. J. (2000). IS Management Handbook: 7th Edition. J. J. Kubie, R. C. Melkus, L.A. Johnson and G. A. Flanagan, CRC Press: 463-480.

[3] L. Wienhofen, C. Lindkvist, and M. Noebels, “User-centered design for smart solar-powered micro-grid communities,” in Proceedings of the 14th International Conference on Innovations for Community Services (I4CS), 2014. IEEE, 2014, pp. 39–46.

[4] J. Glatz-Reichenbach, T. Vilharino, G. Cretella, C. Lindkvist, A. Minde, and L. W. M. Wienhofen, “End user centred interactive software architecture and design: The creation of communities for a smart energy use,” in Proceedings of the 14th International Conference on Innovations for Community Services (I4CS), 2015. IEEE, 2015, pp. 1–8.

Konstanz households are distributed across the City of Konstanz without local relation to each other. This means, that all of them are therefore connected to different low voltage (LV) feeders and branches, respectively. The Caserta households are even more spacious distributed across the province of Caserta. This was necessary, to be able to select a representative amount of willing participants, without the very strict limitation of them being on the same LV branch. Therefore, even though the correct term for the connected households would be a virtual power plant, the selected households were treated in the further simulations and evaluations as if they would actually be located on the same branch and build a virtual neighbourhood. Further, each household (or company or public building) forms an individual Microgrid. The Microgrids are connected via the public grid, for them to end up in so called *Collaborating Solar-powered Smart Microgrids.*

The data collected in the trials include:

- The trace of the PV production prediction updates during the trials tagged with household, device and timestamp
- The trace of the output from all the PV systems
- The trace of the consumption per device
- The trace of the total energy consumption and production per house

The initial plan as described in D6.1 was to observe the use of the CoSSMic prototype with neighbourhood wide coordinated load shifting by real users, and use the simulator to compute comparable results without the CoSSMic load shifting in place, by replaying the event traces from the trials with all the flexibility in the task planning events removed. We planned to collect data over a one year period in order to cover the seasonal variation of insolation, weather conditions and energy use.

The monitoring and data recording part of the system has been deployed and been in regular use in the field trials in Konstanz largely as planned, and we have collected detailed data on the PV production and electric energy consumption of most of the trial buildings for a full year. However, due to significant delays in the implementation of the automatic load shifting mechanism, the initially planned approach could not be implemented. There was simply not enough time to collect data from the use of the coordinated load shifting.

Therefore, instead of observing the behaviour of the automatic load shifting in the trial sites and compute the baseline without load shifting using the simulator as originally planned, we did the opposite. We observed the baseline behaviour of the trial sites without automatic load shifting, and repeated the observed behaviour in the simulator with the automatic load shifting in place. The amount of flexibility provided by the users, which with this change could not be observed in the trials, we estimated based on informal feedback from the trial users during the user centred design workshops and contact with the users during the trial period.

As already mentioned, simulation were carried out using simulation tools developed in the project. These tools enable the execution of the CoSSMic prototype in a simulated environment where the description of the neighbourhood and the input to the system from users and external services are extracted from the data collected in the trials. However, it is also possible to modify the extracted scenarios and to create artificial ones.

The latter feature was intended to investigate the influence of factors that due to practical or regulatory constraints were not so easy to experiment with in a limited trial as ours, for example the number of households of the neighbourhood, capacity of the PV systems, the amount of storage, and the kind and number of appliances of each household. By systematically varying these aspects of the simulated scenarios, we planned to investigate the influence of these factors on the performance of the system. In this way we hoped to overcome to some extent the limited size and representativity of our trials.

However, due to the late arrival of the coordinated load shifting mechanism, there was no time to carry out such simulations.

3 Measured data

This section describes the measured data collected in the trials.

3.1 Energy generation data

The households and the integrated hardware are already introduced and defined in D5.1 and extensively described in detail in D5.3. The following diagram in Figure 1 shows the various energy and power flows, respectively, in a Konstanz household, for simplification, we mark only the energy flow symbols. The stationary battery (storage) is charged always only by PV generated energy.

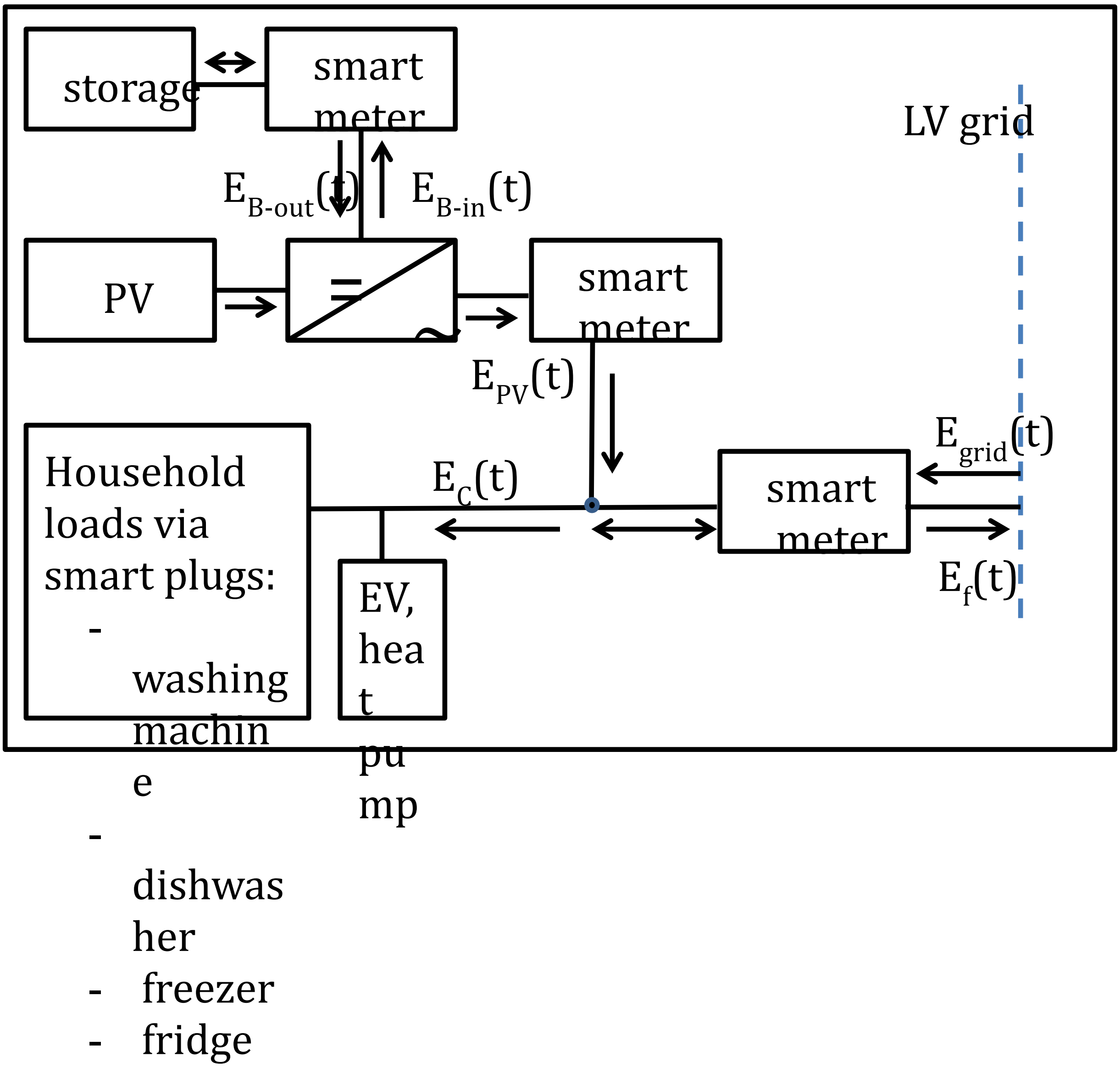

Figure 1: Principle diagram of energy flow of a household. E_f stands for the energy feed into the LV grid and is defined only for positive values as $E_f(t) = E_{PV}(t) - E_C(t)$ when $E_{PV}(t) > E_C(t)$. $E_{B\text{-out}}$ and $E_{B\text{-in}}$ are the energy flows out and into a stationary battery storage system. The EVs are treated as single run loads. E_{PV}, E_C and E_{grid} stand for the energy flows of PV generation, overall consumption and energy taken from the LV grid. Thus self-consumption $E_{SC}(t)$ is calculated as $E_{SC}(t) = E_C(t) - E_{grid}(t)$.

The energy generation data were measured in Konstanz in the standard way by direct integration of the household´s local PV-system by an Elster AS1440 Smart Meter over IEC62056-21 Mode C, connection via RS485 to the gateway Raspberry Pi. The meters transmit energy measurements periodically to Raspberry Pi and these data values, as for all other energy measurements, were stored in kWh unit in time series with the according time stamp.

In Caserta the PV energy generation was measured by a current pick-up coil system with radio frequency ZigBee technique connection to the Modbus gateway and finally to the Raspberry Pi via Ethernet.

Figure 2: The bottom part shows the July 2016 PV energy production of a 10kWp PV system, in green self consumption and in yellow feed in amount, and the upper part the total consumption from the grid in red and again the self consumption in green.

One example is shown in Figure 2. The lower section of the graph displays in green and yellow the amount of PV production that is self consumed and fed into the public grid, respectively. On top the total daily consumption is displayed. In red is the amount from the public grid and in green the amount of self-consumption, which is the same amount as in the bottom graph the amount which is used for direct self consumption (also shown in green in the bottom graph). One can clearly recognize that only on three days the 2nd, 12th, 13th the total PV generation is below the total consumption of the regarded day. The analyzed household KN07 is, by the way, with an average daily consumption of about 15kWh/day, a very heavy electrical energy consumer, well above the average household consumptionin Germany.

3.2 Energy consumption data

The summarized energy consumption data were measured in Konstanz by the commonly installed Elster smart meters via IEC62056-21, as provided by the local electricity distributor. Additionally, the energy consumption of single devices, considered as potentially flexible loads, were measured either by smart plugs, transferring their data via radio frequency, or by installed energy meters. The Elster smart meter is able to measure in two directions if necessary for integrated PV system, i.e. measuring both the energy consumed from the public grid and the energy fed into the public grid.

In Caserta, the overall energy consumption was measured by a three phase current pick-up coil system, transmitting its data wirelessly to a ZigBee-Modbus gateway. The single devices energy consumptions were measured by smart plugs which transferred the data again via ZigBee to the Raspberry Pi gateway computer.

One example is given as the measured energy consumption for a time period of about four weeks of the public user KN06, which is a school in Konstanz. Figure 3 shows the energy consumption over regular and holiday time periods, which can be recognized by the changed slope of the curve and is also indicated in Table 1 to remark the different average energy consumptions.

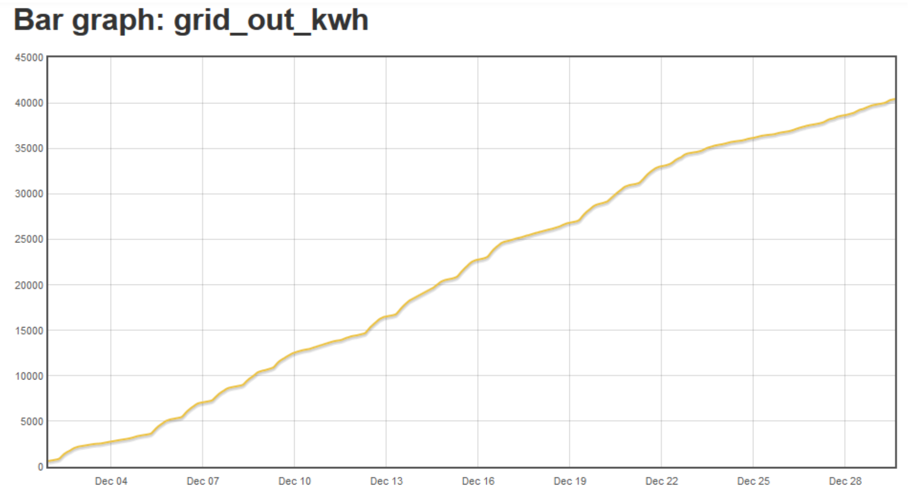

Figure 3: Electrical energy consumption in kWh of KN06 during Dec. 2016.

Meter rating date	Energy (kWh)	Energy/day (kWh/d)	Consumption during
2nd Dec. 16, 00:00am	668,4		
24th Dec. 16, 00:00am	35465,5	1581,68	regular school days
29th Dec. 16, 12:00am	40326,1	883,75	winter Christmas holidays

Table 1: The total consumed electrical energy of KN06 over Dec. 2016.

Another example of the industrial enterprise KN01 with the measured and displayed 15 minutes average power consumption for Oct. 2016 clearly shows reduced power consumption over the weekend days.

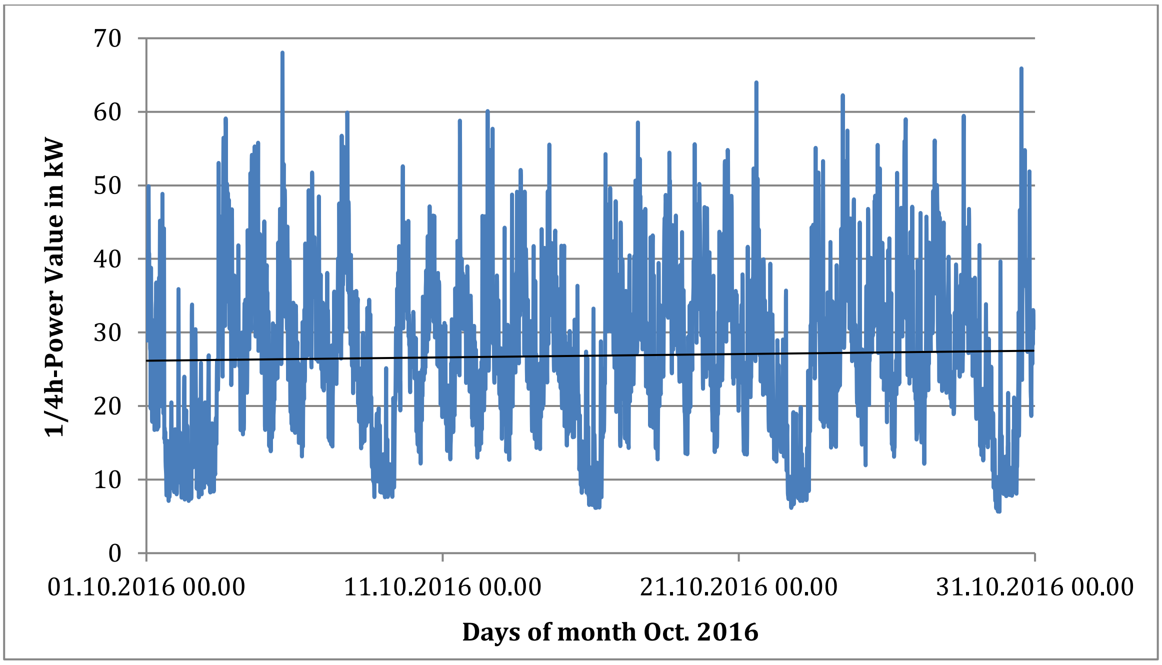

Figure 4: The 15 minutes' average power consumption value of the industry KN01 in Oct. 2016.

3.3 Data of battery charging and discharging

In the trials two different stationary battery systems and two EVs were integrated.

At KN03 a stationary battery system from “Varta Engion Family Energiespeicher” with a charging capacity of 3.7kWh and a commercial integrated control system were integrated. With the installed bidirectional measuring smart meters charging and discharging of this battery could be monitored.

At KN12 a stationary 7kWh Tesla Powerwall battery with a commercially available control system from Solaredge^{TM} was integrated since May 2016.

This Tesla Powerwall battery was integrated together with a PV system and we could not control but observe directly their effect in the displayed grid consumption of the regarded household. More technical details about these devices can be found in deliverable D5.3 and evaluation results in section 5.3 of this document.

The two EVs belonged to KN04 and KN12 respectively, and were only connected for charging. Thus they did not actually act at batteries, but rather as potentially flexible and interruptible loads.

The EV at KN04 was a VW e-Golf with a 24kWh battery and the charging was managed by an integrated “Schletter 261900-005 P-Charge EWS-Box P” charging controller, integrated into the CoSSMic system and fully controllable. Figure 5 shows a possible charging profile for the charging of the e-Golf at KN10 on the 4th of Oct. 2016 requiring 22kWh to fully charge the battery.

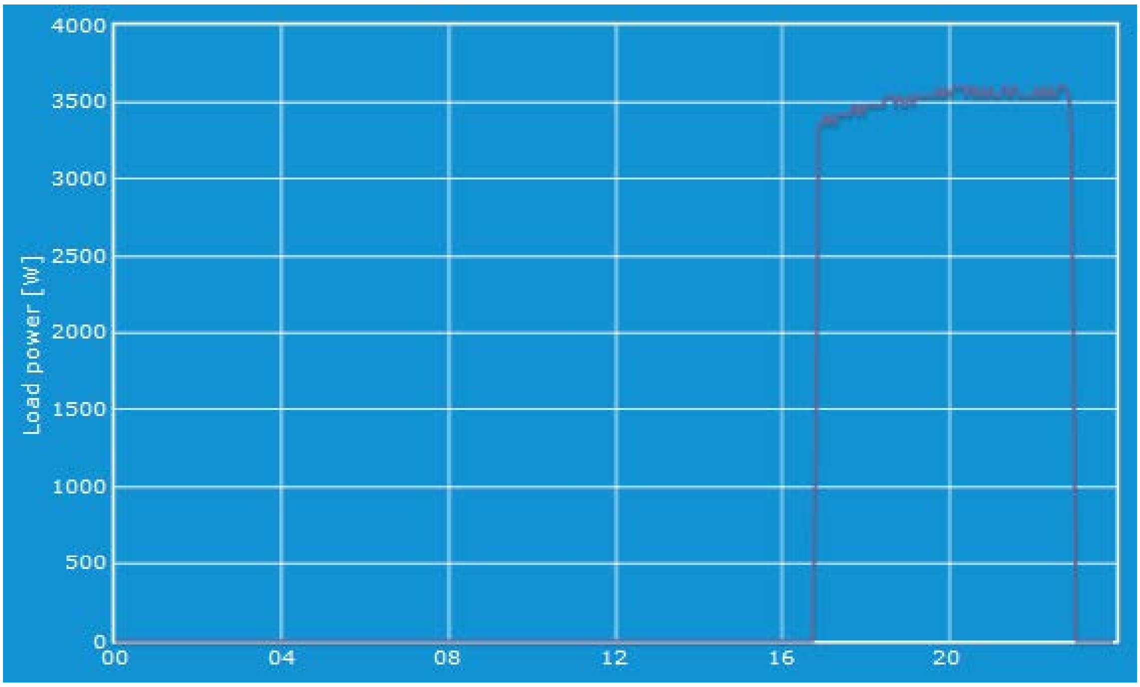

Figure 5: This GUI screen shoot shows one charging of the e-Golf on Oct. 4th 2016 at KN04.

The EV at KN10 was a Peugeot iOn with a 16kWh battery and a self-made battery charger and control system. The charging was monitored for the whole trial period. As can be seen in Figure 6, the energy charged per day appears to spread quite uniformly between 1 and 10 kWh with a few cycles outside that range. The maximum charging energy for one charging day was 14.4kWh on the 25th Feb. 2016 and the total energy used for charging for the entire year 2016 was about 1010kWh.

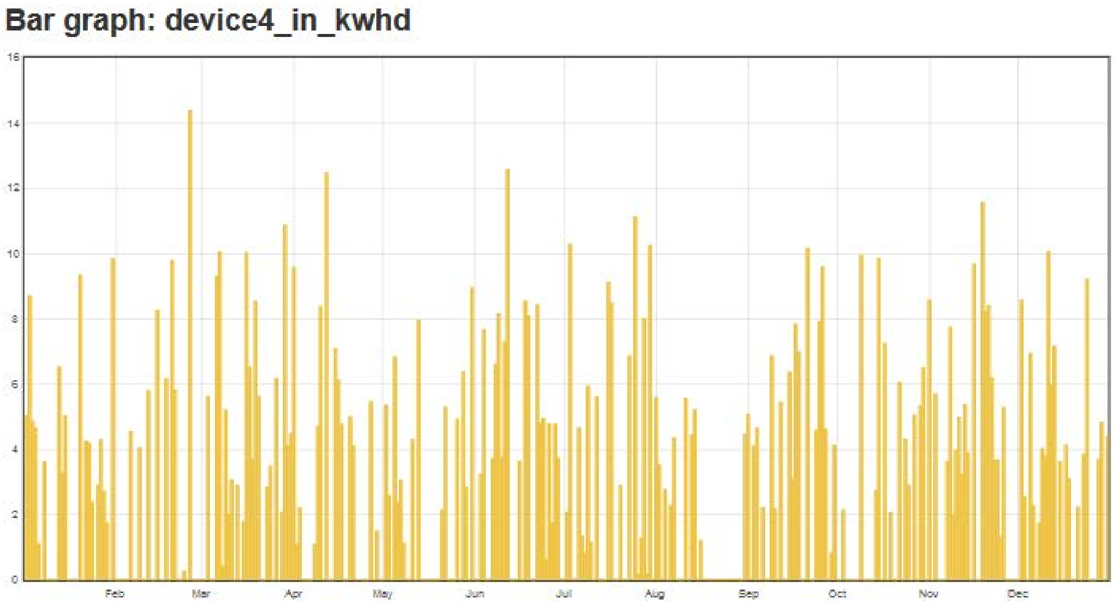

Figure 6: The daily charged energy in kWh of the iOn during the trial year 2016 at KN10.

4 Data analysis

4.1 Data validity and fault detection

With the system being able not only to measure, but also to control the consumed energy for certain household devices like freezers, it got apparent, that certain measures need to be taken to monitor their correct behaviour. Additionally, with cost-effective hardware chosen to measure and transmit acquired and aggregated energy data, the possibility of faulty transmissions had to be taken care of.

The analysis of the measured data in order to decide on their validity must be done under meaningful threshold levels, where measurements were considered valid within the defined borders. The thresholds are selected based on statistical disturbances, cross interferences, manipulations, etc. and will be defined depending on the device to be monitored. By implementing a monitoring mechanism that raises an alarm when certain thresholds are exceeded for a device, we were able to detect such failures automatically and alert users and service personnel.

4.1.1 Device fault detection

The introduction of the fault detection feature, i.e., the automatic notification about potential faults with a specific household device, was triggered for two purposes:

The first target was to warn the user that something may be wrong with a device, and the second to warn the researchers that data may be corrupted. Data could be lost either by malfunctioning devices or communication, resulting in the necessity to put some measures in place, to ensure the correct detection of those faults, depending on the specific devices' characteristics.

It is of vital interest to have online information access of the state of a controlled device, particular to distinguish between regular off states and an interruption of a duty cycle of a device or a data transmission failure caused by a malfunction of the transfer channel.

Basically, due to the nature of the power consumption of the monitored devices, it is very common and likely not to receive a single value above zero for over an hour or even longer. Some power feeds we are measuring show at least 50% of the time zero value, because it is a pulsing compressor, like for a fridge or freezer, a dishwasher or a washing machine which gets used only randomly during the week, or even a households PV generator during night hours.

Furthermore, due to the technique of the radio transmission of measured data from the energy meters to the Raspberry Pi gateway to feed the data into the internet, there is always a probability for a feed not to receive a single value for over an hour or even longer because of a temporary communications failure, for example, between the transmitter and receiver units.

One example is taken as the power consumption of the freezer of household KN07, measured as feed #70, see Figure 7. The data output of the controlled feed could be used to check the reliability of the applied method.

The regular measured power value will be close to zero at least two times within one hour and thus at least 2 times within an hour lower than a percentage of the mean power value. Practically, a threshold level below which a malfunction will be notified after a certain period of time can be applied to the measured power consumption of the continuously running device. At detection, currently an E-Mail notification is sent to the maintenance team, responsible for the corresponding household, to enable them to inform the users only if necessary.

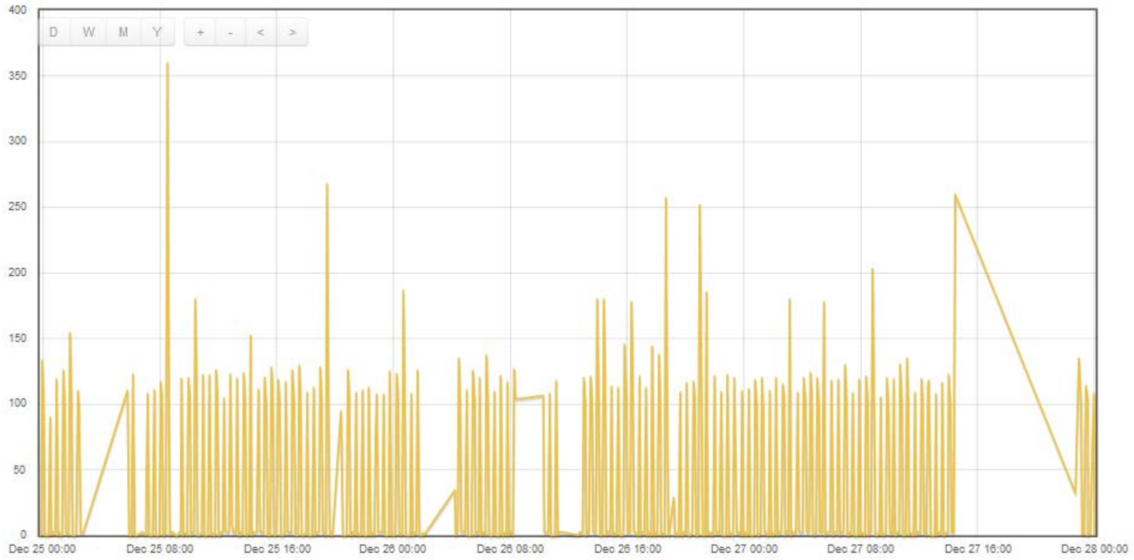

Figure 7: The power consumption pattern of the freezer at KN07 for the 25th to the 28th Dec. 2016 with some data transfer failures.

Additionally, the fault detection was used to warn about potential failures of PV systems. The threshold for malfunctioning notifications was set to a time interval of 24h in which only zero power values got detected. The first trial notification for this kind of fault detection arrived at the end of the year 2016, when snow fall came and covered the PV system entirely.

4.1.2 Device service and detection down times for May 2016

In Appendix 8.3, Table 17 gives a condensed overview of the service times and the data acquisition downtimes of the integrated single run devices (i. e. dishwashers, washing machines, EV charging) of the six Konstanz private households KN07 to KN12 during the month May 2016.

4.1.3 Scattered outlier data values

Almost all metering devices integrated in the CoSSMic system transmit energy values to the emoncms for further processing. The smart meters measure of course current and voltage, but integrate them in time to a physical meaningful energy value. This energy value was then processed to the daily consumed energy and subsequently to power values, and stored in emoncms database.

This processing could result in big outlier data values, as sometimes the communication failed or was misinterpreted, resulting in the energy values transmitted to be incorrect or even negative. Calculating the power out of those data resulted in faulty values, which caused some problems with their visualization.

Some such examples are shown here. An analysis of the measured PV generation data of KN09 in Nov. and Dec. 2016 shows for the 26th Nov. and 15th Dec. single point artefacts (Figure 9), which are the reasons for the wrong display of the daily PV generation data in the GUI, as displayed in Figure 8.

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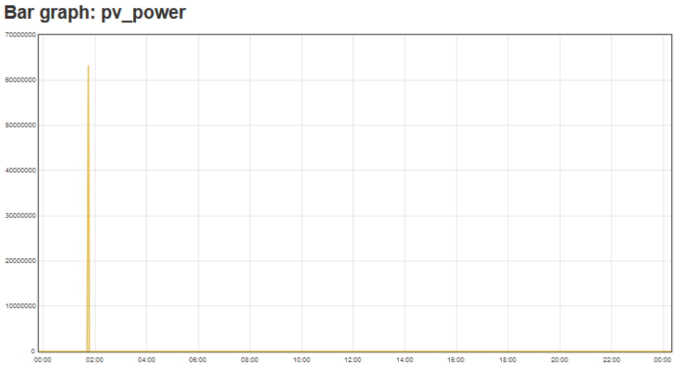
Figure 8: The PV energy production (bottom part, green self consumed, yellow fed in) and consumption (from grid in: red, and again self consumption in green) at KN09 of the year 2016. There was no data acquisition for Jan. and Feb. and serious failure in data acquisition in Nov. and Dec. for the PV generation.



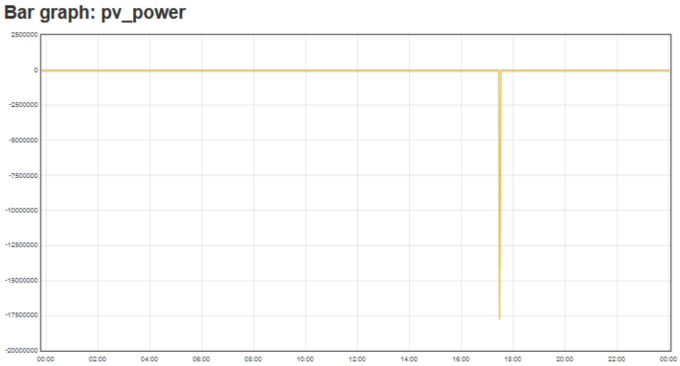


Figure 9: The PV energy production of the household KN09 for the 26th Nov. (top) and 15th Dec. (bottom) 2016 in Watts.

Another analysis shows the reason that high outliers like single high value data points may by checked and filtered or cut off when not reasonable. One example is given in Figure 10 for the grid consumption in Feb. 2016 of KN07.

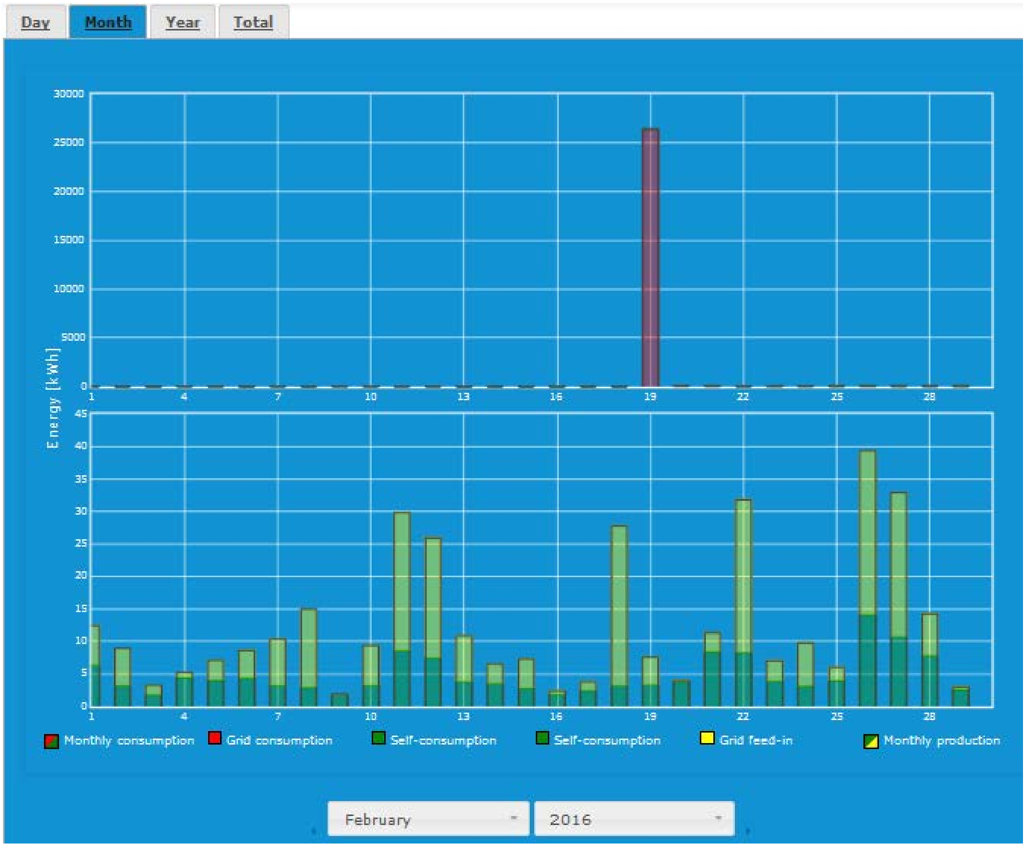


Figure 10: Energy consumption (top) and generation (bottom) of KN07 for Feb. 2016.

A deeper analysis of the displayed energy data for the 19th Feb. 2016, however, shows no evidence of failure of the recorded data, see the grid consumption on a zoomed time scale of Figure 11! It seems that this event is related to an error which occurred during the treatment of the measured data of the grid consumption for the 19th Feb. 2016. Even the largest recorded consumption of the heat pump (Figure 12) does not show irregularities.

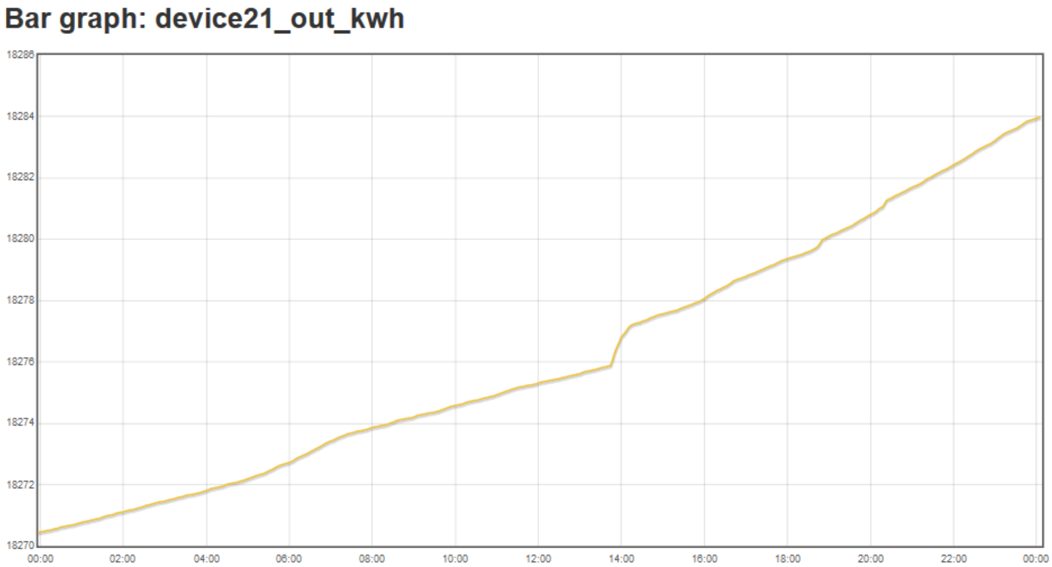


Figure 11: KN09 energy grid consumption of the entire 19th Feb. 2016 without abnormalities. The steep step at around 2pm results in 1.2kWh consumption within 20 minutes.

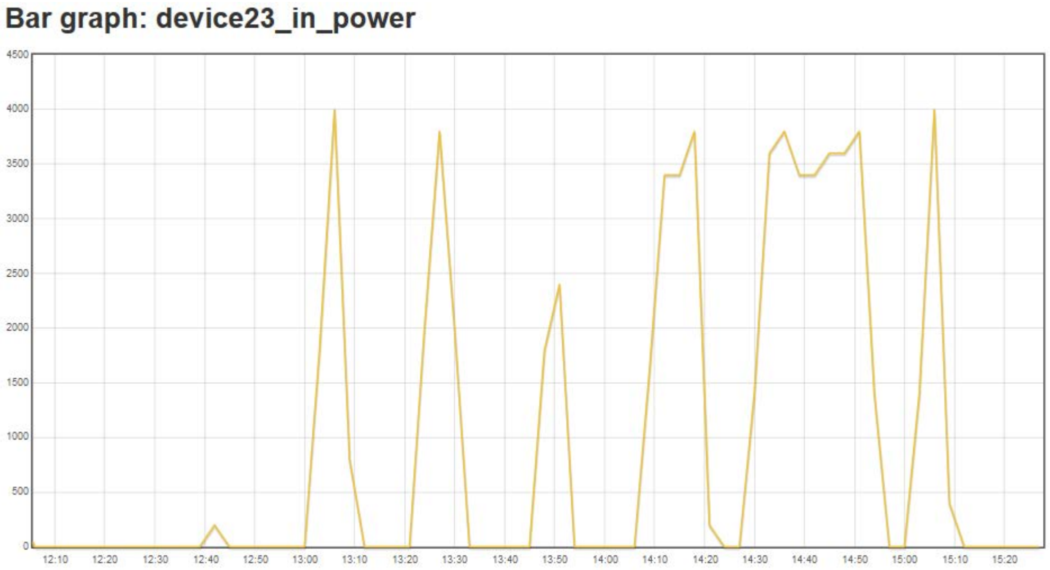


Figure 12: KN09 heat pump power consumption around 2pm of 19th Feb. 2016 without abnormalities. The power peak at 1.50pm is equivalent to a consumed energy of about 0.3kWh.

4.2 Data correction

As described in the previous subsection, failures and off-times may occur during data acquisition, leading to missing and erroneous data which need to be corrected. There are three types of time series data that need to be checked:

1. Time series of data points of feeds from emoncms which have the format (timestamp, measured accumulated energy value)
2. Time series of data points of feeds from emoncms which have the format (timestamp, energy measurement for a certain time period)
3. Time series of data points which were processed from the energy measurement data which have the format (timestamp, calculated power)

The following method was applied to correct errors in the measured data:

- For time series of type 1, remove single data points in data time series with decreasing energy values in time.
- For time series of type 2, remove single data points in data time series with energy values greater than 3 times the observed standard deviation.
- For time series of type 3, remove single data points in data time series-with power greater than 10^3 times the given median value.

4.3 Selection of data for evaluation and simulation

In this section, we outline how we have implemented the proposed evaluation approach described in D6.1 in practice.

For details concerning the evaluation and simulation of the measurement data consult D6.1, Chapter 4 with emphasis on

- the evaluation implementation
- the handling of the measurement data
- the simulation software model design and architecture

with overviews of the software prototype and of components and interfaces for simulation.

The evaluation method includes also computer simulations based on the collected data. By simulation we can overcome to some extent the limited representation of our trial scenarios (size, structure complexity, etc.) and vary factors beyond the limitations in the trials, for example available batteries and their capacities, future grid tariffs, the number and characteristics of households in a neighbourhood and their manifold interactivities.

The simulations were performed using the simulation tool developed in the project. This tool enables event streams observed during the trials, representing household behaviour patterns or behaviour patterns of external factors such as grid tariffs or weather data, to be repeated with the CoSSMic system running in a simulated environment and in simulated time, where we can vary parameters such as the composition of neighbourhoods, the storage and production capacity of households etc.

Due to resource and time constraints caused by late arrival of the simulation tool and the load scheduler, it was not practical to run simulation of a whole year. Instead, we have selected one representative week from each season to get an indication of how the system would perform under varying weather conditions.

In order to select representative weeks for each season, we analysed typical weather condition for each season, the PV yield of all included PV systems, and for the energy demand the consumption behaviour of the households: In particular, we analysed the energy values for the household KN10, which are summarized in Table 2 to Table 6 (in kWh). Furthermore, Table 2 also shows the start and end times of all the controlled single run devices , and the typical on and off switchings (on/ off ratio and power consumption) of the continuously run devices in the regarded spring week.

At KN10	10. April-Sun	11 April-Mon	12. April -Tue	13. April-Wed	14. April -Thu	15.April-Fri	16. April-Sat
PV-yield	61	60	54	20	40	17	29

281 kWh							
Heat pump	5.8(on till 10am; 2/h 2kW on/off 1/2)	0.2	0.2	0.2	0.2	0.2	1.5
Washing machine	0	0	0.85 Start-End: 9.25-11.45	0	0	0	1.1 Start-End: 12.30-16.45
Dishwasher	0.72 Start-End: 2.15-3.15pm)	0	0.05	0.68 Start-End: 14.15-15.30:	0	0.03	0.03
Refrigerator	0.4 (2.5/4h; on/off: 1/2;60W)	0.36	0.36	0.36	0.34	0.34	0.34
Freezer	0.43 (5.5/4h; on/off: 1/2;60W)	0.45	0.45	0.45	0.45	0.43	0.45
EV	8.3 (11am-14pm 5.2kWh; 5pm-6.30pm 3.1kWh)	0	12.5 Start-End: 11.30-16.30	0	0	7.1 Start-End: 13.15-17.45	6.1 Start-End: 15.00-19.00

Table 2 Average spring week 10th-16th Apr. 2016

At KN10 ave. week (taken)	13. July-Wed	14. July-Thu	15. July-Fri	16. July-Sat	17.Jul-Sun	18. July-Mon	19. July-Tue
PV-yield 329 kWh	18.2	27.4	29.7	66.3	63.8	61.1	62.2
bad week (comparison)	11.June-Sat	12.June-Sun	13.June-Mon	14.June-Tue	15.June-Wed	16.June-Thu	17.June-Fri
PV-yield 250.9 kWh	34.8	40.9	23.5	33.7	39.5	19	43.8
max week (comparison)	22. Aug-Mon	23. Aug-Tue	24. Aug-Wed	25. Aug-Thu	26. Aug-Fri	27. Aug-Sat	28. Aug-Sun
PV-yield 392.5 kWh	57.2	58.6	57.3	56.7	54.5	55	53.1

Table 3 Average summer week 13th-19th Jul. 2016

At KN10 average	12. Oct.- Wed	13. Oct.- Thu	14. Oct.- Fri	15. Oct.- Sat	16. Oct.- Sun	17. Oct.- Mon	18. Oct.- Tue
PV-yield 145 kWh	37.1	23.8	12.2	21.9	10.2	11.2	29.0

Table 4 Average autumn week 12th-18th Oct. 2016

At KN10 average	15. Feb.- Mon	16. Feb.- Tue	17. Feb.- Wed	18. Feb.- Thu	19. Feb.- Fri	20. Feb.- Sat	21. Feb.- Sun
PV-yield 87 kWh	11.6	3.3	4.7	31.6	8.4	4.3	23.1
bad week	13. Jan.- Wed	14. Jan.- Thu	15. Jan.- Fri	16. Jan.- Sat	17. Jan.- Sun	18. Jan.- Mon	19. Jan.- Tue
PV-yield ~24kWh	10.8	9.1	0.4	0.5	2.0	0.7	0.7
best week	20. Jan.- Wed	21. Jan.- Thu	22. Jan.- Fri	23. Jan.- Sat	24. Jan.- Sun	25. Jan.- Mon	26. Jan.- Tue
PV-yield ~134kWh	18.8	22.1	13.4	8.9	27.6	28.5	14.9

Table 5 Average winter week 15th-21st Feb. 2016

Spring week (10th - 16th Apr. 2016)	Summer week (13th - 19th Jul. 2016)	Autumn week (12th - 18th Oct. 2016)	Winter week(15th - 21st Feb. 2016)
281 kWh	329 kWh	145 kWh	87 kWh

Table 6 The PV yield of the selected representative seasonal weeks for KN10 only

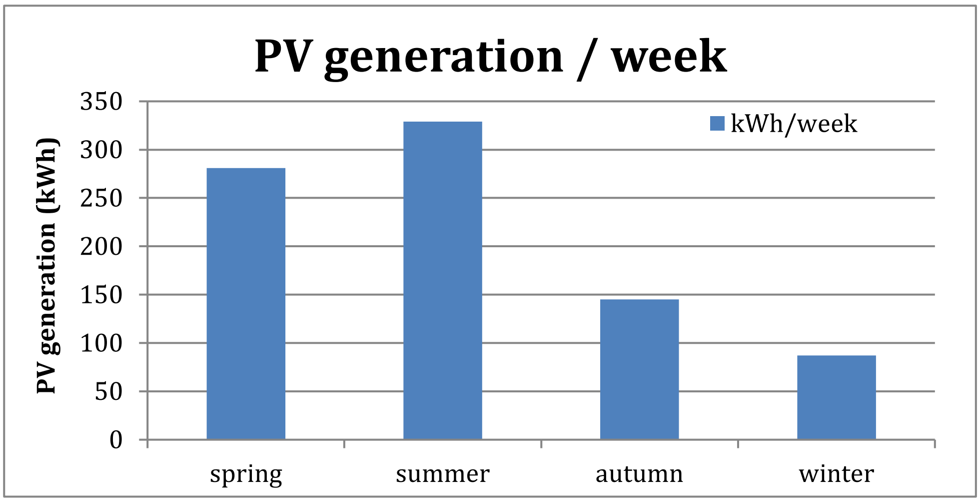


Figure 13: The summarized PV-yield of the representative selected seasonal weeks of KN10.

5 The evaluation of the data w.r.t. the KPIs defined in D6.1

The evaluation will follow the method also defined in D6.1, i.e. we have evaluated the system with regard to the following KPIs:

1. Self-consumption of the whole neighbourhood
2. Stacked peak avoidance
3. Optimization of storage cycles
4. Prediction accuracy
5. Scalability
6. Effect of collective PV systems on total power fluctuation
7. Usability of software
8. Statistics for using the collaborative measures compared to success criteria from WP2
9. Energy cost reduction
10. Return of investment cost

Due to the late availability of a stably working load scheduler, we were not able to collect all the data and run all the simulation we had planned. Therefore, not all the KPIs could be evaluated to the same extent. The measured data were only used for direct and simulation supported evaluation of the 1st and 2nd KPI, and the results of evaluations with and without simulation support were compared.

5.1 Self-consumption of the whole neighbourhood

The self-consumption can be calculated using the following formula:

$$E_{SC}(T) = \int_{t1}^{t2} P_{SC}(t) \ where \begin{cases} P_{SC}(t) \ = P_C(t) \ if \ P_C(t) \leq P_{PV}(t) \\ P_{SC}(t) \ = P_{PV}(t) \ if \ Pc(t) > P_{PV}(t) \end{cases} \quad (1)$$

Where t_1, t_2 is the start and end time of the regarded time interval T,
$E_{PV}(T)$ and $P_{PV}(t)$ the time depending generated energy and power,
$E_C(T)$ and $P_C(t)$ the time depending consumed energy and power,
$E_{SC}(T)$ and $P_{SC}(t)$ the time depending self consumed energy and power.

In the following, we will use the conventions:

- superscript *i* means for household *i*, no superscript means aggregated for all households
- subscript with *s* means for CoSSMic with coordinated scheduling, subscript with *sum* means for aggregated as sum of individual households, no subscript means for aggregated neighbourhood without load shifting.

5.1.1 Illustration of the working of the scheduler

The CoSSMic scheduler obtains a coordinated scheduling of the loads of the neighbourhood via load shifting. The following example demonstrates the scheduling of devices with respect to available PV generated energy in a collaborating neighbourhood performed by the CoSSMic distributed scheduler. The system consists of two households KN09 and KN10 with single run devices as washing machines

(WM) and dishwashers (DW), background load (loads from continuously run devices and other non-controllable loads), one EV and two PV systems.

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Devices List

DeviceName	Node Name	TemplateName	TemplateType			
PV-KN09	KNuser09	SolarPanel	SolarPanel			
DW09	KNuser09	kn11Dishwasher	Dishwasher	New/Modify Task	●	
WM09	KNuser09	kn11WashingMachine	WashingMachine	New/Modify Task	●	
BG_KN09	KNuser09	background	background	New/Modify Background	●	2016-04-10
PV-KN10	KNuser10	SolarPanel	SolarPanel			
DW-KN10	KNuser10	kn10Dishwasher	Dishwasher	New/Modify Task	●	
WM-KN10	KNuser10	kn11WashingMachine	WashingMachine	New/Modify Task	●	
eCar_KN108kWh	KNuser10	KN04_8kWh	ElectricCar	New/Modify Task	●	
BG-KN10	KNuser10	background	background	New/Modify Background	●	2016-04-10

The constraints for scheduling of all single run device tasks were set to EST = 10am, LST = 6pm and Creation Time = 7am. The selected simulation date was the 10th April 2016, a typical German Spring day for the backgound load and PV generation. The table gives an overview of the energy flows for different runs of the same configuration of the 10th April 2016. Runs 320 and 321 are not represenative due to some errors in the collected measurement data as explained under the table.

ExeID	Background load	Total consumption	From grid	Total production	Self-consumed	Date
318 KN09	2.05	3.307	0	23.08	3.307	10.04.2016
318KN10	2.05	11.29	0.305	58.9	10.98	10.04.2016
319KN09+10	4.1	14.6	10.98	82	3.61	10.04.2016
~~320***~~	~~4.1~~	~~20.85**~~	~~0~~	~~82~~	~~20.85~~	~~10.04.2016~~
~~321***~~	~~4.1~~	~~12.99*, **~~	~~0~~	~~82~~	~~12.99~~	~~10.04.2016~~
322KN09+10	4.1	14.6	14.29	82	0.31	10.04.2016
323KN09+10	4.1	14.6	0	82	14.6	10.04.2016
average	4.1	14.6	6,39	82	8,20	10.04.2016

*) one device (WM-KN10) did not start, **) some steep raising loads produce non-realistic high power flows of the order of 1kWh/0,01h=100kW, which may be caused by missing measurement data communication error as we use the cheap smart plugs to collect the data, which do not provide high data accuracy, ***) The two crossed data rows indicate examples of what could happen in a test phase.

Detailed results of run ExeID 318 are given in the following table. Three tasks were started at EST=AST (no shifting), while two other tasks were shifted with AST within the allowed time window between EST and LST (i. e. WM_KN10 and EV-8kWh KN10). A PV energy transfer from one neighbour to the oher neighbour´s device (energy sharing) could be observed twice, as the PV energy from PV-KN10 goes to a device of KN09 and vice versa PV-KN09 goes to a device of as KN10. These observations demonstrated that the scheduler is working. Similar observations can be found for the repeated runs

ExeID 319 to 323. The self-consumption factor $E_{SCs}(T)$ /$E_C(T)$ for run ExeID 318 is calculated to: (14.6-0.305) kWh / 14.6 kWh ~ 97.9%

Device	EST	LST	Creation Time	AST
DW_KN09	10am	6pm	7am	10.01h with PV from KN09
WM_KN09	10am	6pm	7am	10.01h with PV from KN10
DW_KN10	10am	6pm	7am	10.01h from grid
WM_KN10	10am	6pm	7am	11.54h with PV from KN09
EV-8kWh KN10	10am	6pm	7am	12.57h with PV from KN10

5.1.2 *Self-consumption for the baseline*

To compare the self-consumption of a CoSSMic neighbourhood with the same group of households considered as independent households, there are two ways to aggregate the self-consumption of the group of independent households:

1. To apply formula (1) to each household and sum over all households, i.e.,

$$E_{SCsum}\ (T) = \sum\nolimits_{for\ all\ households} E_{SC}^{i}\ (T) \qquad (2)$$

2. To apply formula (1) to the aggregated neighbourhood energy flows $E_{SC}\ (T)$, where the energy flow between households is also counted as self-consumption.

Seen from the point of view of the individual household, it appears most fair to compare with the sum of the self-consumption of the individual households as this is the improvement that they see (case 1). From the point of view of alleviating the integration of local RES into the grid, it may be more correct to compare with the self-consumption computed by the neighbourhood formula (case 2), as that is the difference that counts in that context. Therefore, in the following we include both as **baseline** for our comparison.

We use simulator to calculate the self-consumption of the neighbourhood for the two baseline cases and the CoSSMic case. All the cases are computed using measured data from the trials as input to the simulator.

Appendix 8.2 gives the details about how the simulation results were obtained, describing the neighbourhood configurations (the fix private households in Konstanz), how the background loads are generated (which device loads are included in the background loads and the interval for splitting background loads into smaller loads for scheduling), how many runs were executed, and in which mode (e.g., in sequential days and repeated runs).

Table 7 and Table 8 shows the self-consumption of the neighbourhood with the six private houses as computed using the two methods defined for the baseline. As described before, we selected four representative weeks for each season and run repeated simulations and used average values to compute the self-consumption.

sum of single households (baseline case 1)	$E_C(T)$ (kWh)	$E_{PV}(T)$ (kWh)	$E_{SCsum}(T)$ (kWh)	$E_{SCsum}(T)$ / $E_C(T)$	$E_{SCsum}(T)$ / $E_{PV}(T)$
15.02.2016					
16.02.2016	36,404	56,638	4,388	12,1 %	7,7 %
17.02.2016	37,088	42,961	3,406	9,2 %	7,9 %
18.02.2016	47,877	52,76	5,479	11,4 %	10,4 %

19.02.2016					
20.02.2016	91,75	30,593	7,708	8,4 %	25,2 %
21.02.2016	76,974	88,116	12,944	16,8 %	14,7 %
winter week sum	290,09	271,07	33,93	11,7 %	12,5 %
11.04.2016					
12.04.2016	75,908	186,723	27,75	36,6 %	14,9 %
13.04.2016	60,594	136,556	24,255	40,0 %	17,8 %
14.04.2016	57,789	172,704	25,151	43,5 %	14,6 %
15.04.2016	68,013	91,731	20,214	29,7 %	22,0 %
16.04.2016	71,163	125,146	25,195	35,4 %	20,1 %
17.04.2016	78,73	63,063	29,626	37,6 %	47,0 %
spring week sum	412,20	775,92	152,19	36,9 %	19,6 %
11.07.2016	44,84	173,117	14,872	33,2 %	8,6 %
12.07.2016	50,697	119,162	12,786	25,2 %	10,7 %
13.07.2016	57,115	96,866	12,854	22,5 %	13,3 %
14.07.2016	50,715	158,729	19,532	38,5 %	12,3 %
15.07.2016	50,155	160,982	18,615	37,1 %	11,6 %
16.07.2016	54,852	200,63	15,587	28,4 %	7,8 %
17.07.2016	57,458	206,36	18,306	31,9 %	8,9 %
summer week sum	365,83	1115,85	112,55	30,8 %	10,1 %
10.10.2016	73,387	92,359	16,283	22,2 %	17,6 %
11.10.2016					
12.10.2016	69,708	119,162	17,433	25,0 %	14,6 %
13.10.2016	83,391	96,404	18,914	22,7 %	19,6 %
14.10.2016	88,474	60,721	17,516	19,8 %	28,8 %
15.10.2016	96,051	48,341	13,267	13,8 %	27,4 %
16.10.2016	93,421	53,107	12,139	13,0 %	22,9 %
autumn week sum	504,43	470,09	95,55	18,9 %	20,3 %

Table 7: For each day of the selected weeks of the season, the table lists the overall consumption, PV generation and the *sum of the single household's self-consumption*, together with the relative amounts of self-consumption and self-consumed own PV generation. The empty rows contain erroneous data that make it impossible to run simulations, therefore, are excluded in the calculation for comparison.

Neighbourhood w/o scheduling (baseline case 2)	$E_C(T)$ (kWh)	$E_{PV}(T)$ (kWh)	$E_{SC}(T)$ (kWh)	$E_{SC}(T)$ /$E_C(T)$	$E_{SC}(T)$ / $E_{PV}(T)$
15.02.2016					
16.02.2016	36,404	56,638	8,322	22,9 %	14,7 %
17.02.2016	37,088	42,961	7,871	21,2 %	18,3 %
18.02.2016	47,877	52,76	9,486	19,8 %	18,0 %
19.02.2016					
20.02.2016	91,75	30,593	17,804	19,4 %	58,2 %
21.02.2016	76,974	88,116	26,39	34,3 %	29,9 %

winter week neighbourhood	290,09	271,07	69,873	24,1 %	25,8 %
11.04.2016					
12.04.2016	75,908	186,723	30,961	40,8 %	16,6 %
13.04.2016	60,594	136,556	28,182	46,5 %	20,6 %
14.04.2016	57,789	172,704	28,719	49,7 %	16,6 %
15.04.2016	68,013	91,731	25,852	38,0 %	28,2 %
16.04.2016	71,163	125,146	28,097	39,5 %	22,5 %
17.04.2016	78,73	63,063	37,947	48,2 %	60,2 %
spring week neighbourhood	412,20	775,92	179,758	43,6 %	23,2 %
11.07.2016	44,84	173,117	20,72	46,2 %	12,0 %
12.07.2016	50,697	119,162	19,166	37,8 %	16,1 %
13.07.2016	57,115	96,866	22,554	39,5 %	23,3 %
14.07.2016	50,715	158,729	27,497	54,2 %	17,3 %
15.07.2016	50,155	160,982	27,399	54,6 %	17,0 %
16.07.2016	54,852	200,63	20,417	37,2 %	10,2 %
17.07.2016	57,458	206,36	23,554	41,0 %	11,4 %
summer week neighbourhood	365,83	1115,85	161,307	44,1 %	14,5 %
10.10.2016	73,387	92,359	23,803	32,4 %	25,8 %
11.10.2016					
12.10.2016	69,708	119,162	24,122	34,6 %	20,2 %
13.10.2016	83,391	96,404	30,68	36,8 %	31,8 %
14.10.2016	88,474	60,721	23,706	26,8 %	39,0 %
15.10.2016	96,051	48,341	20,747	21,6 %	42,9 %
16.10.2016	93,421	53,107	20,617	22,1 %	38,8 %
autumn week neighbourhood	504,43	470,09	143,675	28,5 %	30,6 %

Table 8: For each day of the selected weeks of the season, the table lists the overall consumption, PV generation and the neighbourhood self-consumption without load shifting (baseline 2), together with the relative amounts of self-consumption and self-consumed PV generation. The empty rows contain erroneous data that make it impossible to run simulations, therefore, are excluded in the calculation for comparison.

Figure 14 shows the comparison of the measured self-consumption power flow as sum for all six single private households and as the neighbourhood self-consumption on the 21st Feb. 2016. It can be seen that the neighbourhood self-consumption is much larger compared to the sum of the individual self-consumptions.

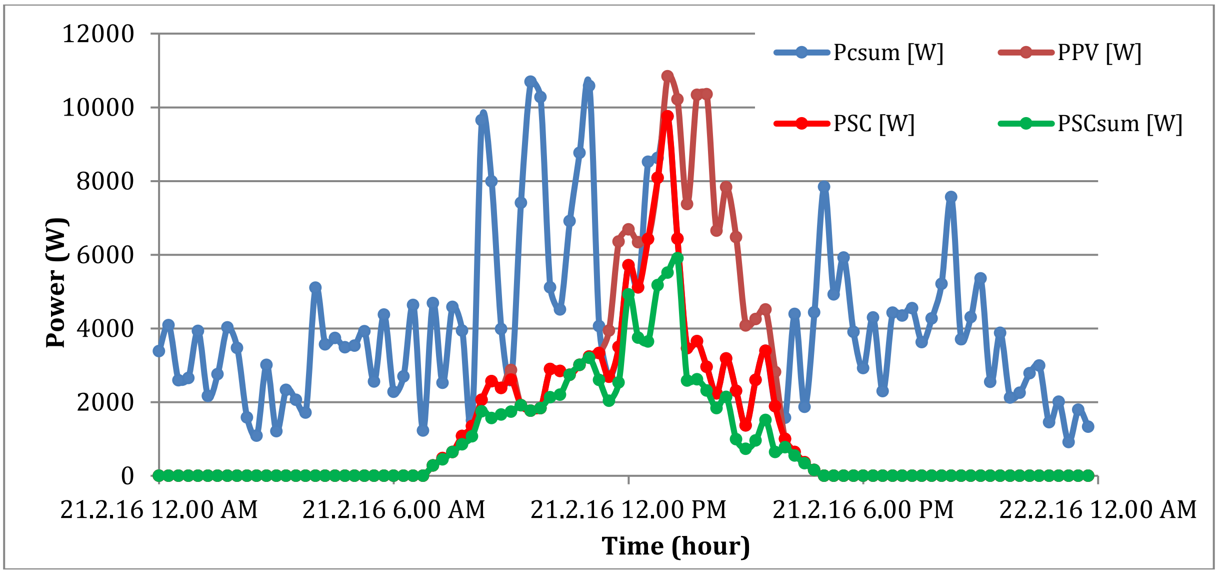


Figure 14: Comparison of the CoSSMic neighbourhood (P_{SC}) and the sum of the households (P_{SCsum}) self-consumption on the 21st Feb. 2016 together with the overall consumption (P_{Csum}) and the PV generation (P_{PV}), i. e. which is equivalent to the fact that the overall consumption from the grid or the feed into the grid is reduced when the neighborhood self-consumption goes up.

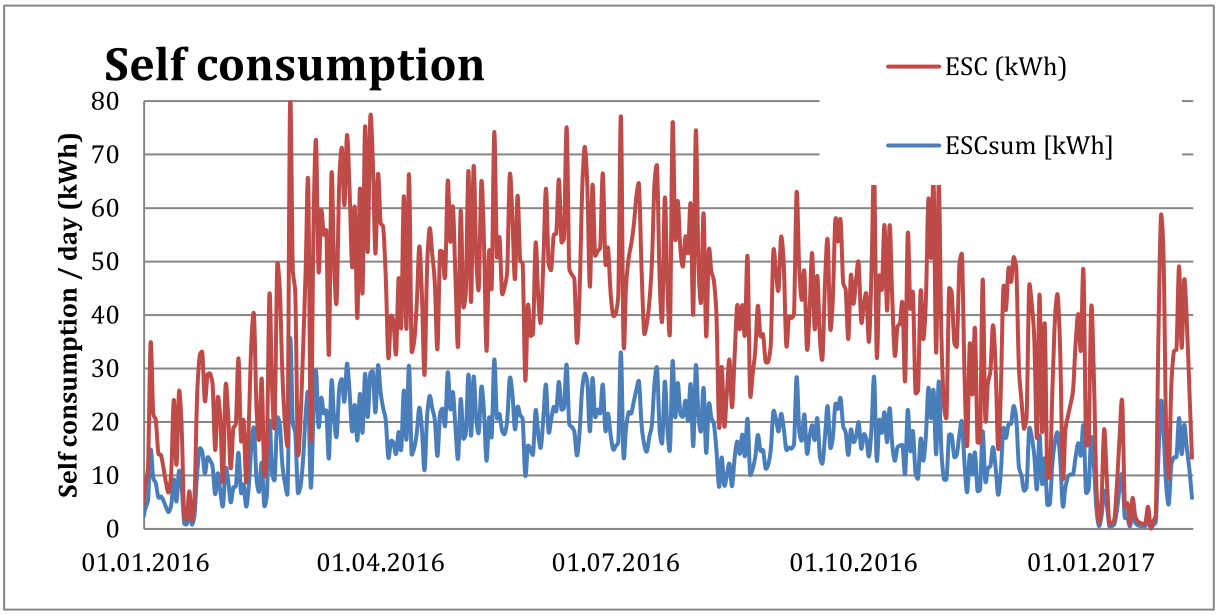


Figure 15: The comparison of the sum of six private households self-consumption E_{SCsum} and the CoSSMic neighbourhood self consumption E_{SC} over the year 2016 and in the beginning of 2017, from the Konstanz trial, both cases without scheduler for load shifting.

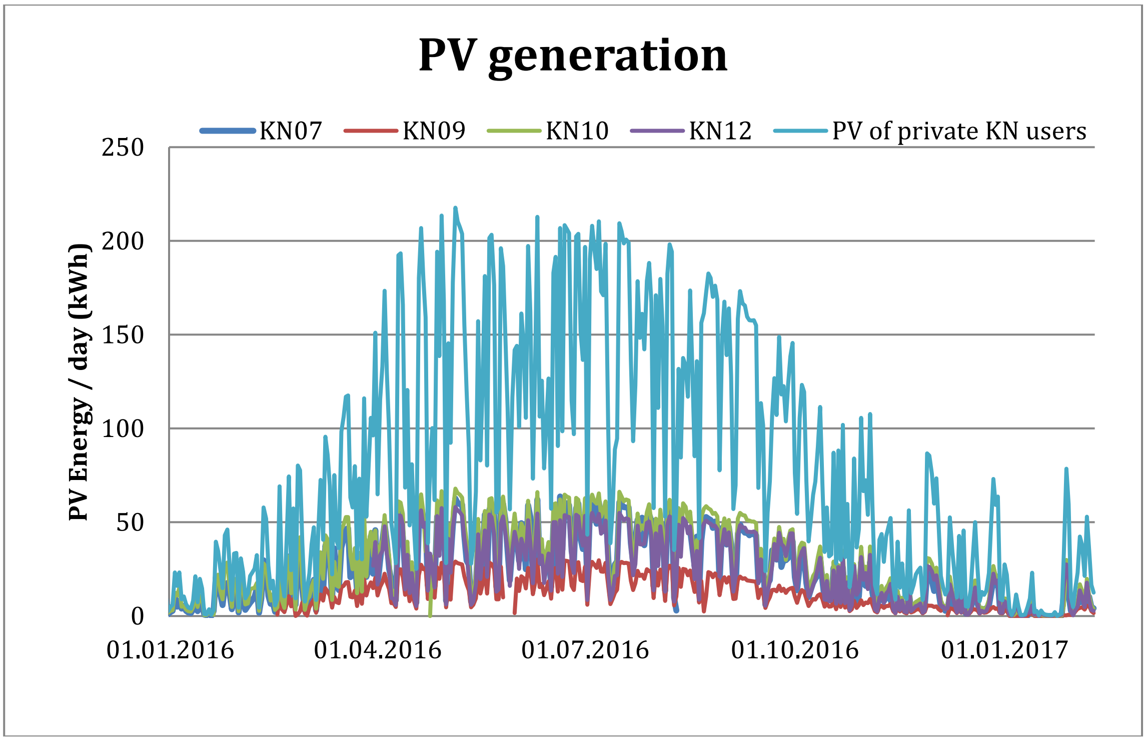
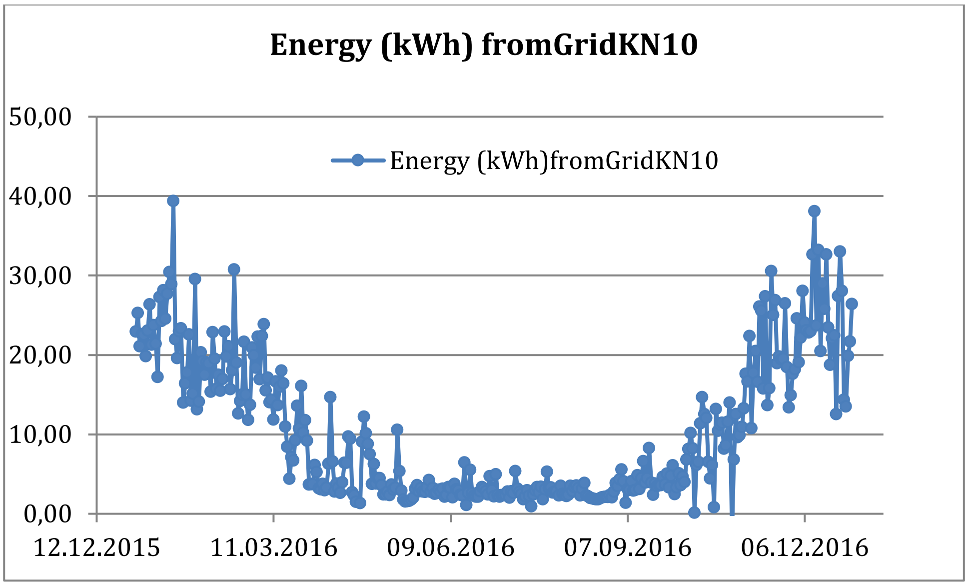
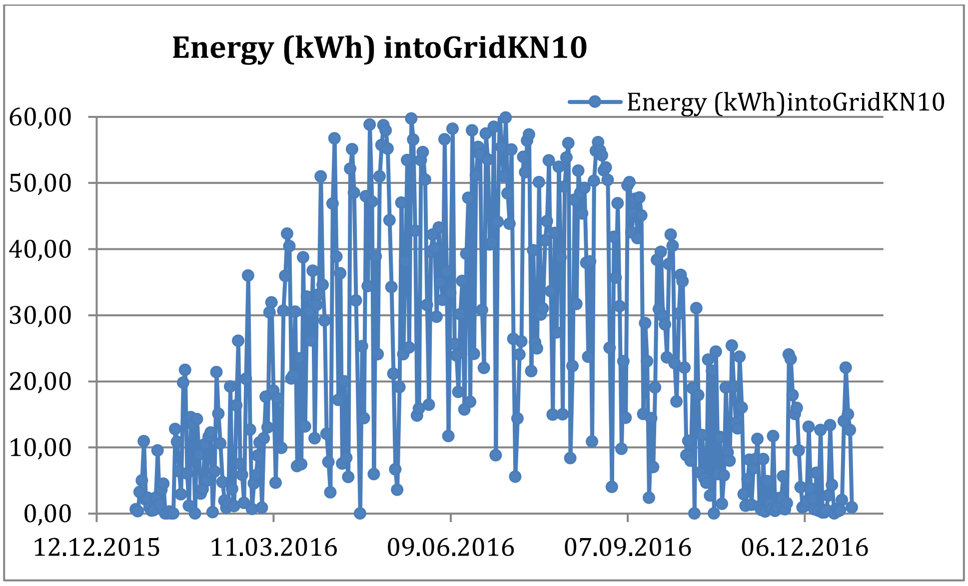


Figure 16: The PV generation of the four out of six private Konstanz households during the trial phase from 1st Jan. 2016. The corresponding self-consumptions of all six private households are shown in Figure 15.

Figure 17: The figure shows in its lower part the energy production (green: self-consumption, yellow: feed into grid amounts) and in the upper part the consumption (grid: red, PV: dark green) of the year 2016 for KN10.


Energy (kWh) fromGridKN10
Energy (kWh)fromGridKN10
50,00
40,00
30,00
20,00
10,00
0,00
12.12.2015
11.03.2016
09.06.2016
07.09.2016
06.12.2016


Energy (kWh) intoGridKN10
Energy (kWh)intoGridKN10
60,00
50,00
40,00
30,00
20,00
10,00
0,00
12.12.2015
11.03.2016
09.06.2016
07.09.2016
06.12.2016

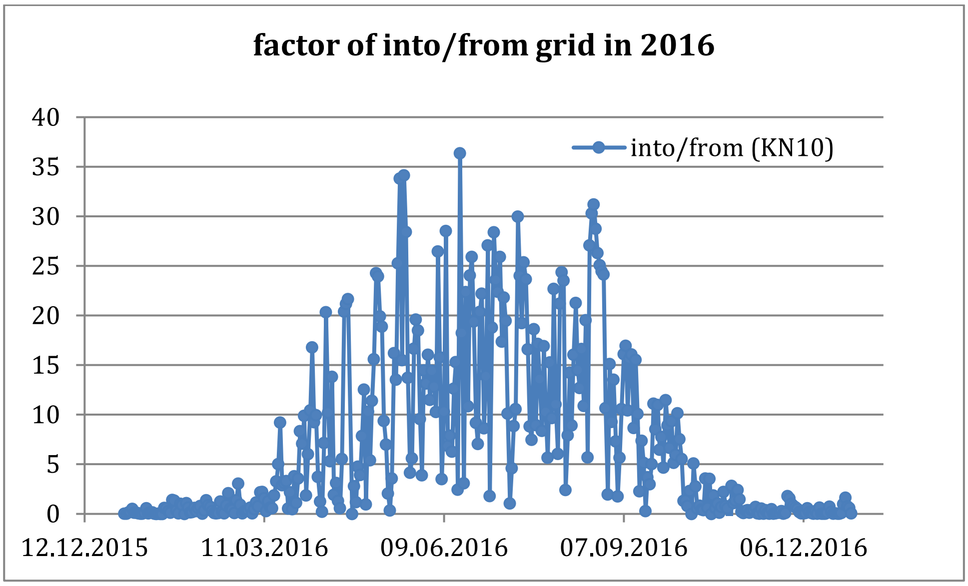

factor of into/from grid in 2016
into/from (KN10)
40
35
30
25
20
15
10
5
0
12.12.2015
11.03.2016
09.06.2016
07.09.2016
06.12.2016

Figure 18: Energy from public grid (top) in kWh, energy fed into public grid (middle) in kWh and the ratio between given into and received from public grid (bottom) over the entire year 2016 for KN10.

Figure 19 shows comparison of energy into and from the public grid for a neighbourhood consisting of KN10 and KN07 over the year 2016. It indicates the trend to reduce the ratio of into/from the grid even for a neighbourhood consisting of only two households as can be seen in the black curve of the figure.

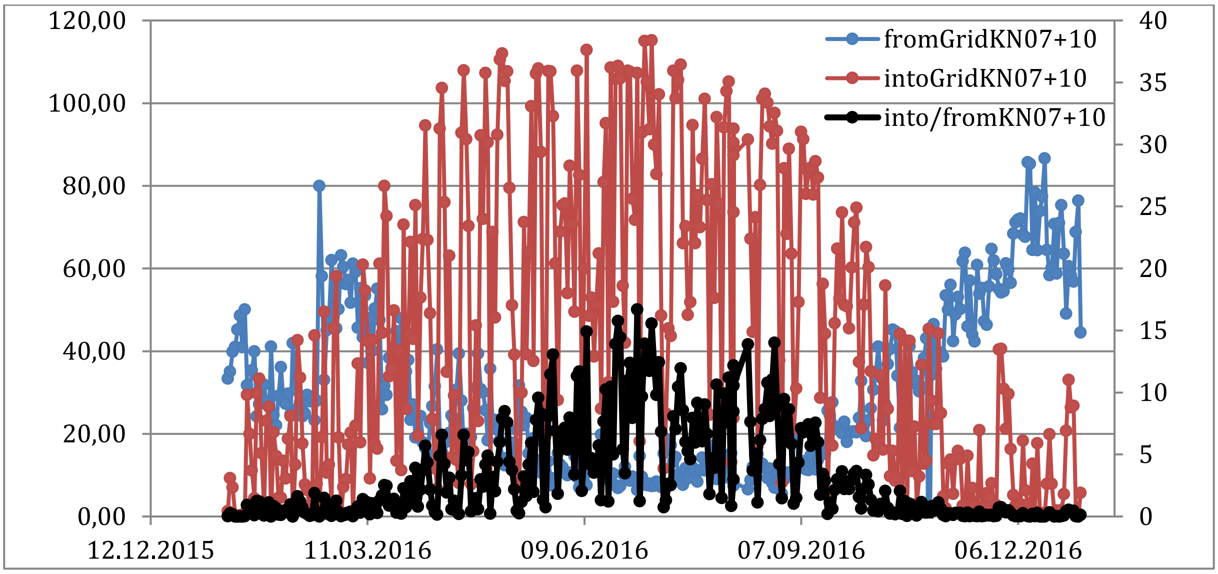


Figure 19: Comparison of energy into and from the public grid for a neighbourhood consisting of KN10 and KN07 over the year 2016. The blue is the energy from the grid in kWh and the brown is the feed-in energy in kWh, both referring to the left axis. The black is the ratio of the feed-in vs. the energy from the public grid, referring to the right axis.

5.1.3 *The effect of CoSSMic coordinated load scheduling*

The results for CoSSMic neighbourhood with scheduling are shown in Table 9 using the same input data as the baseline calculations in Table 7 and Table 8.

CoSSMic neighbourhood with scheduling	$E_C(T)$ (kWh)	$E_{PV}(T)$ (kWh)	$E_{SCs}(T)$ (kWh)	$E_{SCs}(T)$ /$E_C(T)$	$E_{SCs}(T)$ /$E_{PV}(T)$
15.02.2016					
16.02.2016	36,404	56,638	9,464	26,0 %	16,7 %
17.02.2016	37,088	42,961	8,218	22,2 %	19,1 %
18.02.2016	47,877	52,76	13,174	27,5 %	25,0 %
19.02.2016					
20.02.2016	91,75	30,593	20,051	21,9 %	65,5 %
21.02.2016	76,974	88,116	32,62	42,4 %	37,0 %
winter week sum	290,09	271,07	83,527	28,8 %	30,8 %
11.04.2016					
12.04.2016	75,908	186,723	43,709	57,6 %	23,4 %
13.04.2016	60,594	136,556	29,952	49,4 %	21,9 %

14.04.2016	57,789	172,704	28,719	49,7 %	16,6 %
15.04.2016	68,013	91,731	33,9	49,8 %	37,0 %
16.04.2016	71,163	125,146	37,312	52,4 %	29,8 %
17.04.2016	78,73	63,063	38,301	48,6 %	60,7 %
spring week sum	412,20	775,92	211,893	51,4 %	27,3 %
11.07.2016	44,84	173,117	24,898	55,5 %	14,4 %
12.07.2016	50,697	119,162	26,251	51,8 %	22,0 %
13.07.2016	57,115	96,866	27,55	48,2 %	28,4 %
14.07.2016	50,715	158,729	28,915	57,0 %	18,2 %
15.07.2016	50,155	160,982	28,822	57,5 %	17,9 %
16.07.2016	54,852	200,63	29,242	53,3 %	14,6 %
17.07.2016	57,458	206,36	33,017	57,5 %	16,0 %
summer week sum	365,83	1115,85	198,695	54,3 %	17,8 %
10.10.2016	73,387	92,359	25,546	34,8 %	27,7 %
11.10.2016					
12.10.2016	69,708	119,162	28,403	40,7 %	23,8 %
13.10.2016	83,391	96,404	32,785	39,3 %	34,0 %
14.10.2016	88,474	60,721	28,52	32,2 %	47,0 %
15.10.2016	96,051	48,341	28,949	30,1 %	59,9 %
16.10.2016	93,421	53,107	25,707	27,5 %	48,4 %
autumn week sum	504,43	470,09	169,91	33,7 %	36,1 %

Table 9: The self-consumption of the neighbourhood with CoSSMic scheduling.

week of season	Baseline		CoSSMic
	$E_{SCsum}(T) / E_C(T)$	$E_{SC}(T) / E_C(T)$	$E_{SCs}(T) / E_C(T)$
Winter-week	11,7%	24,1%	28,8%
Spring-week	36,9%	43,6%	51,4%
Summer-week	30,8%	44,1%	54,3%
Autumn-week	18,9%	28,5%	33,7%

Table 10: Comparison of the relative self-consumption w.r.t. total consumption of the six single households for the two baseline cases with CoSSMic coordinated scheduling.

week of season	Baseline		CoSSMic
	$E_{SCsum}(T) / E_{PV}(T)$	$E_{SC}(T) / E_{PV}(T)$	$E_{SCs}(T) / E_{PV}(T)$
Winter-week	12,5%	25,8%	30,8%
Spring-week	19,6%	23,2%	27,3%
Summer-week	10,1%	14,5%	17,8%
Autumn-week	20,3%	30,6%	36,1%

Table 11: Comparison of the relative self-consumption w.r.t. total PV production of the six single households for the two baseline cases with CoSSMic coordinated scheduling.

Table 10 and Table 11 summarise the results for the two baseline cases (details as shown in Table 7 and Table 8) and the case for CoSSMic coordinated scheduling (details as shown in Table 9), and compares their relative self-consumption ratios with regard to total consumption and total PV production for the six households. For all season weeks, the self-consumption of the neighbourhood with CoSSMic coordinated scheduling is the highest as compared to the baseline, either computed as the sum of individual households (case 1) or as aggregated neighbourhood without load shifting (case 2).

5.2 Power peak avoidance

Consumption peaks typically are caused b stacking of loads occurring at the same time. One of the already discussed and commonly accepted mechanisms to reduce the maximum power peak is load shifting.

The following figure shows examples of double or even triple loads running during the same time period. A maximum power peak of 10kW is generated at around 1.30 pm, when dishwasher, washing machine and heat pump are running together.

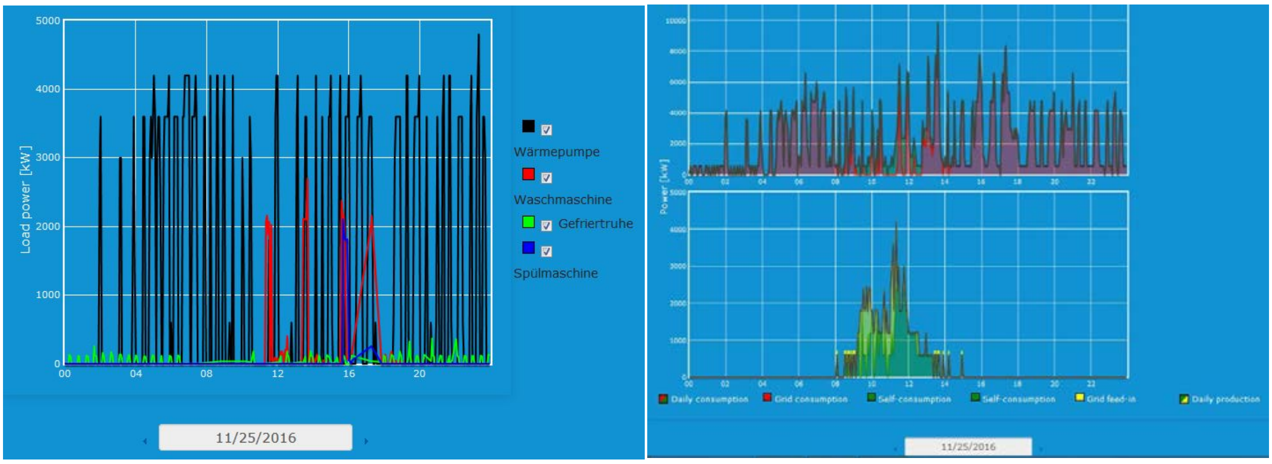


Figure 20: Left figure for consumption power of appliances of KN07: heat pump (black), washing machine (red), freezer (green), dish washer (blue). Right figure: top – consumption power, and bottom - PV generation power.

An even higher load peak of 12.5kW has been recorded by stacked peak at KN10 on the 16th of November 2016.

One of the already discussed and commonly accepted mechanisms to reduce the maximum power peak is load shifting, which we have exploited in CoSSMic.

In the currently available tariffs that take peak loads into consideration, the calculation of power peaks varies depending on how DSOs determine them. Normally, the power peaks are considered as an average of the power in a time interval, typically 15-60 minutes, and whether the peaks occur in a period when the public grid experiences peak demand. In this section, we compare the values and time of occurrence of average power in 60 minutes' periods with and without CoSSMic scheduling. The considered neighbourhood is the same six private houses as used in the evaluation of the effect on self-consumption.

The considered time period is split into p periods of fixed duration T with start time t_p. We use T=60 minutes in our evaluation. The calculation of the power peaks can be described using the following formula:

P_C^{Max}: consumed power peak from grid for the neighbourhood for period T

$$P_C^{Max} = max\left\{\frac{1}{T}\int_{t_p}^{t_p+T} (P_C(t) - P_{PV}(t) \text{ when } P_C(t) > P_{PV}(t), 0 \text{ otherwise})dt\,, for\ all\ p\right\}$$

P_F^{Max}: feed-in power peak as the max sum of feed-in power for period T

$$P_F^{Max} = max\left\{\frac{1}{T}\int_{t_p}^{t_p+T}(P_{PV}(t) - P_C(t)\ \text{ when } P_{PV}(t) > P_C(t), 0 \text{ otherwise})dt\,, for\ all\ p\right\}$$

The following Table 12 show the results for the peaks into and out of the grid for the neighbourhood with the six private Konstanz households with and without the CoSSMic scheduling.

Week	Day	Consumption from grid				Feed-in to grid			
		Baseline		With CoSSMic		Baseline		With CoSSmic	
		T_{start} (hh:mm)	P_C^{Max} (kW)	T_{start} (hh:mm)	P_{Cs}^{Max} (kW)	T_{start} (hh:mm)	P_F^{Max} (kW)	T_{start} (hh:mm)	P_{Fs}^{Max} (kW)
Winter week 15-21 February 2016	Mon								
	Tue	02:04	4,61	02:04	4,61	07:03	9,35	07:03	9,32
	Wed	02:04	4,61	02:04	4,61	07:03	6,32	07:03	6,32
	Thu	02:04	4,61	02:04	4,61	10:02	8,76	10:02	8,11
	Fri								
	Sat	13:02	8,61	13:02	9,30	05:03	3,89	05:03	3,89
	Sun	04:04	6,39	04:04	6,39	09:03	13,31	09:03	13,31
Spring week 11-17 April 2016	Mon								
	Tue	01:04	9,45	01:04	9,45	10:03	22,82	10:03	22,65
	Wed	01:04	9,81	01:04	9,81	08:03	19,34	08:03	19,34
	Thu	01:04	9,54	01:04	9,54	10:03	21,25	10:03	21,25
	Fri	01:04	9,43	01:04	9,43	10:03	13,49	10:03	12,70
	Sat	01:04	9,05	01:04	9,05	09:03	16,85	09:03	16,83
	Sun	17:01	9,34	17:01	9,95	08:03	7,04	08:03	7,04
Summer week 11-17 July 2016	Mon	18:01	3,34	18:01	3,34	10:03	21,33	10:03	20,41
	Tue	19:01	5,69	19:01	6,68	08:03	9,58	08:03	9,55
	Wed	01:44	4,21	01:44	4,81	11:23	12,94	11:23	13,63
	Thu	01:04	6,68	01:04	6,68	08:03	19,62	08:03	19,19
	Fri	01:04	7,88	01:04	7,88	08:03	19,25	08:03	19,23
	Sat	01:04	5,07	01:04	5,07	08:03	22,63	08:03	22,18
	Sun	18:01	5,42	18:01	5,63	10:03	23,23	10:03	23,21
Autumn week 10-16 October 2016	Mon	01:04	13,38	01:04	13,38	06:03	16,13	06:03	16,13
	Tue								
	Wed	01:04	13,94	01:04	13,94	08:03	17,39	08:03	16,22
	Thu	01:04	12,69	01:04	12,69	08:03	14,10	08:03	14,10
	Fri	01:04	12,62	01:04	12,62	06:03	13,34	06:03	12,70
	Sat	01:04	11,70	01:04	11,70	10:02	9,48	10:02	9,48
	Sun	01:04	11,07	01:04	11,07	10:02	11,00	10:02	11,00

Table 12: The maximum power peaks from and into the grid and the start of the time window of their appearance for the neighbourhood of the six private KN households for the baseline and CoSSMic system.

Date	P_{Cs}^{Max}/P_{C}^{Max}	P_{Fs}^{Max}/P_{F}^{Max}
15.02.2016		
16.02.2016	1,000	0,997
17.02.2016	1,000	1,000
18.02.2016	1,000	0,925
19.02.2016		
20.02.2016	1,081	1,000
21.02.2016	1,000	1,000
winter week		
11.04.2016		
12.04.2016	1,000	0,992
13.04.2016	1,000	1,000
14.04.2016	1,000	1,000
15.04.2016	1,000	0,942
16.04.2016	1,000	0,999
17.04.2016	1,065	1,000
spring week		
11.07.2016	1,000	0,957
12.07.2016	1,173	0,997
13.07.2016	1,142	1,053
14.07.2016	1,000	0,978
15.07.2016	1,000	0,999
16.07.2016	1,000	0,980
17.07.2016	1,040	0,999
summer week		
10.10.2016	1,000	1,000
11.10.2016		
12.10.2016	1,000	0,933
13.10.2016	1,000	1,000
14.10.2016	1,000	0,952
15.10.2016	1,000	1,000
16.10.2016	1,000	1,000
autumn week		

Table 13: The ratios of the power peaks with and without CoSSMic scheduling for the power flow from and into the grid based of data of Table 12.

Table 13 gives the ratio of the power peaks with and without CoSSMic scheduling for power flow from and into the grid. From the simulation results, there is almost no dependency of the power peaks on the scheduling. The power peaks into the public grid are always smaller or equal with scheduling compared without scheduling.

If we look closer into the data, we observe that the power peaks were mostly from the background load, which is the largest load in each house. The background load are by definition the loads that cannot be shifted in CoSSMic, therefore, there is no significant effect of load shifting on peak avoidance from the simulation.

5.3 Optimization of storage cycles

The whole evaluation is based on the observations of EV charging at the household sites KN04 and KN10 and charging/discharging cycles at households KN03 and KN12.

However, we were not able to control the batteries and neither to do simulations including batteries. Therefore, we evaluated and discussed the effect of batteries in a solar powered household in general based on our measurements. In this sense it turned out to offer surplus storage capacity when exploited by neighbourhood wide coordination.

For the stationary 3.7kWh battery block of KN03 Figure 21 shows the charging energy during July 2016 and the profile of the 20th July 2016 with an average deposition energy/d of about 5kWh/d.

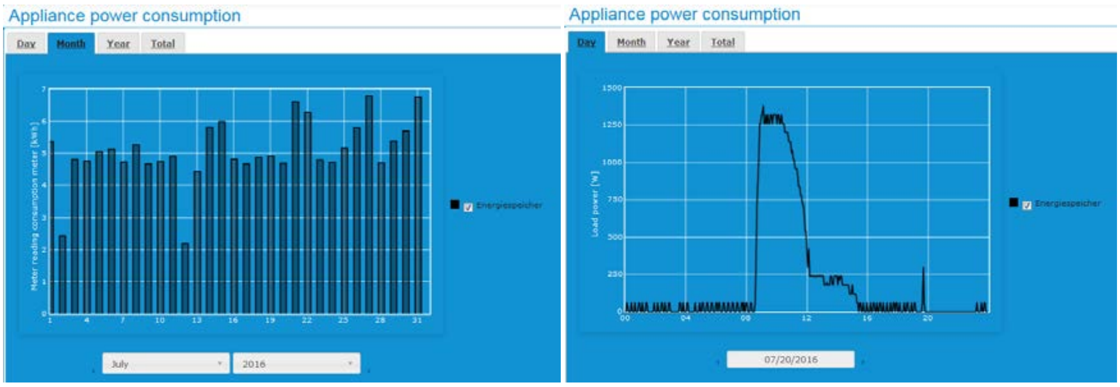


Figure 21: Battery charging in kWh of the entire July 2016 (left) and the power flow in Watt of the charging run of the 20th July 2016 (right).

The charging and discharging started in the summer season typically at late evening from about 8pm which can be seen from Figure 22.

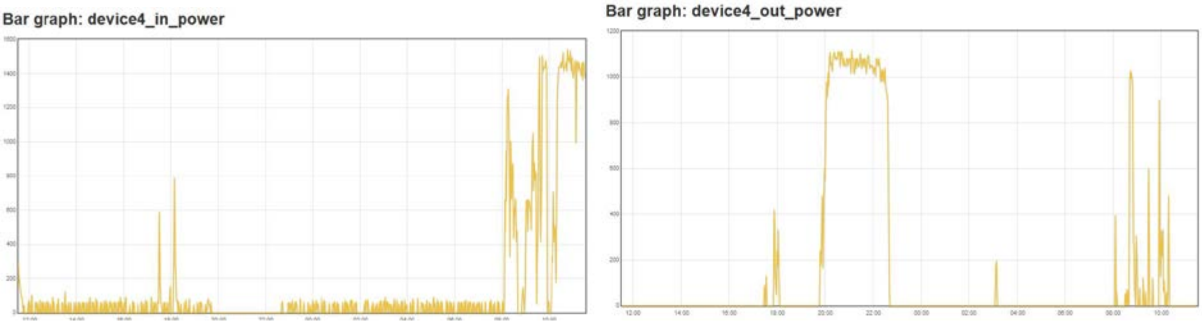


Figure 22: The power flow in Watt into (left) and out (right) of the Engion stationary battery of KN03 between 11.30 and 11.30 from the 8th to the 9th May 2016.

The observed energy input of about 4.7kWh/day can be retrieved from Figure 23 and results in about 1500kWh/a energy depot of green PV energy into the battery. A short calculation by taking into account of 0.26€/kWh grid energy cost and about 0.1€/kWh PV energy overall generation cost, delivers an annual profit of about:

$$0.26\ €/\mathrm{kWh}_{gridcost} - 0.10\ €/\mathrm{kWh}_{generationcosts} = 0.16€/\mathrm{kWh}\ \text{net win} \rightarrow 1.5\mathrm{MWh} \times 0.16€/\mathrm{kWh} = 240€/a$$

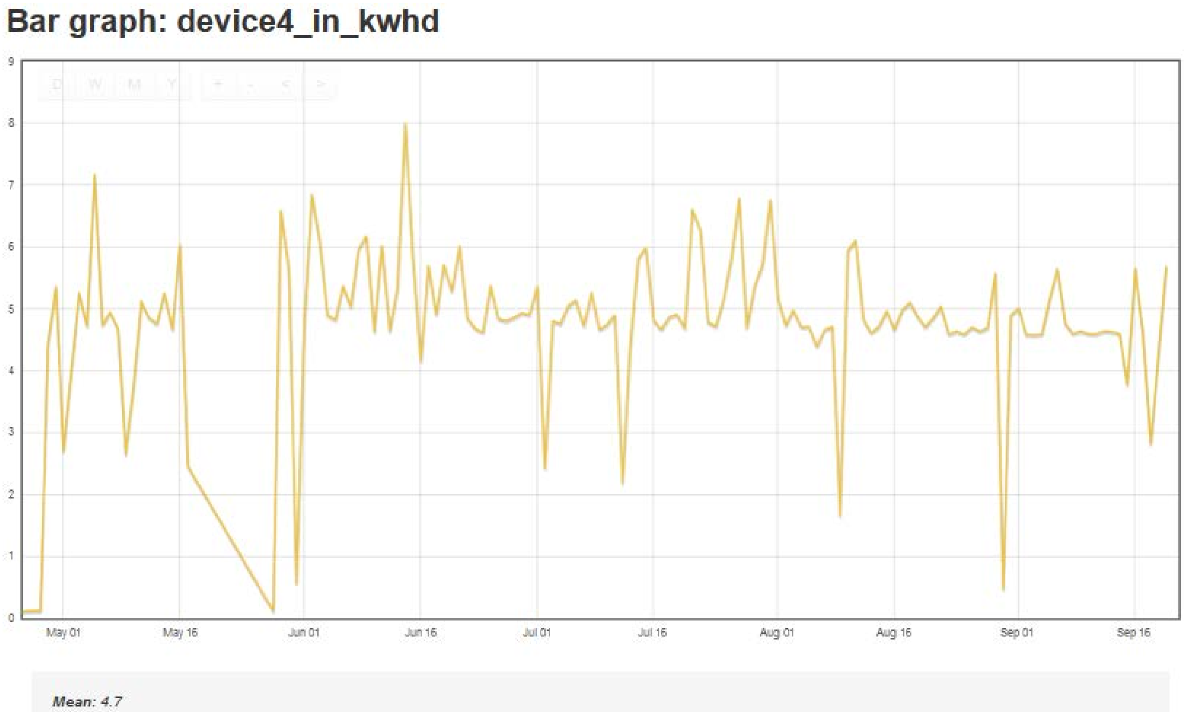


Figure 23: The daily charging in kWh of about 5 kWh of the stationary battery. The data loss from 17th to 28th May is clearly seen.

The household KN12 decided during the trial run to install an additional PV system of a peak power of P_{PV} = 2x12 x $265W_p$=6.36kWp and a 7 kWh Tesla Battery in May 2016 first without direct integration into the CoSSMic system.

The GUI displays in Figure 24 of two different days of very similar PV energy yield one from the 12th Apr. 2016 before and one on the 26th Sep. 2016 after the additional PV system and Tesla battery installation show the difference in the consumption. After the new installation the self-consumption of the new system is no more visible.

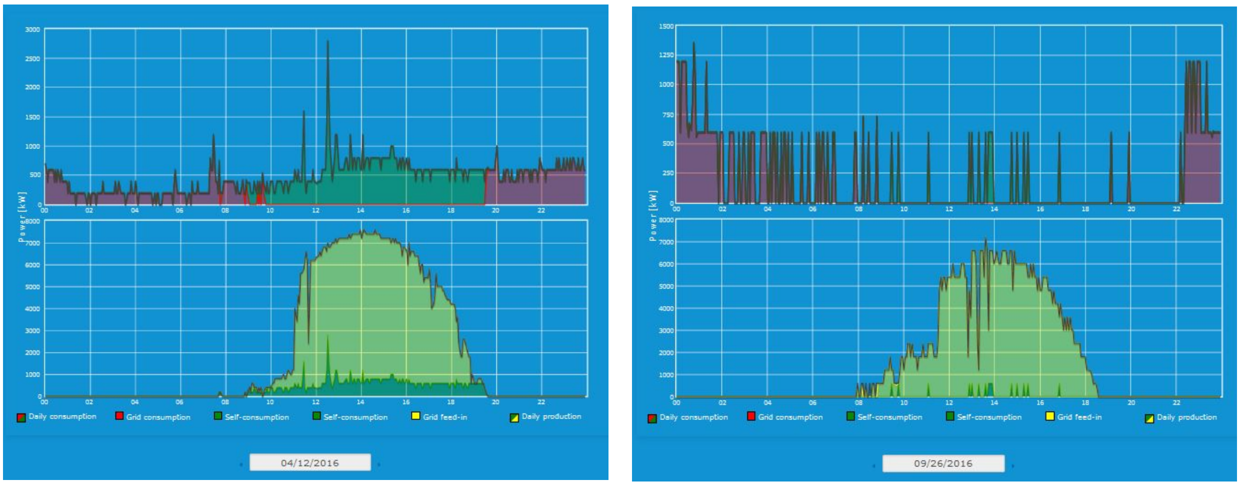


Figure 24: PV-yield (bottom) and CoSSMic monitored consumption (top) before (12th Apr.) (left) and after (26th Sep. 2016) (right) the installation of a Tesla Power battery.

Via SolarEdge^{TM} the Tesla battery data are available and reveal for the regarded 26th Sep. 2016 a full charging and discharging cycle of the Tesla Powerwall battery.

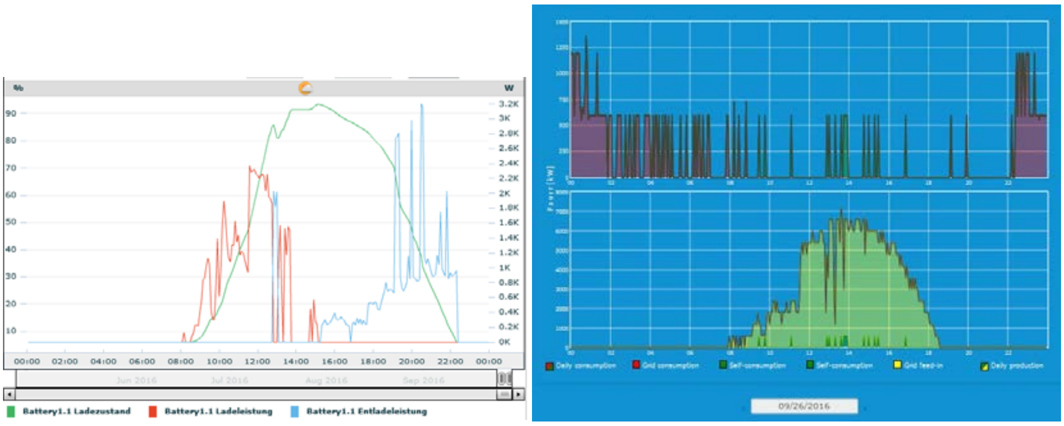


Figure 25: Left part shows the charging (red) and discharging (blue) power flow and the SOC (green line) of the Tesla Power battery via the SolarEdge^{TM} web access. The right side shows CoSSMic monitored power flow of the PV system not feeding into the Tesla Power battery (bottom) and the remaining part of grid consumption.

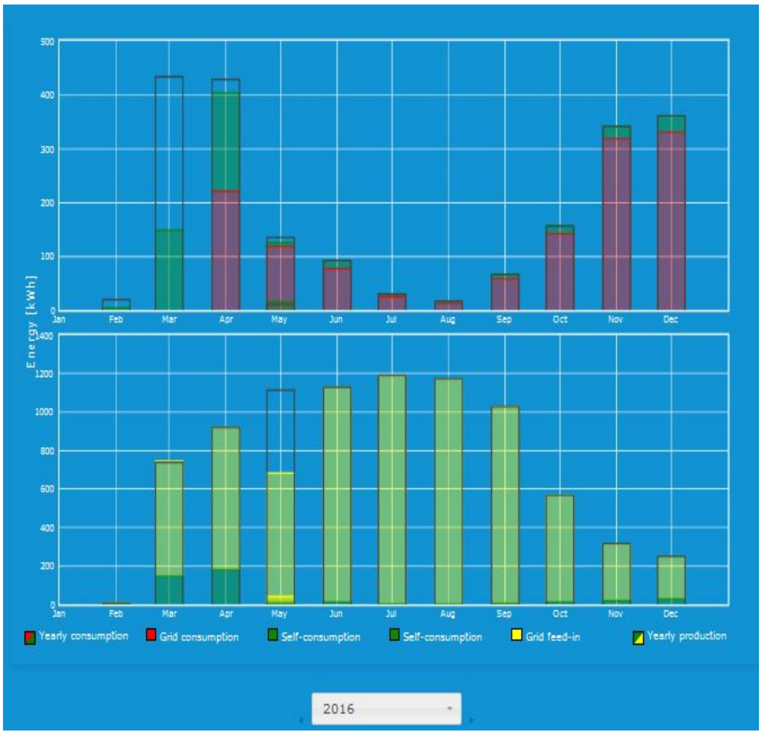


Figure 26: The PV generation (bottom, green) and the grid consumption (top, red) of KN12 shows for the time past the Tesla Power battery installation a strong reduced grid consumption. Btw there is no heat pump system installed which may cause the reduced electrical consumption in the warm half of the year.

Rule of thumb regarding a standard household with some commonly distributed loads as candidates for load shift or to be feed to consume from an installed battery.

For a quick overview one can assume that each single run device like a dishwasher or a washing machine need roughly about 1.5kWh/run, each single run device should run only during sunshine period; back-up loads like freezers, refrigerators consume in average about 20W$_{continue}$ each, which summarizes to about 0.5kWh/d/device and finally to 0.2kWh/night/device, when we do not receive PV energy.

The big problem remains, that some loads like e.g. the lighting of buildings or heat pumps have higher loads, counter cyclically to the availability of sunlight during dusk or even at night, or in winter seasons.

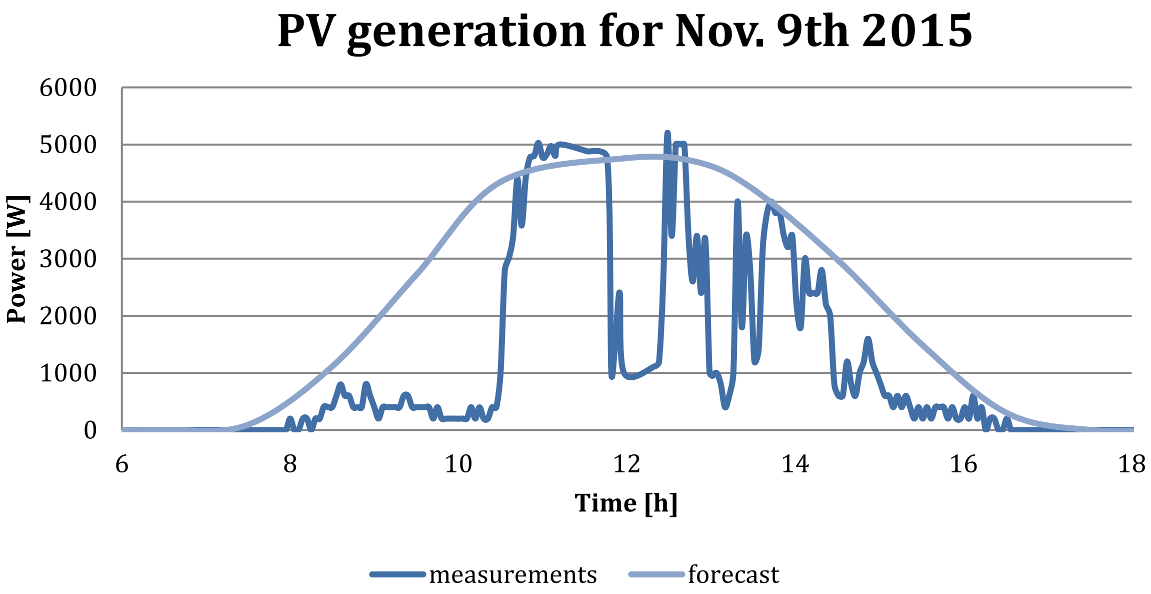
The conclusions for the optimizing of storage cycles can be drawn from the available data of the integrated stationary battery (3.7kWh) at KN03. It show, that up to 300 loading cycles can be expected over a year, which is in line with about 6000 loading cycles over the batteries life time of 20 years. An estimate can show here, that this will be enough to reach a return of 50% of initial investment cost.

Therefore, first priority should still be a strong focus on load shifting and only if this is not possible to store the energy, because of the cost factor. However, future expectations promise an increase of energy costs when provided from the grid and coincident omitted feed-in payment which may favour a battery system. We also expect significant lower battery prices in the near future.
Further studies are mandatory, whether shared storage within a neighbourhood will reduce the life cycle cost of a shared storage system as well.

5.4 PV-yield prediction performance

The ratio of the forecasted to the measured PV energy output of a certain time period can be regarded as a measure of the prediction accuracy.

In order to demonstrate the deviations between predicted and actually measured PV-yields, particularly for days of locally fluctuating weather conditions, Figure 27 provides a first impression.



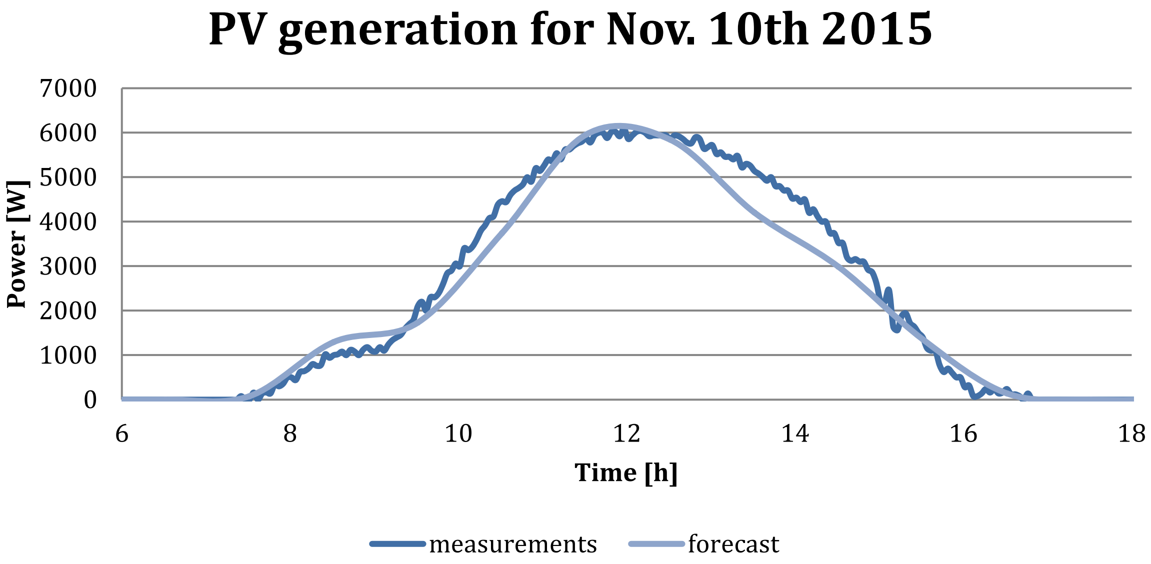


Figure 27: The top and bottom graphs show both the predicted and measured PV yield of a 10kWp PV installation in Konstanz for two consecutive days in autumn 2015, with different accuracies regarding the forecast performance.

5.4.1 PV-Yield prediction

The photovoltaic yield prediction is based on an hourly solar radiation forecast, provided by DWD (Deutscher Wetterdienst), for the City of Konstanz and the Province of Caserta[5] .

The DWD radiation forecast was provided every 6 hours with hourly average predictions for 24 hours. It predicted the diffuse and direct solar radiation on a horizontal surface in W/m² as well as the air temperature in 2 meters height and on ground in Kelvin.

To get the effective incident irradiance from this horizontal direct and diffuse irradiance values, the modules' tilt and orientation to the north need to be included.

5.4.1.1 First evaluation

To integrate a periodically run photovoltaic yield prediction to the "debian" system on a Raspberry Pi, pvprediction[6], an open-source python package, was developed as a result of this research. The goal of this program was to rely only on basic information about the modules, obtainable from the datasheet, without additional measuring equipment to examine the modules temperature.

As a first evaluation of the prediction performance, various system losses were incorporated as static efficiency parameter of 92%, consisting of soiling, field and inverter losses.

In Figure 28, the relative prediction error for each hour of a period of 122 fully measured and valid days, between the 15th Oct. 2015 and 31st Mar. 2016 is shown. During this period, the weather was specifically characterized by fog and rain or snow fall, resulting in difficult conditions for the forecast and prediction. The prediction error is calculated as the ratio of predicted to measured PV output. The figure displays the median prediction error, including upper (light blue) and lower (dark blue) quartiles of the error

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[5] A. Mahran, A. Minde, K. Peter, J. Glatz-Reichenbach, Optimizing the self-consumption of solar powered smart micro grids, Paper presentation on the 32nd European Photovoltaic Solar Energy Conference and Exhibition, München, Germany, June, 20-24th 2016, Topic No. 6 PV Applications and Integration, Session 6AV.4.29

[6] "Bitbucket CoSSMic pvprediction," [Online]. Available: https://bitbucket.org/cossmic_release/pvprediction. [Accessed 1 January 2016].

distribution. Positive values indicate an over-estimation, relative to the measured values in percent, whereas negative values indicate an underestimation. The figure thus provides an overall impression of prediction limits and shows the general trends of the prediction error.

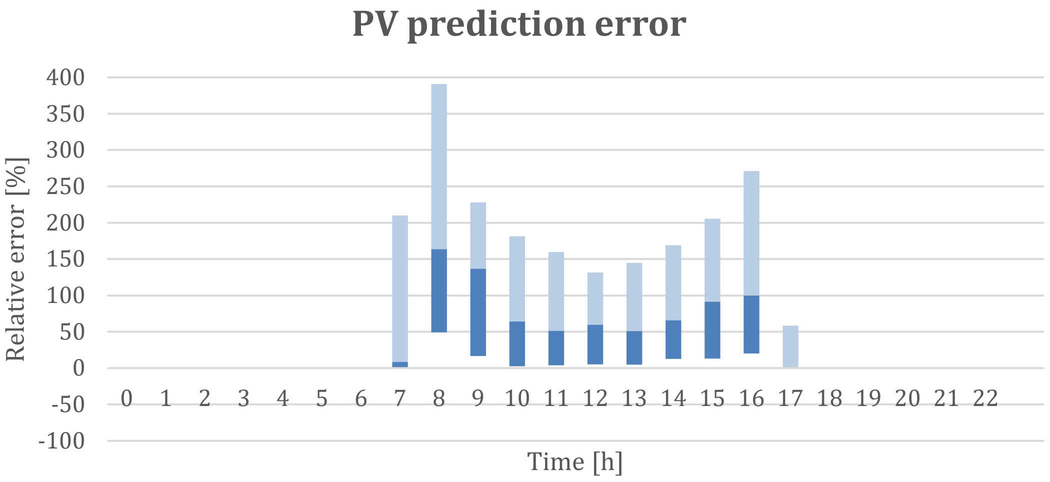

Figure 28: Prediction error of 122 days from 15th Oct 2015 to 31st Mar 2016.

For comparison, a clear blue sky day, i.e. already accurately predicted as such one, was chosen without additional shadowing by clouds and therefore with a minimum of interferences. Thus the prediction error should be expected to be minimised and is shown in Figure 29, This10th Nov. 2015 was chosen as the reference day for further comparison to estimate the generated power yield of the 12kWp PV roof top installation, on the ISC office building.

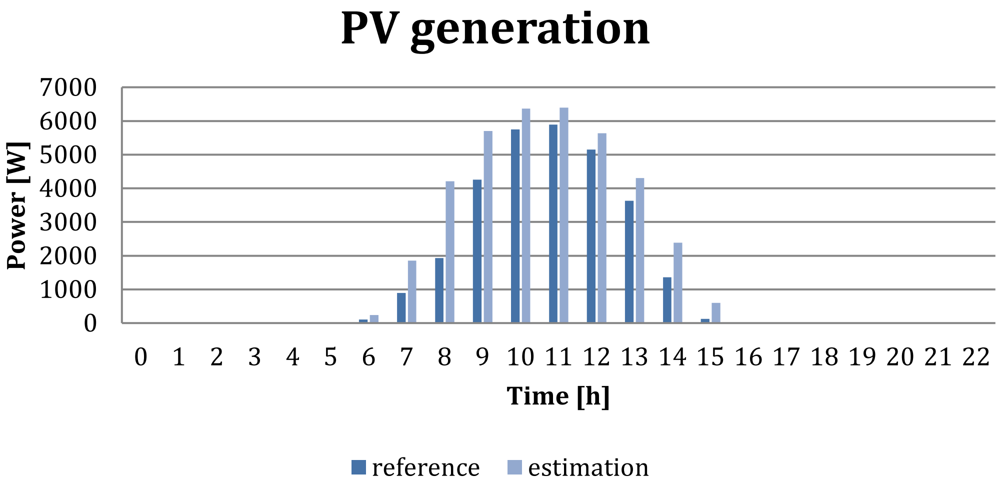

Figure 29: Generation estimate against measurements, 10th Nov 2015.

With an average median error of 34%, a clear over-estimation bias, specifically in the early midmorning and afternoon can be observed. While this could partly be explained by the static treatment of the inverter efficiency, the load dependent efficiency range of an inverter cannot explain such big differences on its own. Additionally, accurate inverter efficiency calculations need voltage measurements of the PV system and detailed empirical data or calculated coefficients of the inverter, which are not easily available for every solar inverter. As of the cost efficiency and practicability as major focus points of this work, those algorithms were not further addressed.

Other major influences could be identified as the simplistic cell temperature model, dirt, dew or reflections of the module glass, or probably most important the 14° tilted modules shadowing each other during the suns decreased elevation in the winter months. Those influences can be hard or impossible to simulate without even more sophisticated models or without creating an expensive 3D model of the neighbourhood.

5.4.2 Optimization

Although most PV systems currently installed were designed for maximum yield with a minimum of shadowing issues, facade or urban installations could increase in importance drastically over the years. Shadowing specifically, but also other environmental influences on a PV systems efficiency, such as temperature, dirt, dew points or aging, are especially hard to statically model in a simulation. Those influences are slowly time-variant though or influenced by weather trends such as the suns position during seasons or absent rain for the soiling of the modules.

To utilize this correlation, a dynamically optimized efficiency value $\hat{\eta}_i$ for each single daylight hour i could potentially increase the predictions performance drastically, especially for installation sites, where shadowing occurs more often. This efficiency values $\hat{\eta}_i$ were implemented in a recursive optimization scheme.

5.4.2.1 Evaluation

With the recursive optimization scheme, the over-estimation for the 10th Nov 2015 got significantly reduced and even resulted in a slight under-estimation, which can be observed in Figure 30, while the average error of the relevant hours between sunrise and sunset was reduced below 1%. The visible discrepancy for single hours of the day, especially in the midmorning hours, could be explained by taking into account, that the optimization period of a whole week heavily relates on previous forecast performance. Which, thanks to regional unique fogginess during that time or fast changing weather conditions, may cause significant efficiency offsets for certain time periods.

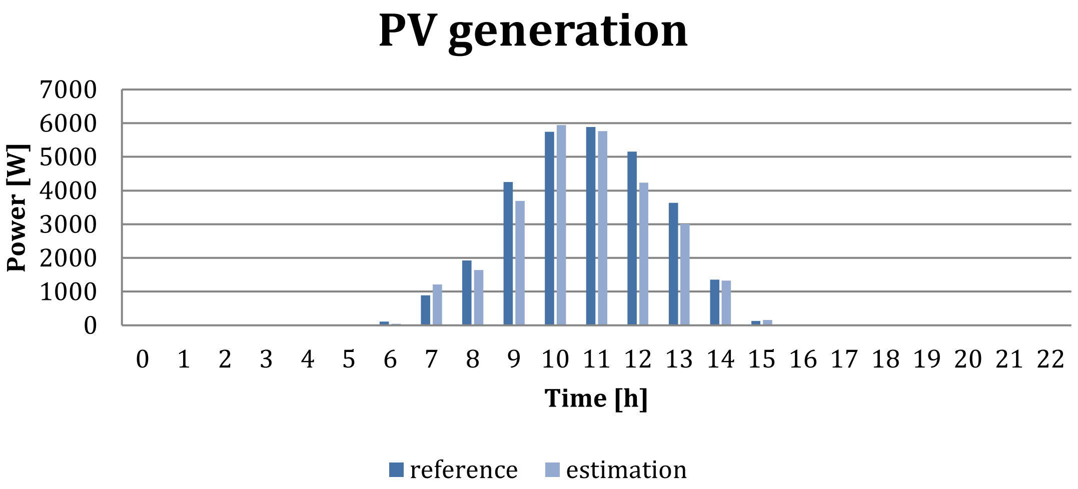

Figure 30: Generation estimate against measurements, recursively optimized with a forgetting factor $\boldsymbol{\lambda} = 0.7$.

Figure 31 shows the prediction error results for 122 days from 15th Oct 2015 to 31st Mar 2016 for the recursively optimized prediction with a forgetting factor $\lambda = 0.7$. The figure shows the clear improvement of both the error distribution for the quartiles, as well as the median error. With an average median error of 0.2%, as well as an improved and more stable error distribution throughout the whole day, the increased performance gets apparent.

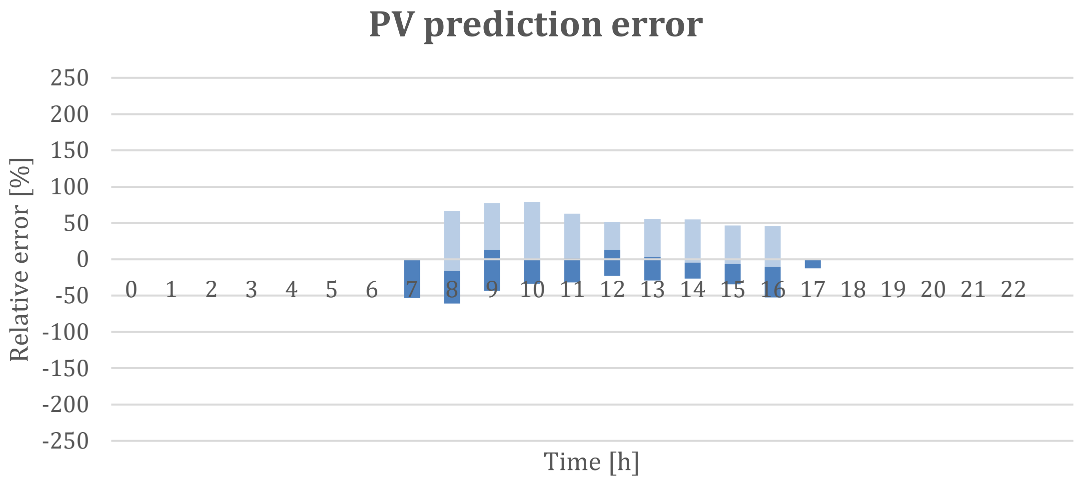

Figure 31: Prediction error of hourly recursive optimized efficiency with a forgetting factor $\boldsymbol{\lambda} = 0.7$.

5.4.3 *Summary for PV prediction accuracy*

An open-source photovoltaic yield prediction, relying only on easy to access data and hardware was developed. The improvement of the prediction performance by simple optimization efforts shows high potential and could be further investigated.

Necessary to simulate environmental factors are most likely slowly time-variant. Soiling of the PV modules' glass and therewith reduced energy yield, as well as its cleaning during rainy periods are slow processes, which could be adjusted by a dynamic optimization.

Most shadowing issues, such as coming from trees or chimneys, increase in importance during low solar elevations during winter season. Reduced solar inverter efficiencies for non-optimal loads occur, depending highly on the suns incidence angle towards the module, at time spans close to sunrise and sunset and seasonal periods. Cell temperature affecting factors, such as the heat accumulation of the installation and its surroundings, wind or humidity are either static or vary with some exceptions mostly in short-time trends with changing weather pressure areas.

Therefore the dynamically optimized simulation results still include uncertainties, with the major uncertainty as the radiation forecast itself. During stable or well forecasted weather conditions though, e.g. during high pressure periods over several days in summer, the predictions error converge close to zero.

Further improvements could be done by taking into account real, measured solar radiation data at different PV installations sites or improving certain model components, such as the cell temperature estimation and details about the influence of pollution of the PV system. This can also be of relevance on effects of collective PV systems on total power fluctuation and energy outcome also discussed in section 5.6.

5.5 Scalability

The optimisation problem of scheduling non-linear and time-varying loads L(t) on time-varying electricity provided by a PV system with the goal of finding the optimal start times for the loads within the constraints of the earliest start time and the latest start configuration time set by the user is a non-linear optimization problem. Non-linear optimisation problems have, in general, exponential time complexity. In other words, the time T it takes to find a solution is proportional to

$$T \sim e^{a \cdot N} \tag{3}$$

where N is the number of loads to schedule and a is a problem and algorithm dependent constant. Now assume that the number of loads increase to K·N for some K > 1.

The time to find a solution is then

$$e^{a \cdot K \cdot N} = e^{(a \cdot N)^K} \tag{4}$$

by the rule of powers. Consequently, as an example doubling the number of loads, K=2, *squares* the time it takes to find a solution.

Furthermore,

$$K \cdot T < T^K \tag{5}$$

if T > e (the base of the natural logarithm) and K > 1,

and so it will always be better to solve K smaller problems than a problem K times as large.

Therefore, in CoSSMic a distributed optimization approach is taken to allow the best possible opportunity to scale the size of the neighbourhood since each household will add multiple additional loads to be scheduled.

The cost of distributed scheduling is the lack of a guarantee of global optimality. The found solution may or may not be optimal, as it depends on the *allocation* of the loads to the individual producers solving individually the scheduling problem for that producer. In the extreme that all loads are allocated to one and only one producer, then it has to solve the global problem and nothing is gained from the distribution. For this reason, a learning based approach is adopted in CoSSMic where random search space exploration is combined with global feedback on each allocation. This will lead to more different allocations being tested, and this should minimise the risk of locking into a sub-optimal allocation for a neighbourhood's load configuration.

For the relatively small neighbourhoods we have tested the execution time of the scheduler which turned out not to be a problem, and unfortunately we were not able to investigate this further by simulation. However, some experiments approximating what may happen when the number of loads under treatment increases were done in WP4, and reported in D4.3. The results indicate that with the partitioning of the optimization problem as done in the CoSSMic architecture, scalability is not likely to be a problem as long as most household have local solar plants.

5.6 Effect of collective PV systems on total power fluctuation

As references to evaluate the prediction performance and calculate prediction errors for further optimization, the integrated PV installations are available.

Almost all PV systems were available from the trial start and were rooftop mounted except of one facade installation at KN04. They were oriented to the south with variations of about ±15°. In the last month of the trial test in May 2016 at KN12 were installed together with a Tesla Power battery 24 PV modules with 260Wp each, 12 modules on a flat garage roof and 12 on a gable wall oriented to the north, all to charge the battery system.

Therefore the total ensemble of all integrated PV systems follows the same time dependency as the single households PV systems.

Furthermore we have to admit at this point, that although the simulator could be used to investigate the effect of changing, for example, the tilt and orientation of the PV system panels, we did not have time and resources to do it.

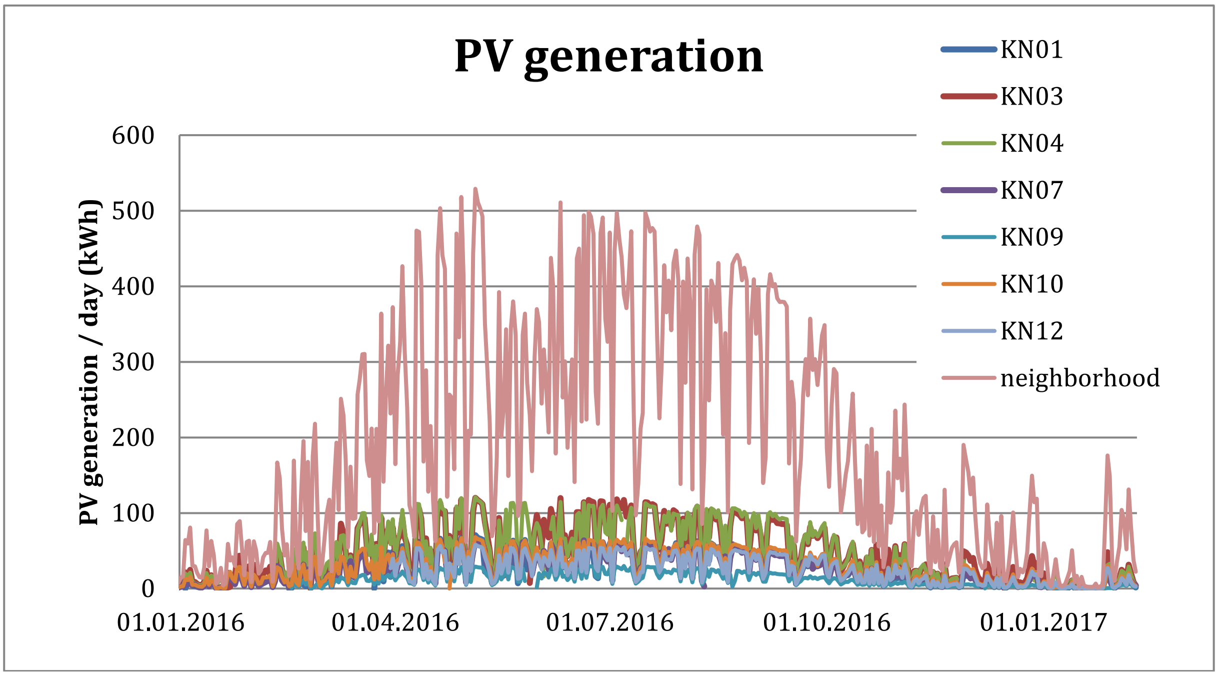

Figure 32: The PV generation of each Konstanz household with PV installation and the total neighbourhood generation.

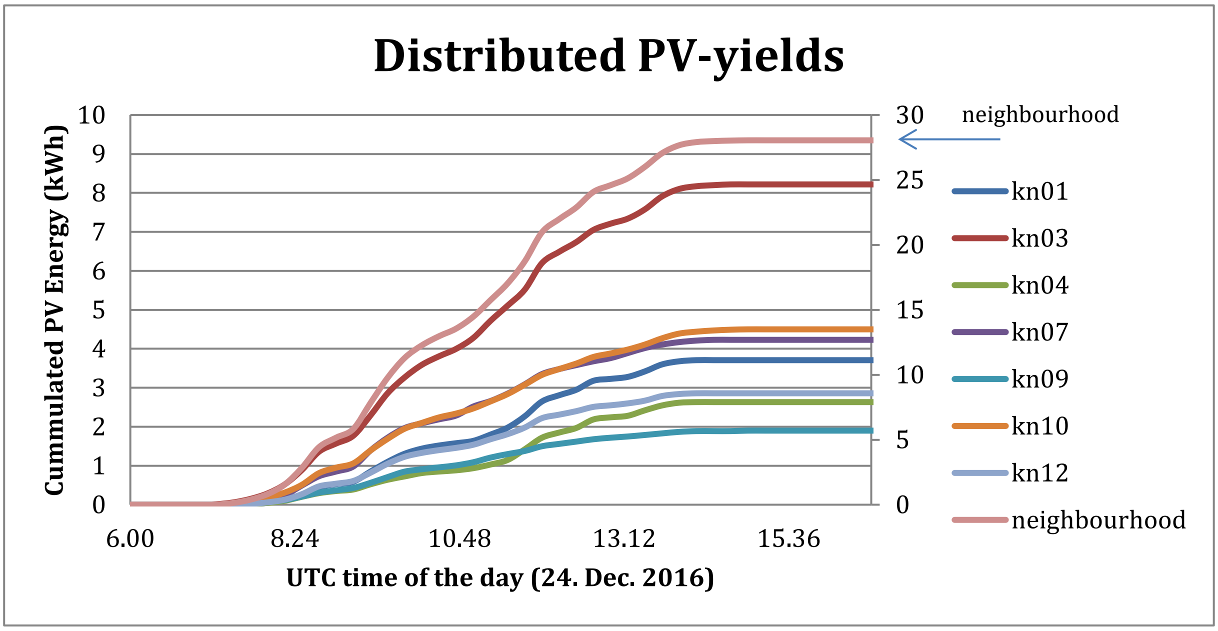

Figure 33: The PV energy yield of Christmas Day 2016 of the distributed PV systems KN01, KN03, KN04, KN07, KN09, KN10 and KN12 refers to the left scale and the summarized energy yield of all refers to the right axis, given always in kWh.

5.7 Usability of software

Early evaluation based on user-centred design principles and user involvement. User requirements have been collected from interviews and workshops at the two trial sites in Germany and Italy with potential trial users. Furthermore, the GUI has been designed following user-centred approach, and the concepts have been co-developed and validated with stakeholders and users in user centred design workshops.

A detailed evaluation on the used CoSSMic software was planned and referred to “CoSSMic GUI Likert Scale” to discuss the display of evaluated measured data. In the Appendix Table 16 gives an overview about the asked questions to the trial users. Due to the rather low answer feedback the evaluation couldn´t be performed in an adequate way which was largely due because the task scheduler did not perform satisfactorily until the end of the trial phase.

During the early trial phase, the trial user found it inconvenient to use the GUI for "task planning" every time, i.e., define settings/constraints for tasks using the GUI every time the user wants to start a device (dishwasher or washing machine). From the results of questionnaires, we found that people in general are in favour of automation (see results of D6.3), i.e., they would like that the system works automatically according to user preferences. Based on this feedback, we changed CoSSMic software design and added some new functionality – default settings and automatic task planning. The system allows the user to define and change default settings, i.e., default Earliest Start Time (EST), Latest Start Time (LST) or delay for scheduling a task after the task has been submitted. Alternatively, the user can add a task with EST, LST or delay differently from the default for one run. In both cases, the task will be automatically detected and scheduled by the CoSSMic system. For example, after default settings have been defined for a washing machine, the user only needs to select the program and start the washing machine as normal operations without using CoSSMic system, the system will automatically detect the start of the washing machine via smart plugs or meters, and consider it a signal for the definition of a new task according to the user setting (default or one-time setting). The system will then control the actual start of washing according to the new schedule planned coordinated with the neighbours. This saves the user from extra work for manually defining tasks every time in the GUI.

At the end of the trial phase the results of the early stage evaluations on the users opinion on the planned (D2.2) and the real developed GUI (2.4) have been reviewed and adapted to the gained trial outcomes.

The scheduling within the simulator is performed by the same code as in the real system, so there is no model that need to be validated. However, the software has been checked with reliable system and measurement data in order to generate results as expected, but not benchmarked against other available simulation software. We made successful functional tests of the single components, which means, the software has been tested but not validated. For detailed information refer to D6.4. Comparison with other software solution is not possible, as we do not simulate a model, which can be simulated by other software as well etc.

5.7.1 Results on concepts of users integration

The iterative design approach initiated a forum where potential CoSSMic users could present their feedback on what is being developed by the CoSSMic team. It has been successful in building up relations between users and the project teams in Konstanz and Caserta. However, whether the approach can be considered a 100% ‘user-centred’ is questionable. The initial workshop that involved projects participants of CoSSMic set the agenda for the ongoing workshops, which was the basis of feedback in the user-centred workshops and at the Konstanz site, some of the project participants also were part of the CoSSMic users (representing a private household and a company). But nevertheless the online adaption of the paper prototypes with and by the users input can be said to be user centred. Despite limitations, there was made clear steps forward in developing relations with and between end users giving the project early feedback on how the preliminary end users community views the project and what an end user would like from the technology and software from CoSSMic.

The feedback from the workshops was the basis for further work in developing a platform for smart solar-powered micro-grid communities during the project and beyond. The early prototype as started on paper and continued in hardware installations supported user involvement right from an early stage. For further details see deliverable D2.2.

5.7.2 Results on users integration software and design

With the ramp-up and start of the at least one year ongoing trials in the City of Konstanz and the Province of Caserta the developed GUI will run on the mediator, which is a Raspberry Pi computer installed at each household to act as the interface between the households and the CoSSMic autonomic ICT based energy managing and coordinating system.

Critical and constructive feedback on the use and application of the GUI was collected from the integrated users as the CoSSMic community, and additional also from a more technical point of view in terms of "how well and reliable" software and its GUI were working. For further details see deliverable D2.4.

Now at the end of the trial phase we hold in hands valuable information to create a next adapted and improved GUI version for release.

5.8 Energy cost reduction

The energy cost reduction can be directly related to an increase of the PV generated self-consumption, and calculated by applying the tariffs given in Table 14. The feed-in tariff is mainly based on the installation date of the PV system. Table 15 gives an overview of the feed in tariff development over the last decade in Germany for a private roof top PV installation of up to 10kWp power rating. The feed in tariffs are dynamic and should decrease at present in Germany with increasing PV installations, but actually remain constant with a trend to go up slightly due to reduced installation capacities.

private household (PV<10kWp)	grid tariff - 1 (00h-24h) p(t)-1 (EUR/kWh)	fixed yearly costs tariff-1 (EUR/a)	grid tariff-2a (06h-21h) p(t)-2 (EUR/kWh)	grid tariff-2b (21h-06h) p(t)-2 (EUR/kWh)	fixed yearly costs tariff-2 (EUR/a)
KN07	0,2559	143.62	0,2559	0,21999	175,75
KN08	0,2559	143.62	0,2559	0,21999	175,75
KN09	0,2559	143.62	0,2559	0,21999	175,75
KN10	0,2559	143.62	0,2559	0,21999	175,75
KN11	0,2672	102,59	0,2672	0,21999	134,72
KN12	0,2559	143.62	0,2559	0,21999	175,75

Table 14: Tariffs according D2.4 section 4.1.3 for the Konstanz trial site provided by the DSO Stadtwerke Konstanz.

Date of validity start	Tariff feed-in payment (EUR/kWh)
01.01.2017	0,1230

01.01.2016	0,1231
01.01.2015	0,1295
01.08.2014	0,1315
01.01.2012	0,2443
01.01.2011	0,2874
01.01.2010	0,3900
01.01.2009	0,4300
01.01.2007	0,4900

Table 15: The German feed in tariffs for a private PV system up to 10kWp rating with dates of validity.

The given tariff model for the energy consumption includes the energy charges, network charges, taxes and subsidies resulting in a price per kWh over time and is represented as p(t), the feed-in tariff per kWh is represented as f(t), the energy consumed from grid (kWh over time) is represented as $E_{grid}(t)$ and the PV feed-in PV production (kWh over time) is represented as $E_f(t)$

The energy cost over a year can be calculated as the

$$\Sigma(p(t)\cdot E_{grid}(t)) - \Sigma(f(t)\cdot E_f(t)).$$

We can now compute the energy cost with CoSSMic and the deployed scheduler for load shifting and without CoSSMic, then calculate the energy cost reduction as their difference.

This has been done based on the simulation results for the six Konstanz private households forming a neighbourhood during the trial year.

The difference without and with CoSSMic scheduler application is a saving of about 190€/a, for the at present valid feed-in and grid tariff.

In near future when the first PV installations start to go off from feed-in payment, accompanied by an expected increase of the grid energy price, the mentioned benefit will be increase at least by a factor of two.

5.9 Return of investment cost

The overall goal would be that the cumulated savings should exceed the investment costs before the end of the lifetime of the investment is reached!

Stationary battery:

An observed energy input of about 4.7kWh/day can be used from section 5.4 which results in about 1500kWh/a green energy input into the battery. The estimation by taking into account of 0.26€/kWh grid energy cost and about 0.123€/kWh feed in payback results in an annual profit of about:

0.26 €/$\text{kWh}_{\text{gridcost}}$ – 0.123 €/$\text{kWh}_{\text{generationcosts}}$ = 0.137€/kWh net win → 1.5MWh x 0.137€/kWh=206€/a

In the next few years the first PV installations will go off from the feed in benefit which will push the self consumption of PV generated energy. This fact increases the benefit of storage systems even more.

Mobile battery of an electrical car:

The example is driven by the result of the charging of the EV of KN10 during the whole trial period which summarizes for the entire year 2016 to a charged energy of about 1010kWh. The overall energy yield during the year 2016 of the household KN10, see Figure 18, is even larger than the EV charging energy amount, so a good argument to assume almost green charging by the energy from the own roof top PV system.

One easy calculation shows under the assumption of:

7kWh/100km (EV)

5l/100km (combustion car)

7kWh result in 0.123€/kWh instead feed in pack back → 0.861 €/100km

5l result in 5 x 1.50€ → 7.5€/100km

6 Security and privacy assessment for CoSSMic platform

Although security is not a main focus in the CoSSMic platform, the system does involve the collection of potentially sensitive data that should be protected. Furthermore the system exposes indirect control of energy consumption to the mobile phone or computer of the households. Unauthorised use of such interface could impact the energy consumption profile and, indirectly, in case of flaws in home appliance or network infrastructure, pose potential security risk and privacy risks. Therefore, security and privacy issues have been investigated and evaluated in two master thesis[7,8]

The work of Kodra assessed the security of the communication between the CoSSMic enabled smart home and the connected devices through HomeMatic smart plugs and investigated common web vulnerabilities for CoSSMic platform. In particular, the following part of the CoSSMic system has been analyzed:

- Emoncms
- HomeMatic smart plug

Through a series of experiments, Kodra found the following vulnerabilities:

1. The communication between the HomeMatic device and the home gateway (Raspberry Pi) can be intercepted, and the traffic can be captured. The captured packets could be later on used to replay commands, for example, a malicious attacker can use the captured packet to switch on/off the device without being noticed by a legitimate user.
2. The web app (Emoncms) is vulnerable to common web vulnerabilities, which can also cause a Denial of Service (the most serious one).

For issue 1, the communication between the HomeMatic device and the Raspberry Pi could be secured by applying security mechanisms, e.g., encrypted communication (such as AES encryption) and strong authentication mechanism. This finding also applies to other devices that communicate with the Raspberry Pi (gateway), i.e., encryptions and authentications should be applied to secure the communication of CoSSMic system with the devices (in driver development).

For issue 2, some of the vulnerabilities reside in the open source technologies we have chosen, e.g., the communication over HTTP is not encrypted (transferring sensitive data in plain text). To counterpart them, VPN is recommended to be used for accessing the web application provided by Emoncms (CoSSMic household interface). In this way, the CoSSMic web household interface is protected by VPN and is not available for unauthorized parties. The use of VPN thus provides secured remote access to CoSSMic system and mitigates the potential web vulnerabilities as identified. In addition, security can be enhanced by protocols like HTTPS and SSH instead of HTTP and encrypted payload instead of plain text.

As the MAS part of CoSSMic was still under development during Kodra's investigation period, the XMPP-based communication between smart homes for energy negotiation has not been evaluated. It has been claimed that "Even the open XMPP network running on the public Internet since 1999 has experienced very few security issues"[9] In addition, "XMPP servers can be isolated (e.g., on a company intranet), and secure authentication (SASL) and encryption (TLS) have been built into the core XMPP specifications"[10] Therefore, XMPP-based communication and negotiation can be considered rather secure.

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[7] [Kodra 2016] Suela Kodra. Smart Home Hacking. Master Thesis, NTNU, 2016.

[8] [VanThiBui 2016] June Kieu-Van Thi Bui. Smarthus hacking – Sikkerhetsrisiko i Collaborating Smart Solar-powered Microgrids. Master Thesis (in Norwegian). NTNU, 2016.

[9] [XMPP the definitive] https://www.safaribooksonline.com/library/view/xmpp-the-definitive/9780596157524/ch12s08.html

[10] [XMPP wikipedia] https://en.wikipedia.org/wiki/XMPP

VanThiBui focused on security risks in CoSSMic. Based on a threat modelling, it presented risk analysis of potential threats against CoSSMic system and proposed corresponding mitigating measures. It also conducted testing of CoSSMic GUI web application and gave similar conclusion as Kodra.

Regarding privacy issues, except for backup trial data to a cloud server for research purpose, the CoSSMic user-related data (e.g., credentials and energy consumption data) are mainly stored locally and not transferred over Internet. All household data are also anonymized, so there is no big risk for privacy concern in CoSSMic. Furthermore, it should be noted that CoSSMic does not introduce substantially new risk, just wider exposure of existing risks in existing infrastructure or home appliances.

7 Conclusion

This report has presented how the data measured in the field trials in the CoSSMic project were analysed and evaluated, including how the data were prepared and used for simulations, and the initial findings of the evaluation.

In order to ensure that the measured data were useful and valid, both for evaluation and simulation purposes, the relationship between the objectives of the project, the KPIs suitable to assess the degree of achievement of the objectives, and the data to be measured in order to calculate the KPIs have been analysed and validated.

Delays in the testing and debugging of the software limited severely the time available for simulations, and the ambition had to be reduced considerably. Therefore, the focus has been on two points:

- the ability of the coordinated automatic load shifting of the CoSSMic system to increase the rate of self-consumption at the neighbourhood level, from which we expect benefit to the households in terms of lower energy cost,
- the effect on the power load peaks, both for the consumption from and into the public grid by the neighbourhood.

We compared the self-consumption and peaks without any automatic load shifting with the results from simulating the same scenarios with coordinated load shifting implemented by the CoSSMic software. The performed simulations indicate that systems like CoSSMic can increase the self-consumption of neighbourhoods significantly. The results showed an increase of self-consumption between 5 and 10 percentage points if we compare with the neighbourhood self-consumption without load-shifting, which indicate the performance of the coordinated load shifting. If we compare with the summed up self-consumption of the individual households, which could indicate the saving on the electricity bill, the increase is between 15 and 25 percentage points. The highest effect occurred in the summer week. This is quite promising considering that only dishwashers and washing machines were controlled by the scheduler and the allowed flexibility was only 2 hours delay, which we believe is a very conservative estimate. On the other hand, the simulator assumed perfect prediction of the PV production and background loads, which is generally too optimistic.

For the peak load and peak feed-in we did not see a significant effect. Closer investigation of the data reveals that the peaks are created by the background loads that we do not control, and therefore the load-shifting has no effect.

In our simulations, only single-run devices were controlled by CoSSMic (for example dishwashers and washing machines), while continuously running devices (for example water heaters and heat pumps) were included in the background load and thus not available for load shifting. By controlling also these devices, we expect to see both higher self-consumption and lower peaks. However, it will require further research to confirm and quantify this.

Both the collected data and the simulator are important results from the CoSSMic project that opens many possibilities for future research into the effects of automatic load-shifting coordinated within a neighbourhood, for example to investigate closer the influence of

- the configuration and size of neighbourhoods,
- the accuracy of the PV production prediction,
- the degree of flexibility allowed,
- refinements of the scheduling algorithm.

The evaluation points out how important ICT based load shifting is to increase the self-consumption of locally generated PV electric energy within a PV based energy producing and consuming neighbourhood.

The PV yield prediction based on weather forecast data from Deutscher Wetterdienst (DWD) refreshed every six hour. The PV yield was calculated with respect to PV installation parameters like orientation, shading, soiling, inverter efficiency, etc. and the support of prediction results of the past days gives fairly good accuracy, especially during stable weather conditions without local disturbances of rain showers and running clouds with prediction errors converging close to zero. However, the accuracy of the weather forecast varies a lot and this is the main cause of deviation between predicted and actual yield.

The expected monetary savings strongly depend on the actual feed-in tariffs. In future when only low or no feed-in payments are expected together with increasing grid tariffs self-consumption will play a growing major role on energy cost saving.

All measurement data are open for public use. We are currently negotiating with an open energy data repository about publishing our data.

As already mentioned, due to the delay of the availability of the coordinating scheduler and lacking implementation of central features, the evaluation could not be carried out as originally planned. This means that some important aspects could not be carried out, but also that there are weaknesses associated with the investigations that we have done. Below we summarize the main issues that threaten the validity of our results, and suggest further research get more reliable results.

Small trial. The simulation of the effect of the coordinated load shifting on the self-consumption only involved the six private households in Konstanz, which is generally too small to draw conclusion on the quantification of the effect. Thus, our findings here must be seen as only a demonstration that it is possible to achieve increased self-consumption with CoSSMic technology. Further trials and/or simulations are needed to quantify the achievable effect.

Guessed flexibility. As already mentioned we have not been able to systematically collect data on the flexibility users are willing to provide to a system like CoSSMic. We think that the 2 hours max delay used in the simulations is a very conservative estimate, but further investigation is required to confirm this. One possibility would be to do simulations with different flexibility to investigate how flexibility influences the performance of the scheduler.

Limited simulated period. Partly due to already mentioned stability problems of the scheduler and that the simulator worked on a day by day basis, each day to be simulated required considerable manual work to check the consistency of the input data and prepare the simulation, and to check that the results were consistent and reasonable. For this reason, we only managed to simulate a few typical weeks, which clearly limits the validity of the results. More reliable conclusions could be achieved by doing simulation based on the full repository of collected data.

Simulator correctness. The scheduling within the simulator is performed by the same code as in the real system, so there is no model that need to be validated. However, the extraction of data from the central repository, the dispatcher and the calculation of results may still have bugs that could lead to erroneous results. To avoid this, the simulator has been tested on small scenarios and the results checked thoroughly by hand for correctness, and this gives some evidence that it works correctly. However, more extensive verification of correctness is desirable.

8 Appendix:

8.1 CoSSMic GUI Likert Scale

	>>CoSSMic GUI Likert Scale<<	**Strongly Disagree**			**Strongly Agree**	
	Question	**1**	**2**	**3**	**4**	**5**
1	The GUI elements provide enough information to help me being more energy efficient					
2	I believe that using the GUI, I will become more energy efficient					
3	I find that the GUI will be useful on my everyday life					
4	I believe that the consultation and usage of the GUI will become part of my routine					
5	It was easy to learn how to use the GUI					
6	I would find it easy to get the system to do what I want it to do.					
7	My interaction with the system would be clear and understandable					
8	I find the system to be flexible to interact with.					
9	It would be easy for me to become skilful at using the system.					
10	The GUI provides enough information for me to make conscious decisions about my energy usage					
11	The comparison with neighbours will drive me to increase my energy efficiency					
12	The GUI is attractive and pleasant					
13	I find the scores useful for keep track of my energy behaviour					
14	I like the tree and forest metaphores					
15	Getting a low score will motivate me to review my energy habits					
16	Getting a low score will trigger me to consult the system for tips on improving my energy habits					

Table 16: Introduced CoSSMic GUI Likert Scale.

8.2 Details about the simulated CoSSMic neighbourhood

The selected neighbourhood configurations as they were used for the neighbourhood simulations:

House: KN07
Device: kn07Heat_Pump - background
Device: kn07washing
Device: kn07freezer- background
Device: kn07dishwasher - background
Device: solarPanelKN07 10kW (PV system)

House: KN08
Device: kn08heater- background
Device: kn08dishwasher
Device: kn08washingmachine
Device: kn08freezer- background

House: KN09
Device: kn09refrigerator - background
Device: kn09freezer- background
Device: kn09dishwasher
Device: kn09washingmachine
Device: solarPanelKN09 5kW (PV system)

House: KN10
Device: kn10electricCar
Device: kn10heater- background
Device: kn10refrigerator - background
Device: kn10freezer- background
Device: kn10dishwasher
Device: kn10washingmachine
Device: backKn10
Device: solarPanelKN10 10kW (PV system)

House: KN11
Device: kn11refrigerator - background

Device: kn11dishwasher

Device: kn11washingmachine

House: KN12

Device: kn12freezer- background

Device: kn12dishwasher

Device: kn12washingmachine

Device: kn12heater- background

Device: solarPanelKN12 9kW (PV system)

The background loads are generated with an interval of 2 hours.

The devices included into the background load for each house are indicated above by “background”.

Each simulation was executed in a regular way 5 times.

8.3 Overview of single run devices of private households KN07-12

The following table gives an overview about the scheduled single run devices of the neighbourhood created by the six private households KN07, KN08, KN09, KN10, KN11 and KN12 of May 2016. The off times of data acquisition of CUL or/and Raspberry Pi off-times are marked in gray. In red are indicated the time spans when more than one device in a household is running, as known as stacked peak load.

KN07	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	▨ CUL or/and RPi off
	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	Mi	Do	Fr	Sa	So	Mo	Di	
1	▨			▨					▨													▨										🟥 DW+WM or DW, WM+e
2	▨			▨				▨	▨													▨										
3	▨							▨	▨						▨						▨	▨										🟧 WM: washing machine
4								▨														▨										
5								▨									▨					▨										🟨 DW: dish washer
6					▨												▨					▨										
7					▨				▨													▨										🟩 e: e-car charging
8					▨				▨													▨		DW		DW				DW		
9							WM		WM		▨				DW									WM								
10										WM	WM										▨											

11																		WM						WM							
12					DW						WM																		WM		
13	DW									WM							DW							WM							
14											DW													WM							
15																															
16															DW									WM							
17											WM		DW									DW									
18							DW																								
19									WM									WM													
20																	WM		DW		DW		WM								DW
21						WM			DW																						
22																															
23																															
24																															
KN08	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
	So	**Mo**	**Di**	**Mi**	**Do**	**Fr**	**Sa**	**So**	**Mo**	**Di**	**Mi**	**Do**	**Fr**	**Sa**	**So**	**Mo**	**Di**	**Mi**	**Do**	**Fr**	**Sa**	**So**	**Mo**	**Di**	**Mi**	**Do**	**Fr**	**Sa**	**So**	**Mo**	**Di**
1																															
2																															
3																															
4																															
5																															
6																															
7				WM																											
8					WM		WM																								
9														WM		WM	DW			WM		WM									
10	DW					WM		WM				WM			WM											DW	DW	WM		DW	
11																	WM						WM			WM					
12		WM				DW																									
13																															
14		DW		DW																			DW						WM		
15													WM																		
16																															
17																			WM												
18																												DW			
19																															

20							DW					DW								DW											
21										DW					DW																
22																					DW										
23																															
24																															
KN 09	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
	So	**Mo**	**Di**	**Mi**	**Do**	**Fr**	**Sa**	**So**	**Mo**	**Di**	**Mi**	**Do**	**Fr**	**Sa**	**So**	**Mo**	**Di**	**Mi**	**Do**	**Fr**	**Sa**	**So**	**Mo**	**Di**	**Mi**	**Do**	**Fr**	**Sa**	**So**	**Mo**	**Di**
1																	WM	WM													
2																					WM					WM					
3																															
4																					WM										
5																															
6																															
7									DW								WM														
8										DW					WM						WM										
9																WM		WM	DW/WM												
10	DW				DW							DW		WM		DW	WM									WM					
11							DW	WM										WM	WM												
12	WM						WM								WM						WM										
13																						DW									
14	DW		WM	WM	DW										WM																
15							WM							WM				WM			DW/WM										
16								WM							WM		WM			DW/WM	WM										
17										WM	WM					WM		WM			WM										
18								WM									WM				WM				DW/WM						
19										WM					WM						WM		DW								
20	DW										DW/WM		DW		WM		DW				WM										

21							DW									DW/WM				WM	WM			DW							
22														DW/WM	WM		WM			DW					WM						DW
23			DW							DW									DW	WM											
24																															

KN10	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
	So	**Mo**	**Di**	**Mi**	**Do**	**Fr**	**Sa**	**So**	**Mo**	**Di**	**Mi**	**Do**	**Fr**	**Sa**	**So**	**Mo**	**Di**	**Mi**	**Do**	**Fr**	**Sa**	**So**	**Mo**	**Di**	**Mi**	**Do**	**Fr**	**Sa**	**So**	**Mo**	**Di**
1																															
2																															
3																															
4																															
5																															
6																															
7																															
8										WM															WM						
9				WM		DW	e							WM																	
10							e															e						e			
11							e															WM+e			WM			e	e		e
12		e	e					WM			e		e								WM+e	e				e		e	e		e
13	WM	e	DW+e		e	e					e		e								e	e		WM	DW	e		e	e		e
14	DW	WM+e	e		e	e		DW		DW	e		DW+e								e					e		DW+e			e
15		e			e						e		e	WM												e					e
16		e						e					e															e			
17		e						WM+e					e		DW													e			
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▨ CUL or/and RPi off

DW+WM or DW, WM+e

WM: washing machine

DW: dish washer

e: e-car charging

Table 17: Overview about the scheduled single run devices of the neighbourhood created by the six private households KN07, KN08, KN09, KN10, KN11 and KN12 of May 2016 and data monitoring off times.

8.4 Glossary

Aggregator

An aggregator is an entity that can coordinate the activity of a number of resources (i. e.: distributed energy resources as intermittent sources like wind turbines, solar power installations, storage and demand side management) reducing or increasing their net production or consumption in a predictable way.

Agent (i. e. software agent)

In computer science, a software agent is a computer program that acts for a user or other program in a relationship of agency, typically exhibiting some aspect of artificial intelligence, such as learning and reasoning.

AGPL

The Affero General Public License (Affero GPL) refers to two distinct, though historically related, free software licenses. The first is the Affero General Public License, version 1 which was published by Affero, Inc. in March 2002, and is based on the GNU General Public License, version 2 (GPLv2). The second is compatible with the GNU Affero General Public License (a variant of the original Affero GPL license).

Emoncms software is licensed under AGPL. Some CoSSMic software modules that built on Emoncms are also licensed under AGPL.

API

An application programming interface (API) specifies how some software components should interact with each other.

AST

Actual Start Time (AST). In CoSSMic system, the scheduler assigns the AST of a load coordinated with other loads in a neighbourhood and the load controller then starts the load when the AST arrives.

Background load

See "load".

Bitbucket

Bitbucket is a web-based hosting service for projects that use either the Mercurial or Git revision control systems. It is used to host the CoSSMic open source code and documentation.

Community

A CoSSMic community is a group of people already using CoSSMic systems as well as people interested in getting started. Ideally this can be an online community where people can come together to exchange experience and advice, and which may serve as a portal to necessary software and hardware and associated documentation.

Emoncms

Emoncms (Energy monitoring Content Management System) is a powerful open-source web-app for processing, logging and visualizing energy, temperature and other environmental data. It is part of the OpenEnergyMonitor.org project.

Energy Smart Neighbourhood (ESN)

See "Neighbourhood".

EST

Earliest Start Time (EST) refers to the earliest time when the load should be started. It is a parameter used for defining the user constraints.

EV

Electric Vehicle

GPL

The GNU General Public License (GNU GPL or GPL) is a widely used free software license, which guarantees end users the freedom to run, study, share and modify the software.

GUI

Graphical User Interface

Home Gateway

A home gateway is usually a computing node at home that communicates with outside networks. A CoSSMic home gateway executes the intelligence based on distributed computing and is also responsible for communication both with devices within the household and with other neighbours.

Household

A household is a building (or part of a building or group of buildings), where a number of people, the household members, live or work.

LGPL

The GNU Lesser General Public License (LGPL) is a free software license published by the Free Software Foundation (FSF). The license allows developers and companies to use and integrate software released under the LGPL into their own (even proprietary) software without being required by the terms of a strong copyleft license to release the source code of their own components. The license only requires software under the LGPL be modifiable by end users via source code availability.

Some CoSSMic software modules are licensed under AGPL.

Load

Loads represent the estimated energy consumption of planned tasks. Each load has a profile of the estimated energy consumption, computed based on device profiles and environment conditions including weather forecasts. The optimisation part of the system works with loads, and decides the exact scheduling of the loads and thus the tasks they are associated with.

Some loads are controllable by CoSSMic and can be scheduled by the CoSSMic system. There are other energy consuming loads that are not controllable, but need to be considered during the planning and optimisation. Such loads are considered together and referred to as *background load*.

LST

Latest Start Time (LST) refers to the latest time when the load should be started. It is a parameter used for defining the user constraints.

Microgrid

In CoSSMic, a microgrid refers to a building or a group of buildings embedding rooftop photovoltaic (PV) panels, a number of power consuming devices and storage. A microgrid is typically confined in a smart home or office building, and although connected to the public grid, possibly via a smart meter, the microgrid is normally outside the control of the regulated companies operating the public grid.

MUC

Multi User Chatroom

Multi-agent System

A multi-agent system (MAS) is composed of multiple interacting intelligent agents within an environment. They can be used to solve problems that are difficult or impossible for an individual agent to solve.

Neighbourhood

A neighbourhood is a collection of households located close to each other.

An Energy Smart Neighbourhood (ESN) is a neighbourhood whose energy use is managed in a coordinated way.

A CoSSMic neighbourhood is an ESN that uses CoSSMic system to plan and schedule coordinated energy use and storage of the neighbourhood. An ideal CoSSMic neighbourhood consists of geographically close households that are part of the same low voltage subnet branch. In the CoSSMic trials, it is not feasible to recruit such a neighbourhood instead the trial neighbourhood is a logical neighbourhood that demonstrates the CoSSMic idea.

Peer-to-Peer (P2P)

Peer-to-peer (P2P) architecture is a type of decentralized and distributed architecture in which individual nodes (called *"peers"*) act as both suppliers and consumers of resources, in contrast to the centralised client server model where client nodes request access to resources provided by central servers.

Profile

A profile describes the predicted evolution of a given parameter over a given time period. Profiles are represented as time series, i.e. series of time value pairs, and are used for various purposes in the system. Each device has one or more profiles describing its energy consumption, production, or charging characteristics, depending on the kind of device. There can be consumption profiles for the predicted energy consumption of devices, production profiles for PV, weather profiles for predicted weather data and prices profiles for predicted price signals. The profiles can be parameterized to reflect the influencing factors.

REST

Representational state transfer (REST) is an architectural style consisting of a coordinated set of constraints applied to components, connectors, and data elements. REST ignores the details of component implementation and protocol syntax in order to focus on the roles of components, the constraints upon their interaction with other components, and their interpretation of significant data elements.

Self consumption of a household

The self-consumption of a household refers to the locally produced solar energy which is consumed by the household.

Smart meter

A smart meter is usually an electrical meter that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing purposes. Smart meters enable two-way communication between the meter and the central system. Unlike home energy monitors, smart meters can gather data for remote reporting. Such an advanced metering infrastructure (AMI) differs from traditional automatic meter reading (AMR) in that it enables two-way communications with the meter.

Stacked load peak (SLP)

In CoSSMic, stacked load peaks refer to peaks caused by stacking of loads in the neighbourhood.

Task

In CoSSMic, tasks refer to the planned utilization of devices by the user. The tasks are classified as single or continuous runs. Single run tasks are the energy consumption of devices like dishwasher and washing machine. Continuous tasks are the energy consumption of devices like fridge, freezer and heat pumps.

User

The primary users of the CoSSMic system are the people inhabiting or working in buildings which need electric energy for various important functions and possibly also are equipped with PV panels producing electric energy locally, and storage units where surplus energy from the PV panels can be stored temporarily.

Virtual power plant (VPP)

According to the CIRED Working Group on Smart Grid, "a virtual power plant is a collection of small decentralized generation units that are monitored and controlled by a superordinate energy management system that enables to forecast, schedule and control its output." [reference: CIRED Working Group on Smart Grids, "Smart Grids on the Distribution Level – Hype or Vision? CIRED's point of view", 23.05.2013, p 18]

VPN

A virtual private network (VPN) extends a private network across a public network, such as the Internet. It enables a computer to send and receive data across shared or public networks as if it were directly connected to the private network, while benefiting from the functionality, security and management policies of the private network. This is done by establishing a virtual point-to-point connection through the use of dedicated connections, encryption, or a combination of the two.

XMPP

Extensible Messaging and Presence Protocol (XMPP) is a communication protocol for message-oriented middleware based on XML (Extensible Markup Language).