



## **RES integration and DER management Module D7.5**

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# Deliverable

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## DISSEMINATION LEVEL

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## Statement of Originality

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# Executive Summary

This document is deliverable 7.5 "DER Management Module" of the TwinERGY project, funded by the European Commission's Innovation and Networks Executive Agency (CINEA) under its Horizon 2020 Research and Innovation programme (H2020).

The objective of this deliverable is to describe the ideas and concepts behind the module as well as the structure of the software that is developed for the operation during the pilot phase.

The DER management module will generate several kinds of signals that will be used by other modules (e.g. module 4) for their operation. Also, the signals deliver a possibility to be utilised by local assets like a battery storage to shift the timeframes with higher power demand to daytimes, where more renewable energy is available and thus reducing the overall CO2 emission of a household or a whole community.

The needed information and calculations for a reliable analysis are quite complex and the different aspects of these processes are described in their respective chapters.

During the integration and the testing phase of the pilot-sites, the module will be further expanded as more data is available, additional hardware is installed and the other modules start to work together with the DER management module.

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# 1 Introduction

## 1.1 Scope of the deliverable

The scope of this deliverable is to indicate the functionality of the DER module. It is an addition to the program code published within the deliverable. It solely describes the internal functionality and signals it generates for other modules and the participants at the pilot sites. All documentation is done in accordance to the current implementation and planned functionalities. It is highlighted that some of the functionalities need input of other modules and services around the TwinERGY ecosystem, thus this further development will be made during the integration and test phase of the system.

## 1.2 Structure of the deliverable

The deliverable starts with the concept of the DER module and an overview (Chapter 2). The next chapter (3) describes the forecast functions of the RES. To interact with other modules and participants, different signals will be send out. Chapter 4 shows the design and capabilities of the Incentive Curve approach, the Demand Response Signal and the Energy Light. The following chapter describes the grid calculation. Lastly, the control strategy of public devices (such as Batteries) is shown in Chapter 6.

## 1.3 Reference documents

This document is based on the following reference documents:

- TwinERGY Grant Agreement No.957736
- Horizon 2020 AGA – Annotated Model Grant Agreement
- Horizon 2020 Online Manual:  
[https://ec.europa.eu/research/participants/docs/h2020-funding-guide/index\\_en.htm](https://ec.europa.eu/research/participants/docs/h2020-funding-guide/index_en.htm)
- D1.1 - “Project Management Handbook”
- D1.5 - “Project Management Plan”
- D4.3 – “System’s architecture”
- D5.1 – “TwinERGY Common Information Model”
- D7.1 – “Modules interoperability”

## 1.4 Abbreviation list

The main abbreviations that are used in this document are shown in Table 1.

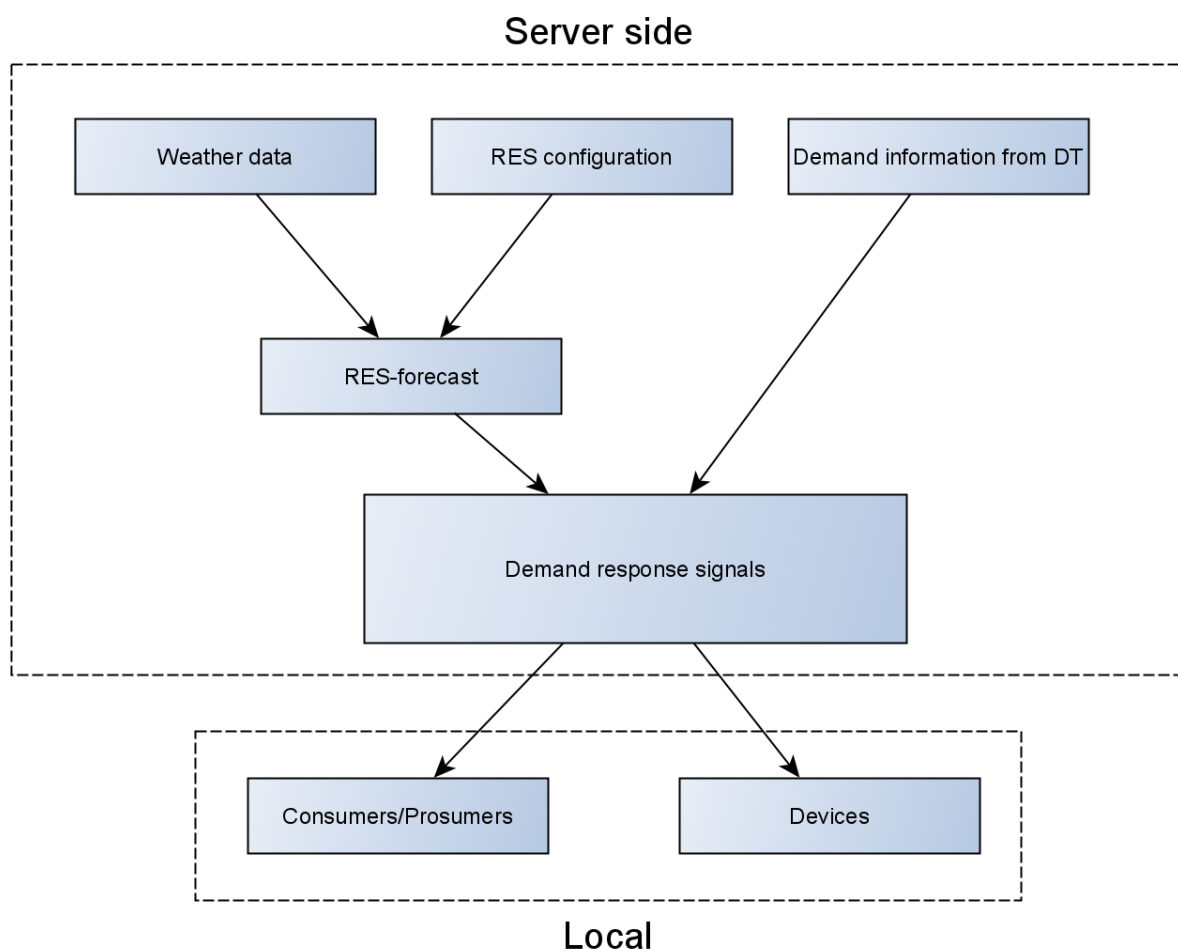
*Table 1: Abbreviation list*

Acronym	Full Name
API	Application Programming Interface
DER	Distributed Energy Resources
DR	Demand Response
DT	Digital Twin
DSO	Distribution Service Operator
EEA	European Environmental Agency
EV	Electric Vehicle
H2020	Horizon 2020 programme
ICC	Incentive Curve
IT	Information Technology
SLP	Standard-Load-Profile
SM	Smart Meter
RES	Renewable Energy Source
WP	Work Package

# 2 Concept

## 2.1 Initial Idea

The core idea of the DER module is to increase the flexibility of the electricity demand of the participating parties to comply with the varying production of RES. By doing so, energy communities can use the produced renewable energies more efficiently by shifting non time-critical consumptions to times, when more green energy is produced. To communicate the information about RES-production and possible flexibilities, several kinds of signals will be generated, which are then utilised by people or technical devices in the local communities (see **Figure 1**).



**Figure 1:** Flow chart of the demand response signals generation.

To interact with people in the pilots, it is necessary to find a way to communicate the complex ICC in a way that is easy to understand, even to participants with little to no technological background.

Another challenge is, to find a way to be visible and not too patronising at the same time to reach a maximum level of acceptance in the households.

Since humans are hardly remote controllable, the approach is to communicate the ICC in a very basic resolution of three values and rely on the inhabitants to utilise this on their own responsibility (see Chapter 4).

Controlling technological devices is a significantly easier task. By using remotely accessible APIs, often available for modern Smart Home appliances, the usage of these devices can be controlled directly or indirectly by the DER module to optimise their operation. Still, it is crucial to take the inhabitant's needs into account while doing so. If the control of devices based on the DR signal impairs participants in their everyday life, this also reduces the grade of acceptance during the testing period. Since the task of the DER module is to provide the flexibility information in form of signals, it is in the responsibility of other modules to utilise it (see T7.4).

## 2.2 TwinERGY integration

The role of the DER module in the TwinERGY system is to gather information provided by other modules (e.g., temperatures, power demands, daily routines) via the demand forecast and process it in a way that the energy consumption can be optimised with a focus on CO<sub>2</sub> emission reduction also by other modules. The interaction with other modules will be reached by communication with the database interfaces from WP5 and the digital twin platform developed in WP6. The results of the processed data will also be made available for other modules via the interfaces mentioned above.

The DER module itself can be run locally on relatively weak computers or even minicomputers like the Raspberry Pi. Alternatively, it is possible to run on a central server with multiple instances for every pilot site, as long as every instance is configured for the given community. Additional to this software, which runs on a central computer as a server, there are special devices, which run on a local machine, such as the battery storage and the charging station. The only requirement is to have installed the latest version of Python3 and the additionally needed python modules used in the software.

## 2.3 Module overview

The DER module can be separated in five main categories, which are depicted in Figure 2. The main categories contain several subcomponents which are implemented in the context of the categories.

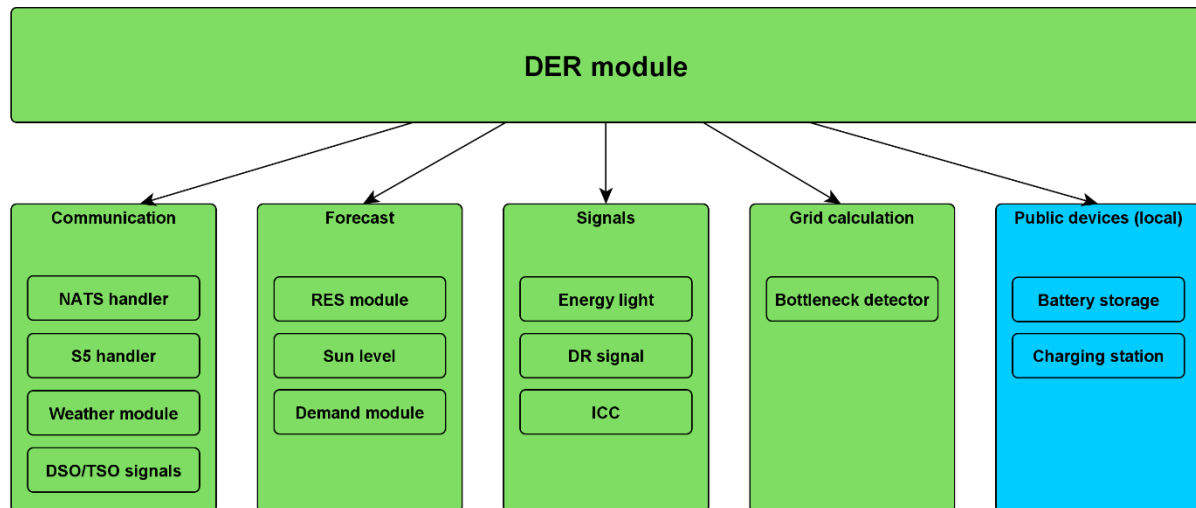


Figure 2: Components of the DER module.

The first category is the communication section. It contains all parts of the software, which have the task to communicate with other services in any direction. The NATS handler coordinates and processes any data, that is communicated over the NATS protocol of the TwinERGY server (see D4.3). This means, data is both downloaded and uploaded to the server and has to be in a shape that it can be used by either the DER module or other parties accessing this data.

The S5 handler accesses the Suite5 database (see D5.4). It basically has similar tasks like the NATS handler. The weather module has to process the weather data. This data is especially important, since it is crucial for accurate forecasts of the RES production, which are the foundation of the ICC and the DR signal. At the current state of development, the weather module gets its information from the OpenWeather API (see references). Alongside with the integration of the module for the pilot sites, it is planned to incorporate weather data from dedicated TwinERGY services.

The DSO/TSO signals will be information from the respective distribution service operator (e.g. data from the transformer stations). Although a basic operation of the DER module will be possible without the information from the DSO, these are necessary for the later operation of the grid calculation and full utilisation of the community storage (see chapters 5 and 6).

The second group of modules is the forecast group. It contains any functionality, that is used to make predictions for the near future (at least 24 hours). The heart of this subgroup is the RES part, which sums up all the RES production forecasts. These are later used for the calculation of the ICC.

The solar altitude component, calculates the position of the sun relative to the photovoltaic device, that is calculated. It is incorporated in the PV-forecast functionality. The demand module estimates the power demand of the households throughout the day. In a first step, a static standard-load-profile (SLP) is evaluated, which is planned to be replaced by a more sophisticated load estimation, when more data is collected from the pilot sites during the evaluation process. This data will later be provided by the digital twin of the community via the TwinERGY services.

The third group are the signals provided by the DER module. The core signal is the "Incentive Curve" (ICC), which gets calculated based on the RES forecast and various other data about the pilot community and the households. The ICC provides information about the CO<sub>2</sub> emissions of the energy production throughout the day, which can be used to find optimal times for energy consumption (see 4.1). The DR signal is the real-time counterpart to the ICC, which is calculated for a 24-hour timeframe, it is a simpler version and can be used in applications with no intention to plan ahead.

The "Energy Light" is an approach to communicate the DR signal to people in an as-easy-as-possible manner. It uses three states that are derived from traffic lights (red, yellow, green), where green represents the best possible time to use energy. In this way, it creates an additional awareness in the households and can potentially contribute to CO<sub>2</sub> optimised consumption. In the current state of development, the energy light is a simple console output, which will be replaced by hardware in the field.

In the grid calculation block, the current state and the forecasted future states of the local low voltage grid is analysed or predicted. Since there is a dependency on the measurement data and communication protocols, that will be implemented in the pilot during the hardware installation phase, the integration of the software will happen after the needed data and protocols are available. It is described in more detail in chapter 5.

The public devices like the battery storage and the charging station are not strictly a part of the DER module, that is run on the servers, but are included in the overview, since they are highly connected with the forecasts and thus, can be controlled by the module.



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## 2.4 Program execution

The DER module in operation will run through a predefined loop, which is described in this chapter. A flow chart diagram is shown in Figure 3.

The first step is to initialise the configuration data for the community the DER module is running at. This includes data like wind turbines or PV-configurations. Also the current state of hardware devices (e.g. energy light or the state of charge of the battery) is loaded. The initialisation is done every time the module gets restarted.

After the initialisation, the main loop is entered, which is executed every 15 minutes. The optimal frequency of the loop repetition will be evaluated during the pilot phase.

The first step is to gather data from the TwinERGY services and download them to the server. If this step is successful, the program will continue with further processing. In case it is not possible to access the needed data, a fall-back strategy comes in place. For example, when there's no weather data accessible, it is downloaded from OpenWeather. With the weather and configuration data, the estimated RES-power production is calculated both for wind and photovoltaic production. The next step is to calculate the local power demand of the community. After that, the local grid state will be determined to prevent any bottleneck situation. With all the gathered data, the ICC for the next 24 hours is calculated and based on the ICC, the same happens for the DR signal, which is the real-time counterpart of the ICC. With the DR signal, the state of the energy light is set and in case of a change, a message gets changed.

As the final step of the loop, all the calculated data is uploaded to the TwinERGY server to be used by other modules. When this last step is successful the new iteration of the loop starts, when the desired time delay is exceeded.

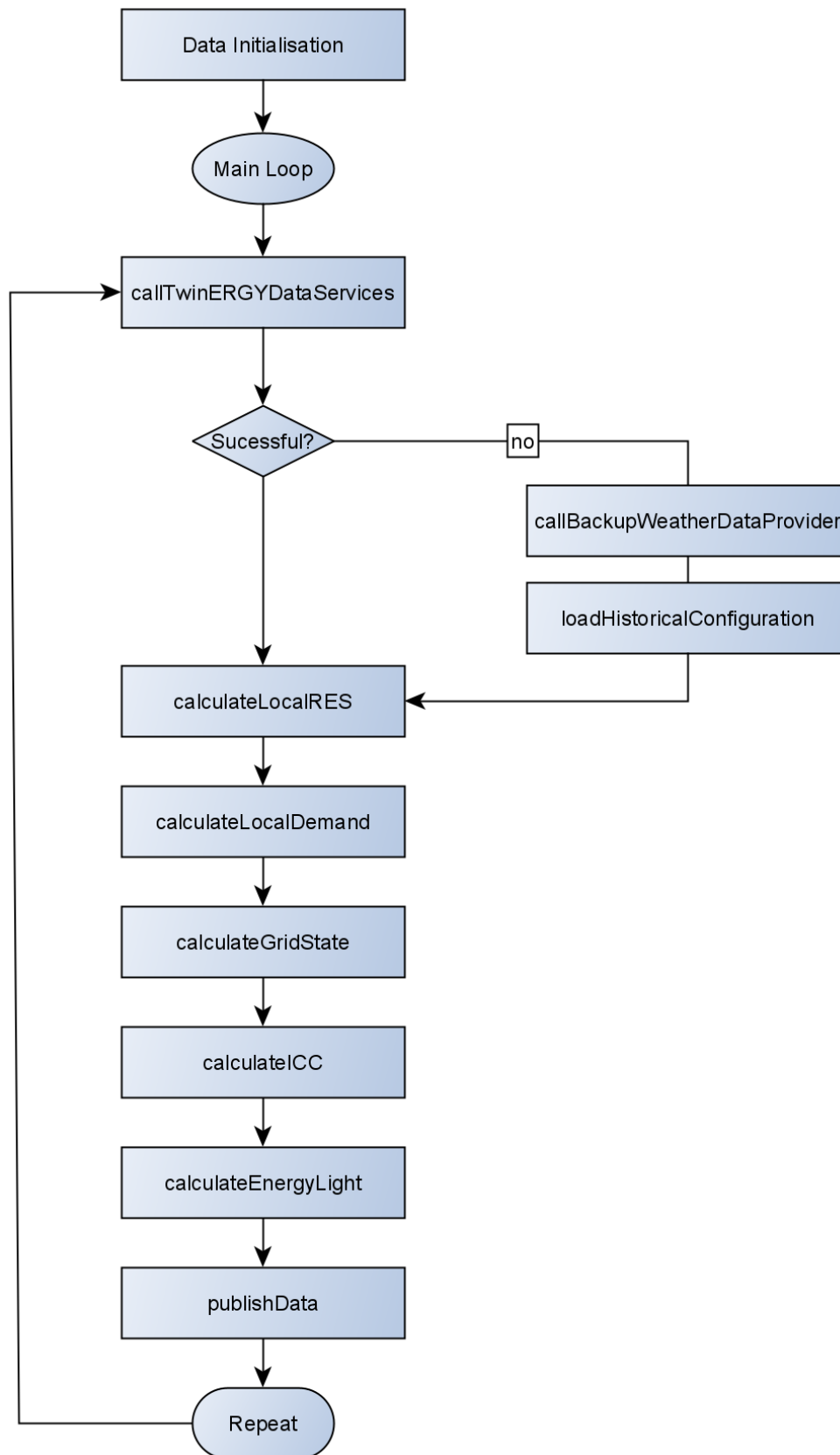


Figure 3: Process flow of the DER module main loop.

# 3 Forecast

## 3.1 RES

The production of renewable energies consists of several production sources. In the DER module, the focus is on photovoltaic production of the pilot and energy generated by wind turbines in the municipality.

The calculation of the RES-forecast is based on the 24-hour weather forecast, which can be provided by different sources. At the current state of development, the weather data is provided by OpenWeather, which can be grabbed via the OpenWeather API.

A 48-hour forecast is accessible for free users (a registered account is needed). Since the DER module only needs a forecast for 24 hours, this is more than sufficient for now.

Besides the token provided at account creation, the longitude and latitude of the wanted location has to be configured in the module's code.

To calculate the pv-forecast the following parameters for each photovoltaic installation are necessary (Table 2):

*Table 2: Parameter list for pv forecast.*

<b>Latitude</b>	Latitude of the photovoltaic installation in degree.
<b>Longitude</b>	Longitude of the photovoltaic installation in degree.
<b>PV peak</b>	Peak power of the photovoltaic installation in kWh ( $P_{PVPeak}$ ).
<b>Azimuth</b>	Orientation of the photovoltaic installation with respect to the cardinal direction in degree. The azimuth is in the range of $[-180^{\circ}...0^{\circ}...180^{\circ}]$ , where $0^{\circ}$ is an orientation to the south. Lower values represent a rotation towards east, higher values represent a rotation towards west.
<b>Inclination</b>	The inclination of the photovolatic installation, which represents the angle to the horizontal plane in degree.

In addition, the forecast calculation depends on the following variable parameters (Table 3):

*Table 3: Variable parameters for the PV forecast.*

<b>Datetime</b>	The day of the year $[1...366]$ , where 1 is the 1st of January, as well as the time for the forecast are necessary to calculate the forecast.
<b>Clouds</b>	The cloudiness for the specified datetime. The value is typically taken from the weather forecast and provided as a

	percentage value between 0%...100%. In this context, 0% means no clouds and 100% totally clouded.
<b>Temperature</b>	The temperature for the specified datetime, provided in °C. This value is typically taken from the weather forecast as well.

The following part describes the key aspects of the forecast calculation. The irradiance on the inclined plane of the photovoltaic modules ( $E_{G,gen}$ ) is made up of the direct ( $E_{dir,gen}$ ) and diffuse ( $E_{diff,gen}$ ) irradiance as well as a portion reflected from the ground ( $E_{refl,gen}$ ). The values are summed up as shown in the following equation:

$$E_{G,gen} = E_{dir,gen} + E_{diff,gen} + E_{refl,gen}$$

The calculated irradiance is factorised with a cloud coefficient ( $a_{clouds}$ ), which is based on the provided clouds value and a temperature coefficient ( $a_{temperature}$ ). The calculation of the final photovoltaic forecast is shown in the following equation:

$$P_{forecast} = P_{PvPeak} * \frac{E_{G,gen} * a_{clouds} * a_{temperature}}{1000}$$

Like the PV-forecast, the wind-energy-forecast demands information about the wind-turbine configurations as well (Table 4). It is important, that each wind-turbine, that is considered as contribution to the local RES-production is configured individually.

Table 4: Parameter list for wind turbine output calculation.

<b>v_cutin</b>	The minimal wind speed for the turbine to operate
<b>v_cutout</b>	The maximum wind speed, above which the device is deactivated due to safety issues
<b>p_meas</b>	The measured output power for given wind speed
<b>v_meas</b>	The wind speeds corresponding to the measured output powers
<b>community_inh</b>	The number of inhabitants of the given energy community

For wind power estimations, aside from the obvious power data points, it is also necessary to take the number of the pilot's inhabitants into account. Since wind-turbines generate a massive amount of power, which is distributed via the medium-voltage-grid, the number of inhabitants in relation to the whole city's population is taken as a baseline

to calculate its share of the generated wind power. In the future evaluation, this rather simple approach can be updated with more sophisticated calculations for the RES-share.

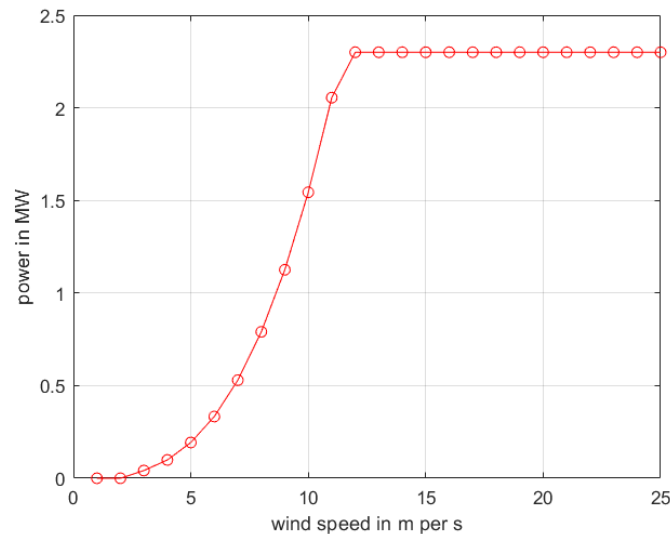


Figure 4: Output characteristics of a wind turbine located near Hagedorn.

In Figure 4 the power characteristics of a real wind turbine are depicted. Based on the data provided by this curve, the non-linear behaviour between 3m/s and 14m/s is approximated via a cubic function.

This is the baseline for the wind-power-forecast, which has to be configured for any configuration based on which location the DER module shall be operating.

For every configured wind turbine, the generated power for a given is then calculated and accumulated.

## 3.2 Demand

In addition to the generation forecast, the consumption forecast is essential for the calculation of the signals from the DER module. The consumption forecast is calculated in the module by the sum of the forecasts for the individual buildings:

$$P_{total,usage} = \sum_{i=1}^{all\ Buildings} P_{i,usage}.$$

The forecasts for the individual buildings come from the digital twin and are provided by the TwinERGY database. This information was not yet available for the current implementation. Classical standard load profiles (SLP) were used as a simplified alternative. These profiles describe the statistical consumption of buildings and are scaled with the annual energy consumption. Ultimately, the total forecast for the entire

neighborhood is obtained by adding up all SLP's. This forecast (Figure 5) is used to calculate the ICC (see section 4.1).

As soon as the forecasts from the TwinERGY database are available, the SLP's will be replaced.

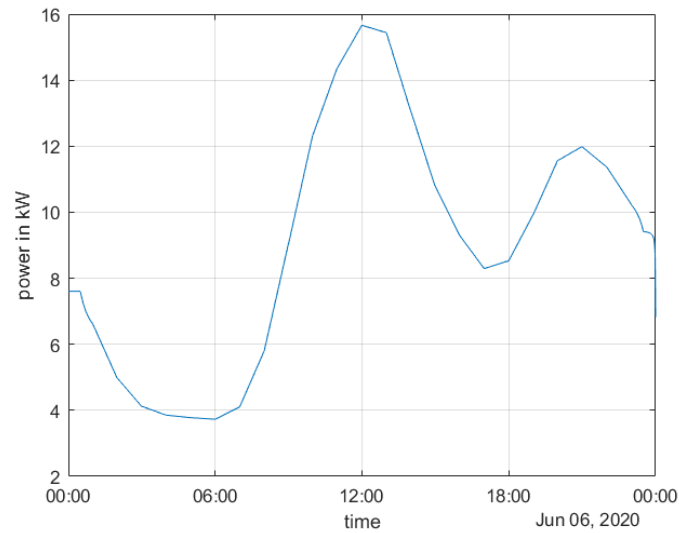


Figure 5: Demand forecast with SLP's for the 6th June 2020 in Hagedorn

## 4 Signals

The DER module will provide different signals for the other modules and the participants in TwinERGY. For optimisation purposes, the Incentive Curve is the most sophisticated way (Section 4.1). Additionally, a demand response signal is calculated out of the Incentive Curves (Section 4.2). Lastly, the module generates an easy to understand signal in form of an energy light (inspired by the well-known traffic light) with three levels for the participants to indicate the best times for electricity use in the pilots.

### 4.1 Incentive Curve

The Incentive Curve is an approach for sophisticated smart grids. An incentive is given to the customers (consumer, prosumer, businesses) to control devices in optimised ways. The incentive can be different, such as a price, a CO<sub>2</sub> value or virtual points. For the TwinERGY project, a CO<sub>2</sub>-based incentive will be used. The EEA provides CO<sub>2</sub> intensity values without the up- and downstream for the European electricity production mix, which are used for the grid values. As there is more than one possible energy source (local PV, Wind, Water, Biomass, CHP), the Incentive Curve is a combination of all sources of electricity. In the Project, the point of view is the local transformer station or the village/city as a whole. It depends on the level of detail and the area of the participants.

The calculation of an Incentive Curve is shown below. The example is based on the small village Hagedorn, the German pilot site, a village with high photovoltaic penetration in the grid. Nearby, a small wind power unit produces additional renewable energy. Lastly, all other electricity is supplied by the power distribution system. As the calculation of the Incentive Curve follows the physical flow of the energy (local sources will be used first), the calculation starts with the decentralised photovoltaics production. For an easy understanding, the Incentive Curve starts at midnight and has a length of one day. In the Pilots phase, the Incentive Curve will be calculated in an hourly process for each pilot site and will have the next 24 hours defined. It is defined by a 3-dimensional matrix, which varies in time, power and the carbon footprint of the supplied electricity. All following figures display the time and power on the axis, while the carbon footprint value is displayed by the surface colour.

Figure 6 shows the Incentive Curve of the photovoltaic systems in the small village. At sunrise, around 06:00, the systems starting production and providing energy to the village in the low voltage distribution network with a carbon footprint of 45gCO<sub>2</sub>/kWh (with up- and downstream [4]). The photovoltaics reach a peak load of 110kW at midday and fell

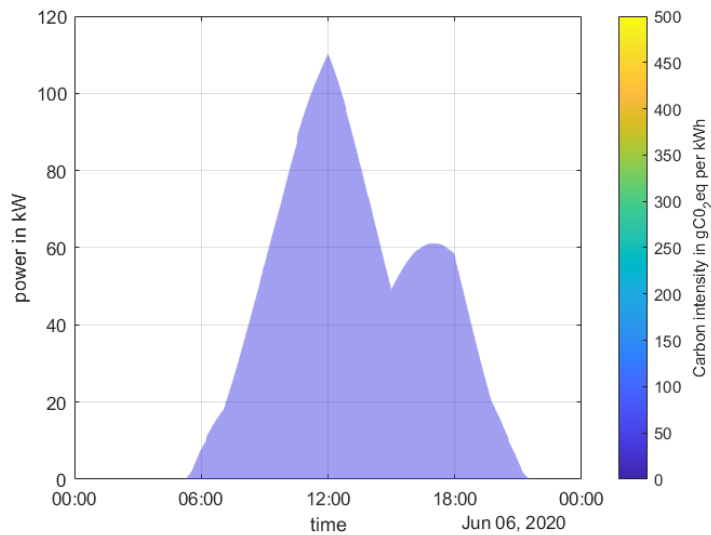


Figure 6: Incentive Curve of local photovoltaics

back to zero until 20:00. During the night, the photovoltaic systems don't supply electricity.

The second source of electricity in the small village is a nearby wind power unit (Figure 7), which supplies the medium voltage grid. It is scaled down to the habitants of the village, as it also supplies other villages nearby. The production is low during the night, while a

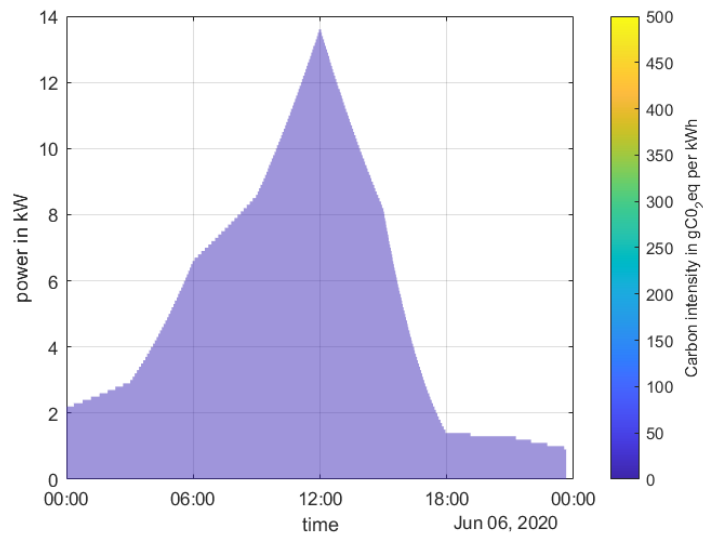


Figure 7: Incentive Curve of local wind power units



peak at midday is foreseen. However, the power is much lower than the local photovoltaic systems.

The last source of energy is the medium voltage grid (Figure 8: Incentive Curve of the electricity supplied by the medium voltage grid.). For the start of the pilot phases in TwinERGY, the carbon intensity of the electricity supplied by the grid is valued with the mean carbon intensity of the last year of the energy production of the country (without up and downstream). For Germany, where Hagedorn lies, the carbon intensity has a rating of 366gCO<sub>2</sub>/kWh for the year 2020 [3]. The local transformer station is rated with 250kVA, which it can provide permanent. Because of this, the Incentive Curve is time invariant. With a dynamic value of the carbon intensity, it would be changing during the day, as the production mix and demand changes.

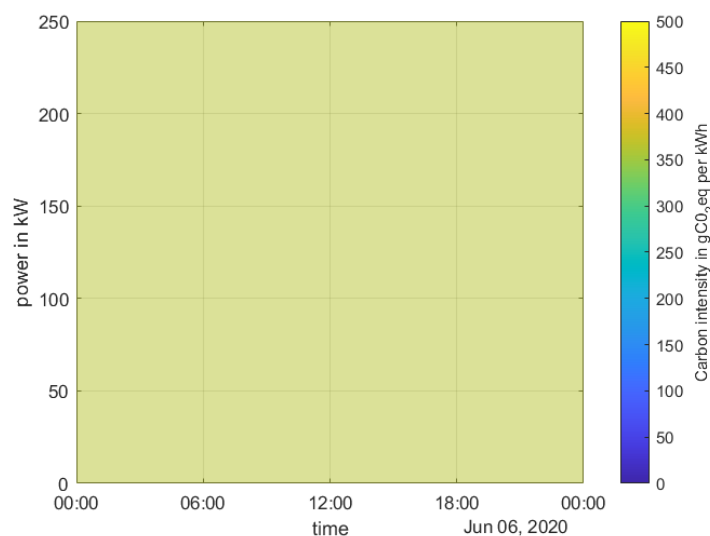


Figure 8: Incentive Curve of the electricity supplied by the medium voltage grid.

All Incentive Curves can be matched together to form a local valid Incentive Curve. Figure 9 shows the energy supply Incentive Curve of the whole village on the 6<sup>th</sup> June 2020. It is foreseen, that a maximum of 370kW could be supplied in the local grid at midday. As the carbon intensity of the local RES is much lower than the grid supplied electricity, an optimisation of the demand of flexible loads is possible.

Nevertheless, many inflexible loads (refrigerators, IP-router, cooking and lights) cannot be adapted. Therefore, all inflexible loads can be subtracted from the Incentive Curve before optimisation. Figure 10 shows the final Incentive Curve. Different to the Incentive Curve previously, there is no electricity with low carbon emissions left for optimisation,

as the load of inflexible loads is higher than the supply of wind power unit. An Incentive Curve like the one shown here will be published via the NATS server for each Pilot Site.

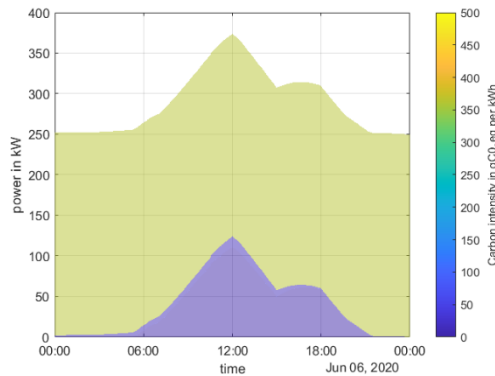


Figure 9: The Incentive Curve for the energy supply in Hagedorn on the 6th June 2020.

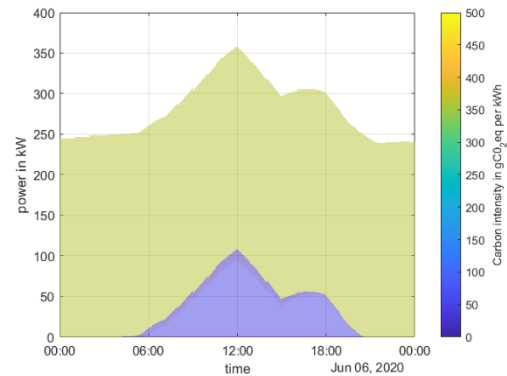


Figure 10: The Incentive Curve after subtracting the inflexible loads.

## 4.2 Demand Response Signal

The Incentive Curve is a sophisticated way to run optimisations based on it. Nevertheless, the optimisation needs knowledge of the system, its capabilities and limitations. For direct demand response actions, a signal will be generated out of the Incentive Curve. For each time slot  $t$ , the mean carbon intensity ( $K_{mean,t}$ ) of the whole energy supply is calculated.

$$K_{mean,t} = \text{mean}(\text{CarbonIntensityValues}_t).$$

On times with high local RES penetration, the value will be lower and indicates the best times for consumption (Figure 11). On this day during the night, the value is equal to the grid supply value, which is the worst time to consume (red line). During midday, as the photovoltaics reach the maximum power values of the day, the carbon intensity reaches the lowest level (green line). With the following equation, the Demand Response Signal is calculated:

$$\text{DemandResponseSignal}_t = \left(1 - \frac{K_{mean,t} - \min(K_{mean})}{\max(K_{mean}) - \min(K_{mean})}\right) \times 100\%.$$

It is normalized to 1 and scaled in percent. A value of 100% indicates the best time in the next 24 hours to consume energy, while a value of 0% indicates the worst time. Only the current value (here at 00:00) will be published via NATS for each pilot site. Figure 12 shows the Demand Response Signal on the 6th June 2020 in Hagedorn. As the later values than the current (00:00) can change in accordance to further Incentive Curves calculated

during the day, only the first hour is valid. But as there will be only a slight change it indicates already an impression.

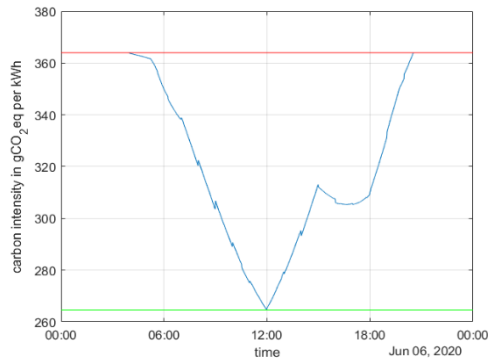


Figure 11: Mean carbon intensity level of the supplyable electricity.

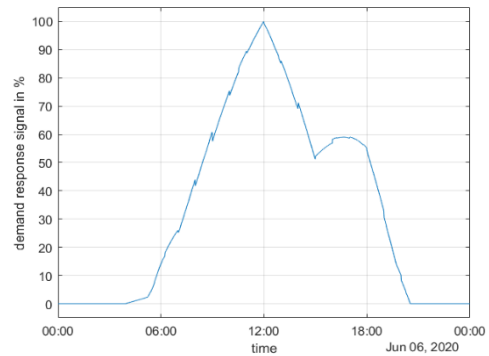


Figure 12: Demand Response Signal at Hagedorn on the 6th June 2020.

## 4.3 Energy Light

The last signal is the energy light. It is an easy to understand signal for direct actions of the participants. Unlike the Demand Response Signal, it only has 3 possible states to indicate the best times for consumption. It is directly coupled to the Demand Response Signal and calculated by the following function:

$$EnergyLightValue = \begin{cases} green & \forall DemandResponseSignal > 66.6\% \\ yellow & \forall 33.3\% < DemandResponseSignal \leq 66.6\% \\ red & \forall DemandResponseSignal \leq 33.3\% \end{cases} .$$

Applied to the Demand Response Signal on the 6th June 2020 in Hagedorn (Figure 13),

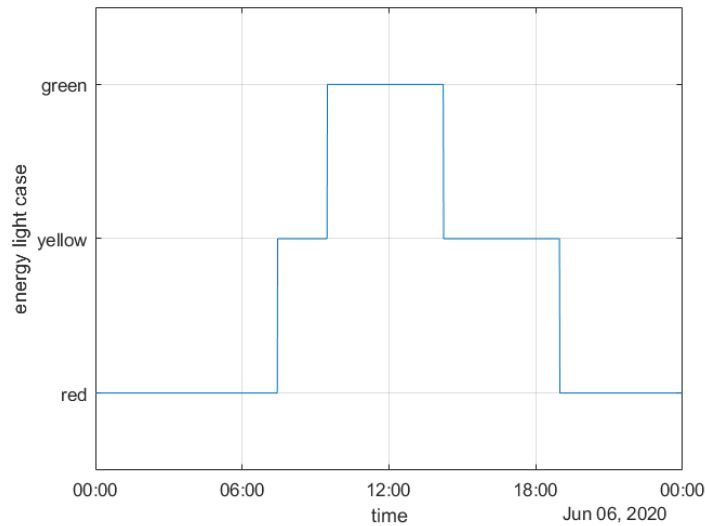


Figure 13: Energy light values in Hagedorn on the 6th June 2020.

during the night the energy light will be red. In the morning around 7:00, the light will change to yellow and followed by a green phase from 10:00 to 14:00. As the production of local energy resources is lower in the afternoon, it changes back to yellow till 19:00. After that time, it will change back to red. The Energy Light Signal will be published by the NATS-Services for each pilot-site.



Finally, some results of the network calculation are presented here. For this purpose, temporary test measurements were performed in the pilot. The final consistent implementation in the DER module can only be performed with the real measured values in network operation. Thereto, the final implementation within the DER module follows as soon as the real-time measurement of the pilot is available.

## 5.1 Grid state calculation

A network calculation tries to represent the physics of an electrical energy network in a simplified way. The most basic requirement for this is that it is an interconnected network. All connection points to other networks must be known and provide at least voltage, current and phase information. In addition, the network calculation has high requirements for the complete basic data. Thus, all cable types and lengths, house connections, nodes, coupling points and internal generation plants must be known. For the measurement data, the more the better. The less measurement data available, the more underdetermined is the simulation and the greater are the uncertainties. In the example of the pilot in Hagedorn, the network is abstract as shown in Figure 15.

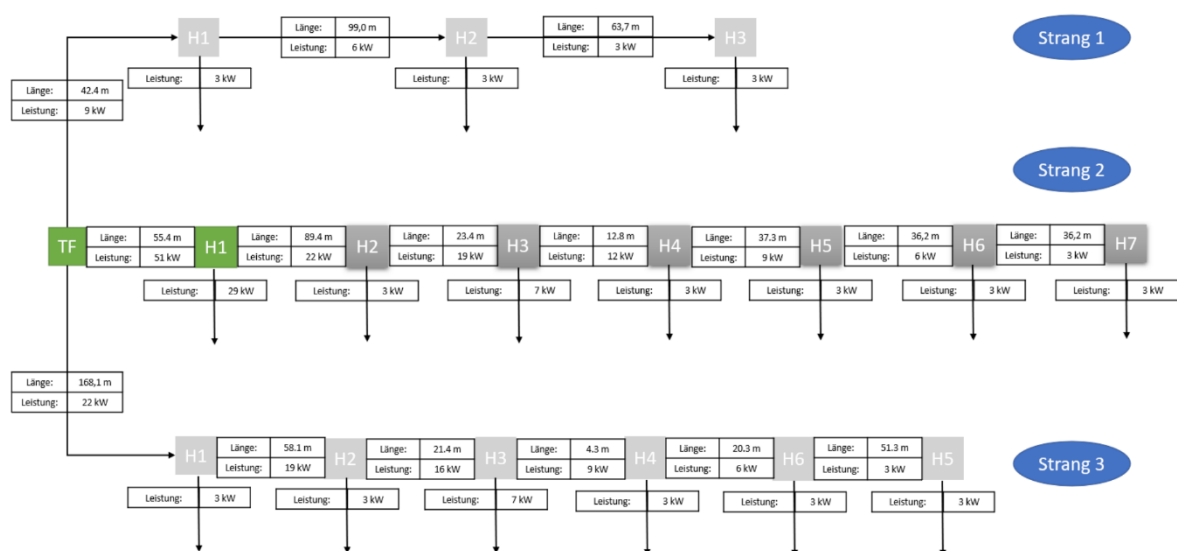


Figure 15: Scheme of the grid in Hagedorn connected via transformer station "Im Dorfe". It shows the length of the lines and default power values for the households. All green parts are equipped with measuring devices.

The network calculation was developed in such a way that it is possible to deliver meaningful results even without measured values at all nodes. This is important, because in the pilot and also in the expansion plan for the German power grid not all buildings receive intelligent measuring devices. This also makes it possible to modify the measured

values and thus integrate additional virtual consumers and generators and ultimately also to calculate with predicted values.

As an example, strand 2 from the example network in Hagedorn is considered below without restriction of generality. In the current state of expansion at a fixed but arbitrary point in time, the following picture of generation (positive values at the house row H1-H7) and consumption (negative values at the house row H1-H7) results in addition to the master data (Figure 16).

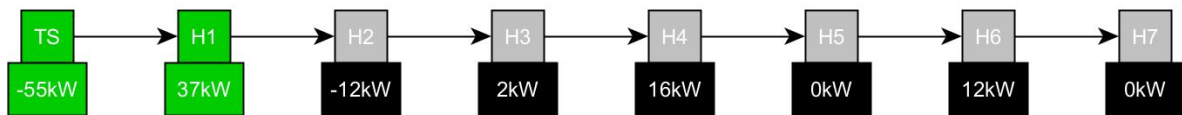


Figure 16: Power flow of line two of the transformer station (TS) "Im Dorfe" in Hagedorn. Positive values indicate power fed into the low voltage grid, while negative values indicate power drafts.

In the example, which corresponds to the current state of expansion, real measured values are available at the green blocks, while the black ones are forecast. After the final integration of the smart meter data from the pilot, more real-time data will be available. The network calculation considers the corresponding currents and voltages and calculates the voltages at the house connection points on the basis of the power specifications and the network. The result is shown in Figure 17.

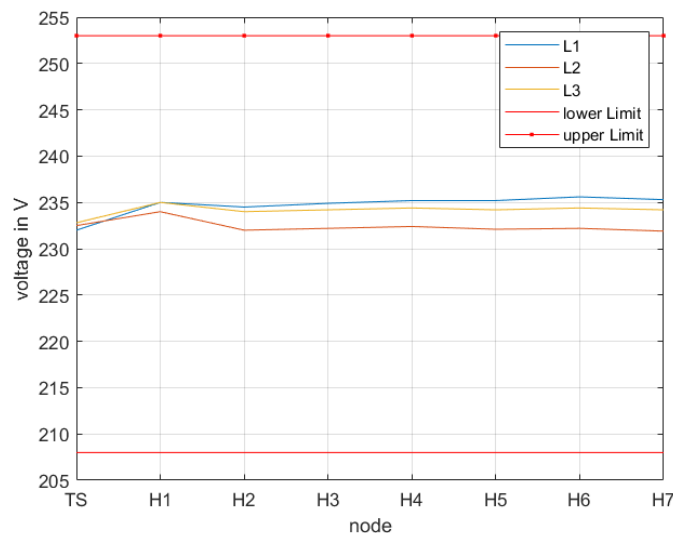


Figure 17: Results of a grid state calculation with the actual RES in Hagedorn. The voltage limits are unreached.

The large voltage increase in house 1 resulting from the feed-in of 37kW power is clearly visible. In the further course, the voltage in the line stabilizes. It is important to note that the voltage is calculated at the house connection points, not on the main line of the string, where the voltage increases more evenly and logically has no dip. Overall, the voltage is well within the permitted grid limits (208V-253V).

As an example, a scenario with massive amount of photovoltaic devices in line 2 is assumed (Figure 18).

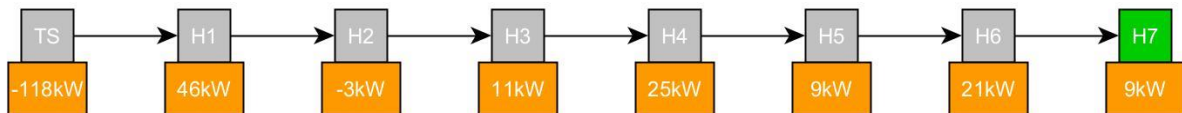


Figure 18: Massive upgrade of PV-Systems, all orange blocks are modified.

The orange blocks have been power-modified. In this case, the photovoltaic power has been drastically increased, which results in the following voltage curves (Figure 19).

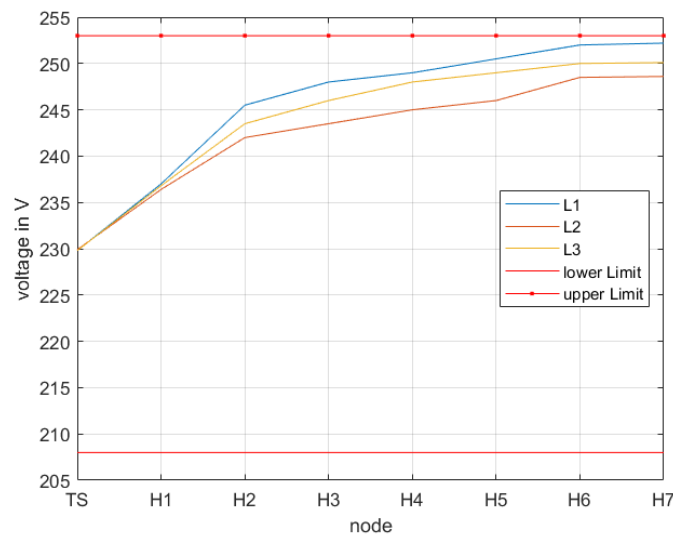


Figure 19: Voltage diagram with massive increase of photovoltaic systems in line 2. H7 nearly reaches the upper limit.

The large voltage increases up to the last house in the string is clearly visible. Almost the upper voltage limit is violated in the last two houses (this is how the example was set up). Overall, no grid bottleneck would occur in this situation.

Just as in the last example the power at the houses was modified by additional photovoltaic systems, the simulated power values from the digital twins of the buildings (D6.2 - Demand flexibility models) can be used for the short-term future grid calculation.



## 5.2 Bottleneck Detection

The bottleneck detection is based directly on the network calculation. If the limits for the voltages, currents or powers are violated at any point within the simulation. A warning is generated. As an example, an oversized photovoltaic feed-in of 247kW at house 1 was assumed (Figure 20).

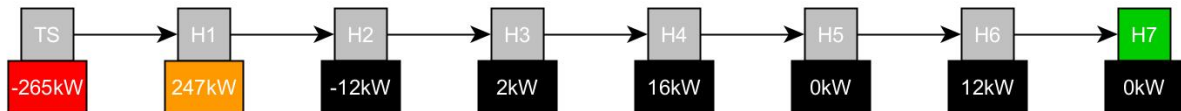


Figure 20: Active bottleneck at the transformer station because of an overload due to massive induced power at H1.

This would cause several limit values to be exceeded. On the one hand, the transformer would be operated with an impermissible power ( $P_{max} = 250\text{kW}$ ). Furthermore, the voltage calculation (Figure 21) shows that the permissible maximum voltage is exceeded.

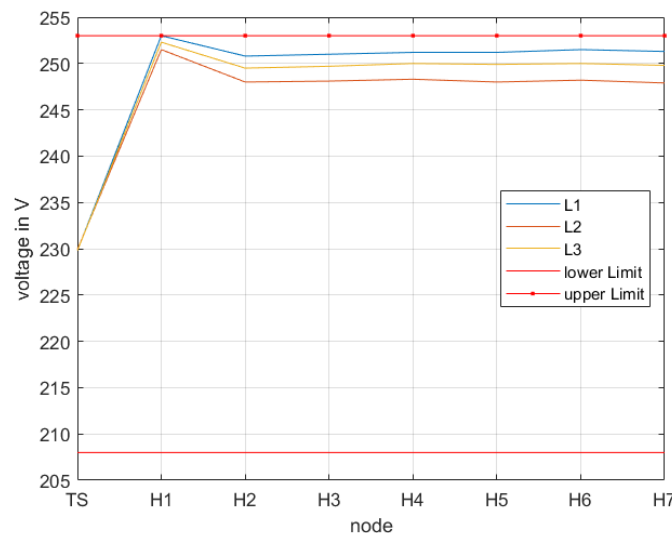


Figure 21: Bottleneck at H1 due to a massive induction of energy into the low voltage grid. The voltage values are above the maximum rating.

These bottlenecks will be detected by the simulation and corresponding warnings will be created. If a continuous calculation for the next 24 hours will be possible by the measured values and forecasts, a simple correction plan will be created after the new calculation.

This specifies when preferably more or less electrical power should be consumed in the network.

## 5.3 Countermeasures

The network calculation is overall a passive element, as output for the DER module the correction plan is ultimately important. This shows potential future network bottlenecks. Avoiding these future bottlenecks is the goal in the DER module. An acute bottleneck is solved by the hard safety devices in the network. In case of doubt, this means interlocking of generation plants or load shedding. The DER module then no longer has any influence on this. Therefore, it is all the more important to consistently avoid grid bottlenecks in advance.

For this purpose, the correction plan is integrated into the ICC calculation as a grid stabilization measure. If there is too much power in the grid and stability is endangered, the ICC offers power at zero cost. (Figure 22).

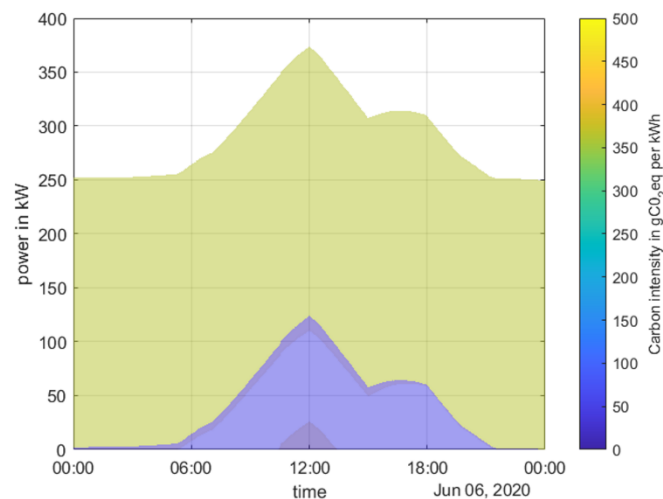


Figure 22: ICC with zero rating between 11:30 and 12:30.

All controllable consumers will want to take advantage of this offer if possible and thus increase consumption as much as possible. As an even more extreme measure, one could also be paid for decreasing power. However, this should be avoided if possible, because it strongly encourages waste.

In the event that there is too little power in the grid, comparably significantly increased prices could be inserted into the ICC at the appropriate times. The controllable consumers would then try to avoid these times as much as possible and thus free up power reserves.

# 6 Public devices

In addition to server-side services, the DER module can also make different publicly shared network infrastructure usable. In this specific case, the module can actively operate a battery storage system and additionally set power limits for charging stations. These limits allow the operation of the charging station in interaction with the TWINEV module 7.6.

## 6.1 Battery Storage

Electric storage units integrated directly into the grid are operated in an optimized manner by the DER module. For public utility operation, the storage system must be integrated into the grid in accordance with Figure 23. Furthermore, the storage system must have its own safety functions, for example protection against deep discharge. This is inherently important because the DER module passes optimized performance specifications to the storage unit. As a result, there is a clear separation between storage and energy management and the module is able to operate with all storage devices with a corresponding software interface (in this case Modbus TCP).

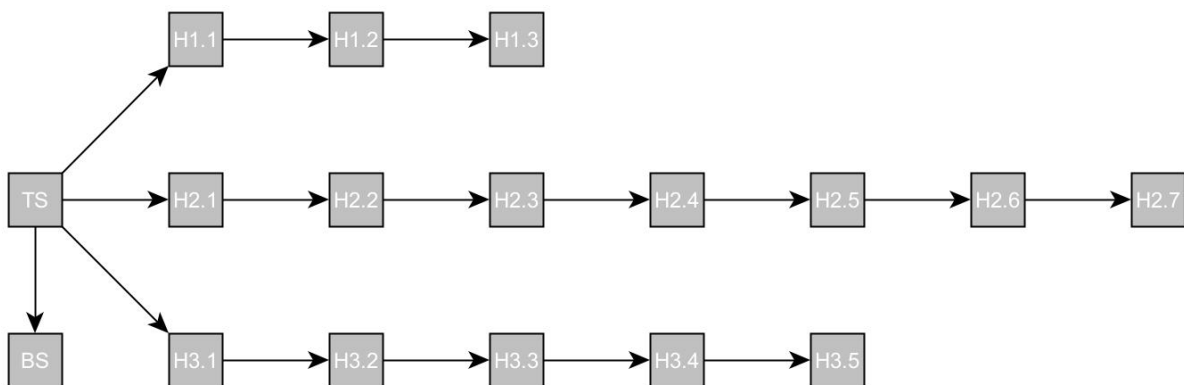


Figure 23: Schematic grid view with integrated battery storage (BS) nearby the transformer station (TS).

The starting point for optimized storage operation is also the ICC (Figure 24). On this basis, the MILP optimization procedure is applied. As an example, the ICC of a day with a significant amount of renewable energy is shown here and used as a starting point.

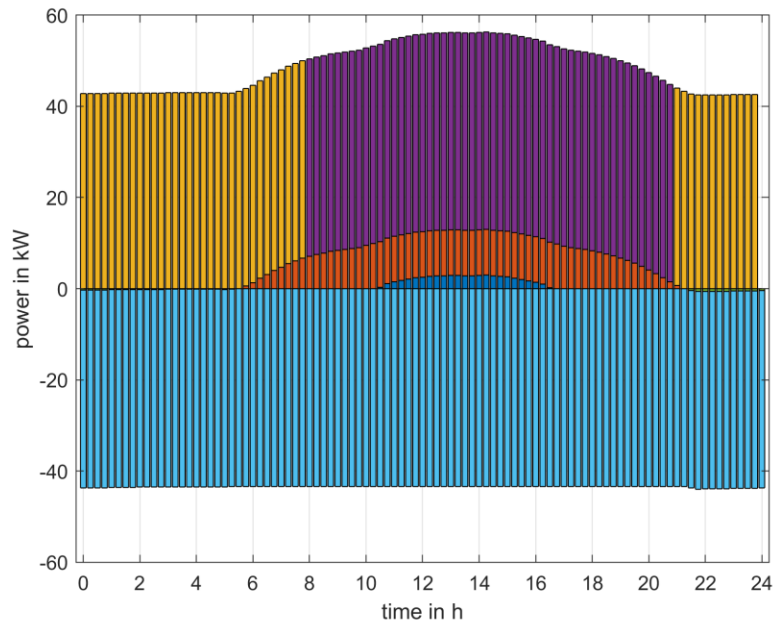


Figure 24: ICC for the optimisation of the battery storage control.

For storage operation, in addition to the positive side of the ICC, a 'negative side' of the ICC must also be inserted. This corresponds to a payment for energy fed into the grid, or, in ecological terms, a CO2 credit. Without this incentive, the optimization logically finds the trivial solution that no energy is stored. The storage is passive in this case.

In the example, which optimizes for minimum costs, the loading plan shown (Figure 25) results. Visible here is the green area, in which the storage delivers energy for the supply of a quarter (in the negative area). In the red area the storage is charged with photovoltaic energy, in the blue area even with energy that should have been shut off. At the end of the day, the storage unit releases energy into the power grid to supply the quarter.

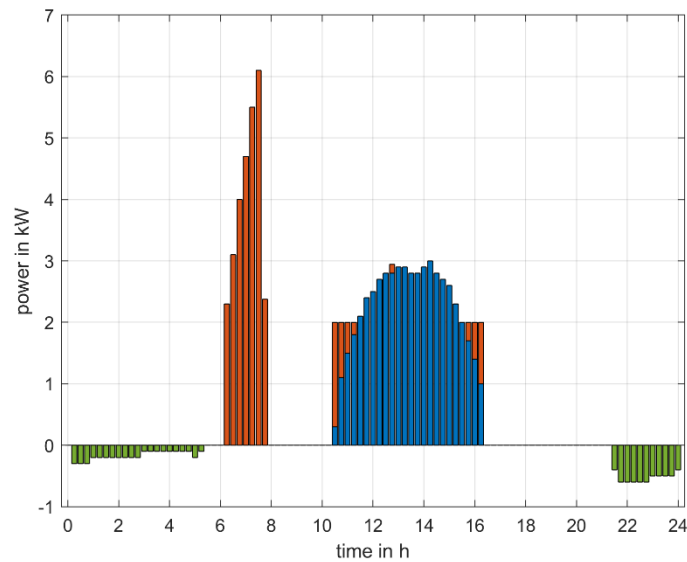


Figure 25: Optimised batter power profile.

The battery storage submodule runs locally on the quarter control computer. The final implementation can only be carried out once the quarter memory has been installed in the German pilot.

One issue that still needs to be resolved experimentally is the allocation of the storage capacity. All planning and forecasts have a residual uncertainty, thus there will always be a residual load. This can be either positive or negative and is significantly smaller through planning than in an unplanned quarter. In a conventional mode of operation of the electric storage tank, it exclusively compensates for this residual load. Since in module 7.5 this residual load is to be balanced as far as possible, a part of the capacity of the storage system is to be reserved for this purpose and removed from the planning. How large this portion must be for good operation must be determined by simulations with the data from the pilot and corresponding experiments.

## 6.2 Charging infrastructure

The charging infrastructure, which is controlled by the TwinEV module 7.6, is given power limits by the DER module, which are ultimately determined from the network calculation. In the specific case, a charging station with a maximum power of 10kW is used in the pilot. Since this is publicly used by the project but not directly installed in the public grid, a direct limitation of the charging power is not possible. Furthermore, the initial grid calculation has shown that in no case there can be an enpass in the grid due to the power draw of the charging station. Therefore, in the current implementation, the charging power is not limited externally. From the DER module, however, both the ICC and the DR signal are provided for the TwinEV module. This allows the TwinEV module to schedule the charging station in an optimized way. In return, the TwinEV module makes its charging

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plan available to the DER module. This charging plan is then included in the calculation of the available energy quantities in the next iteration of the ICC creation.

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## 7 Conclusion

This document shows the functionality of the DER module. Basing on the idea shown in chapter 2, it is followed by the internal functionalities for RES production and demand forecasts (chapter 3). For all modules, which interact with this module, different signals will be send out (chapter 4). The local grid calculation (chapter 5) and the control of public devices (chapter 6) shows the DER modules capability for local grid optimisations, but is limited to the pilot in Germany.

While all internal functionalitys are ready to deploy, the connection to the TwinERGY services (NATS and TwinERGY data services) will be implemented in the modules integration phase. The local grid calculation and optimisation via the battery control will be deployd during the hardware installation phase at the pilot site.

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