Annex: 1

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Smart Grids und internationale Kooperationen

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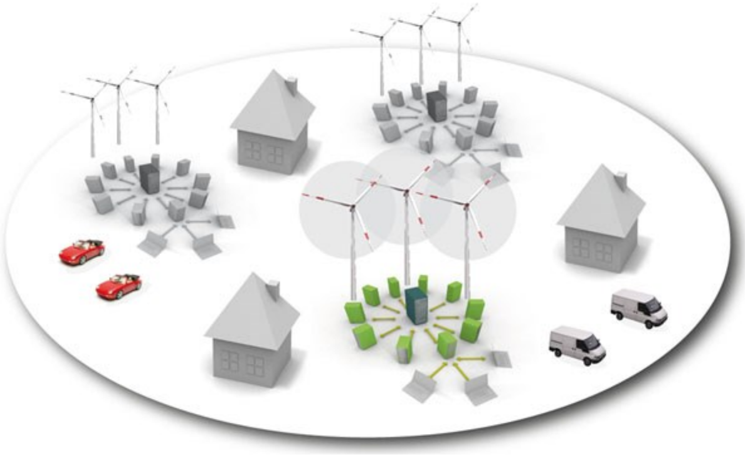

G(e)oGreen

Optimizing green energy and grid load by geographical steering of energy consumption

Project Consortium:

Kurztitel	G(e)oGreen
Langtitel	Optimizing green energy and grid load by geographical and temporal steering of energy consumption
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Synopsis	The G(e)oGreen projects aims at bringing a different approach to supply demand matching. It considers consumption mobility both in terms of time and space. In particular, electric vehicles and data centers processing tasks can be considered as mobile consumers which can consume their power at alternative geographical locations. The project goals are determining relevant scenarios, development of a high-level hierarchical system model, the analysis of Vehicle to Grid (V2G) applications and analysis of storing energy in large functional buildings with optimal control strategies and scheduling algorithms.

Abstract

G(e)oGreen – Optimizing green energy and grid load by geographical steering of energy consumption – represents a project in scope of the second call of SmartGrids ERA-Net program (http://www.eranet-smartgrids.eu/).

The intermittent and unpredictable nature of renewable energy sources complemented with mobile consumers such as electric vehicles (EVs) leads to power peaks in the distribution network which are correlated in time and space: given the dependency on local weather conditions and the individual mobility patterns (time- and location-dependent) of commuters. Options to cope with these uncertainties might be the massive deployment of energy storage systems along with reinforcements of the electricity network, which would lead to increasing costs. Alternatively, optimization of demand and supply by time shifting of energy consumption is being researched. However, the geographical distribution of both energy consumers and producers could be an important parameter for optimizing the energy grid.

The electric vehicles and the processing tasks running on data centers can be considered as mobile consumers which may have alternative geographical locations to “present” their energy consumption load. In fact, EVs could be steered for charging to locations close to renewable generation or skip charging at locations which might be currently undersupplied with renewable energy. Additionally the stored energy in the EVs may be used for consumption once the power level of energy from renewable sources has dropped below the demanded power level. All of this can only happen if all boundary conditions are satisfied (e.g. enough energy left for driving, quality of the compute service, service level of the building, etc.) and the benefits outweigh the drawbacks (such as the negative impact on battery lifetime, energy losses, additional costs, response time, etc.).

The project objectives of G(e)oGreen included the description of use cases, the development of a high-level hierarchical system model, the analysis of batteries used in V2G applications, optimal coordinated battery charging/discharging algorithms, optimal building management control strategies, optimized scheduling algorithms aimed at deciding when and where to consume energy, routing algorithms to optimize communication for energy efficiency, infrastructure dimensioning and placement algorithms for vehicle charging points and data servers. Reference ICT architectures for realizing the above have been proposed.

The system concept of G(e)oGreen is based on the definition of cells and the elements they may contain. The G(e)oGreen Cell represents an aggregation of G(e)oGreen elements in which it is possible to optimize energy balance by exploiting flexibility of Entities. In order to make optimization possible, a cell should contain at least one Infrastructure element, a Flexible entity and a Cell manager. Cells could be organized in hierarchical manner in a way that one cell can contain other cells. Basic, low level, cells are defined statically, while higher level cells can be defined in run-time through reorganizations. Each Cell, no matter on which level has to contain one Cell manager.

The work done by the Austrian project team of G(e)oGreen, consisting of AIT and TU-Wien, focused besides the definition of the system concept on the analysis of relevant components and the proof of the

concept. The analysis of relevant Infrastructure and components, in respect to the defined cell concept, includes the potential and specifications of energy storage in EVs and effects of V2G activities (in respect to specific technologies, acceptance of users and degeneration effects). Further on the potential of storing energy in clusters of buildings by controlling and optimizing within specific strategies was analyzed and appropriate methods for simulations developed.

In front of performing a proof of concept, suitable coordination strategies and algorithms had to be investigated, profiles of renewable energy sources collected and a simplified grid topology was developed along to a defined scenario. For the proof of concept a multi agent approach was selected for the simulation environment. The simulation environment consists of several tools (EV simulation, Power grid simulation) and an optimizer (cell manager) connected and communicating via OPC within a round robin approach.

The cell concept developed during this project provides prospering features and options for future work. Especially the applicability of the concept within the European area would provide an ideal base for the further development of optimization algorithms and control strategies. Its modular and hierarchical approach would also allow and embrace agent based concepts which gain increasing attention from the scientific community.

Based on the experiences and findings gained during the work on the proof of concept, the development of the simulation environment and the EV scenario, the existing simulation environment will be revised. The future approach regarding the simulation environment abandons the traffic simulation tool and focus on generic method for creating an agent population for specific scenarios based on identified mobility patterns and probabilities. The advantage of this approach would be an increased performance and flexibility for simulating areas which lack of necessary data. Findings from project G(e)oGreen will be used for reference and validation purposes.

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1 Einleitung

1.1 Ausgangssituation und Motivation des Projektes

The presence of large functional buildings is increasing at populating urban regions, which also may host big energy consumers (e.g: data centers) or, in the near future, large amounts of electric vehicles (EVs). The possibility to combine storage capacity from buildings, centers or EVs provides opportunities to absorb energy from renewable sources (such as from PV systems or wind turbines). The unpredictable nature of renewable energy sources leads to power peaks in the distribution network. These are correlated in time and space and therefore within regions load conditions on the grid will vary. One approach to cope with these fluctuations is the massive deployment of energy storage systems but also the temporal and spatial shifting of energy consumption is possible but not widely used at the moment. This project will therefore address the question of assessing the technological challenges and potential benefits (in terms of optimizing energy usages) of exploiting geographical load shifting in addition to time shifting.

1.2 Schwerpunkte des Projektes

G(e)oGreen aims at optimal balancing of energy demand and supply with special regard to efficient utilization of renewable energy generation sources. In this sense, bringing consumption closer to renewable energy sources (RES) as well as coupling peak of consumption with highest expected output of renewable generators represent basic challenges to be addressed by the project. Therefore, in order to successfully meet these challenges we have introduced a novel concept named ‘G(e)oGreen Cell’ as a logical encapsulation of mobile consumers, energy supplying infrastructure and supporting ICT architecture.

The project objectives include:

- The identification of system requirements, description of use-cases, development and validation of a system model
- Analysis of batteries used in vehicle-to-grid (V2G) applications, analysis of solutions for storing energy in buildings
- Optimal coordinated battery charging/discharging algorithms, optimal building management control strategies, optimized scheduling algorithms based on renewable energy generation

The goal of G(e)oGreen is to explore technological challenges and potential benefits of exploiting geographical load shifting in addition to time shifting for the purpose of higher usage of renewable energy while focusing on the case of electrical vehicles and data center tasks. In order to achieve this goal, the feasibility of this approach is evaluated in a proof-of-concept.

1.3 Einordnung in das Programm

The objective of the program “ENERGIE DER ZUKUNFT” is to develop technologies and concepts for energy grids to increase the usage of renewable energy sources and to ensure an energy-efficient and flexible energy system in the long term which is able to meet our energy needs. Through a wide range of technology related activities and accompanying measures, decisive impulses should be set and thereby at the same time new opportunities for the Austrian economy shall be opened. Based on Austrian areas of strength in research and technological development (solar, biomass, etc.) this program is an essential contribution to the achievement and protection of technology leadership. The program covers several different topics:

- Energy systems and networks
- Advanced bio-fuel production
- Energy in commerce and industry
- Energy in buildings
- Energy and customers
- Advanced storage- and transformation technologies
- Foresight and support of strategies

The Project G(e)oGreen specifically addresses the program Energy systems and networks ("ENERGIESYSTEME DER ZUKUNFT") in which the respective areas of the integration of Austrian actors in international activities such as the EU research programs (in this case SmartGrids Era-Net) and activities of the International Energy Agency.

About SmartGrids Era-Net:

Power grids deliver electric energy to all European consumers. These electricity networks are the key to a Europe of tomorrow that has access to electricity produced from low-level carbon resources besides renewables, and an electrical supply that is abundant, affordable, secure and flexible. However, the networks (considered state of the art in design when built in the middle of last century) must first evolve into a smart, robust and effective pan-European grid that is capable of meeting future demands. The challenge of renewing these systems is an unavoidable task faced by every country in Europe. The solution is a new grid architecture created by over 200 experts, which is referred to as the SmartGrids design, a revolution for Europe’s whole electricity ecosystem. Beyond vision, the concept has now entered its critical research phase, which the established ERA-NET will coordinate across international, national and regional levels.

1.4 Aufbau der Arbeit

To achieve the project’s objectives, the project is structured in 6 Work Packages (WP) The project management is covered by WP1. In WP2, the System requirements were gathered, analyzed and discussed by all participants. This lead to a requirements and use cases document. Based on these findings a system design was created by means of a hierarchical executable system model. WP4 creates the component models for the electrical storage in electric vehicles, the thermal storage in buildings and the data center energy consumption. WP3 covers the coordination, scheduling and routing algorithms and collection of renewable energy profiles. These algorithms together with the component models from WP4 and the collected renewable energy profiles were used in WP3 for analyzing the energy related effects of moving consumption on the grid stability. To make things work, ICT architecture will be defined and created in WP5. This work was used in WP6 where the system was simulated from energy and communication perspectives.

Note:

Even though some of the methods and findings in this report are partly based on contributions from several partners of the whole G(e)oGreen Consortium, this report only covers the work done by the Austrian part of the G(e)oGreen Consortium, which are AIT – Austrian institute of Technology and TUV – Technical University of Vienna.

1.5 Verwendete Methoden und Tools

For accomplishing the objectives of G(e)oGreen different methods, tools and data was used. The following section should provide a brief overview, which methods, tools and data was used from AIT and TUV for the individual tasks, based on the structure of the project (as shown in section 1.4). More detailed information regarding the methods can be found in the main section of this report (section 2).

WP 3 – Moveable consumption	
Tools	Meteonorm [1] This commercial tool provides weather date, based on measured annual time series, for specific locations and areas. HOMER2 [2] This tool was used for processing the weather data
Methods	Tool chain for processing weather data into area related renewable energy profiles. Detailed information regarding the methods used for individual tasks can be found in section 2.
Data	Data bases [3] regarding existing renewable energy sources and future potential [4] was used as input for the correct scaling of the energy profiles per district.

WP 4 – Infrastructure and Components	
Tools	Dymola [5] Simulation tool for creating models and simulations of electric vehicle and battery MATLAB [6] Tool for the analysis
Methods	Detailed information regarding the methods used for individual tasks can be found in section 2.
Data	Data was collected during a survey on V2G Technologies

WP 6 – Proof-of-concept	
Tools	MATSim [7] A Multi-Agent transport simulation tool which was used for simulating the traffic in Upper Austria EVSim [8] Electric Vehicle Simulation Tool, where technical specifications of vehicles and charging infrastructure are set and events of Agents are handled. Matricon OPC [9] Tool for connecting different tools and the communication between them PowerFactory [10] The power simulation tool used for calculating load flows in the simulations. RAPSim [11] Simulation tool for the data center use-case
Methods	Time line analysis for investigating the EV use case (uncontrolled)

	Round robin schedule for running co-simulations Detailed information regarding the methods used for individual tasks can be found in section 2.
Data	Statistical traffic data from Upper Austria [12] was used for generating profiles for moving and charging electric vehicles. Statistical information regarding the population [13] in the scenario area were used along with data regarding existing buildings and their heating systems [14]. Data regarding existing Power Plants [15][16][17] and potential future ones [4] were used for shaping the scenario along with data regarding the passenger car fleet in Upper-Austria [20]. OSM [19] Data regarding the street network in the scenario area was used for the simulations with MATSim. Data regarding existing data centers [20] were used for the data center use-case in WP6.

2 Inhaltliche Darstellung

2.1 Definition of System Design an Requirements

One of the first and essential objectives within the project G(e)oGreen was the development of a structure for cell architecture. Future Smart Grids are considered to consist of a variety of different functions, roles and stakeholders. Despite this diversity of entities it was possible to define a concept which consists of only a few entities but provides an appropriate structure, all necessary relations and enough flexibility to be able to be applied around the European market area. The G(e)oGreen Cell concept can be defined as such:

> *G(e)oGreen Cell is an aggregation of G(e)oGreen elements in which it is possible to optimize energy balance exploiting flexibility of Entities. In order to make optimization possible, cell should contain at least on Infrastructure element, Flexible entity and a Cell manager. Cells could be organized in a hierarchical manner in a way that one cell can contain other cells. Basic, low level, cells are defined statically, while higher level cells can be defined at run-time through dynamic reorganizations. Each Cell, no matter on which level, has to contain exactly one Cell manager.*

The size of the cell was discussed to cover approximately one medium voltage branch. Based on this structure a general, a smart charging and a datacenter use-case were defined. This “G(e)oGreen Cell Concept” was an essential step in the project for being able to continue with the follow up work, but offers also a basis and options for follow up work after this project. Especially for the development of optimization algorithms, which take flexible loads such as EVs into account, this concept provides a simple but applicable approach. Flexible and static entities represent either suppliers or consumers of electricity. A flexible entity can either be flexible in time, space or both. Electric vehicles can be considered to be flexible in the consumption of electricity in time as well as in space, if controlled charging is considered. Energy from RES, like PV Systems or wind turbines are, due to their stochastic nature, considered to be static. Flexible entities can be smart grid enabled automated functional buildings or data centers (time flexible), or electric vehicles (time and space flexible).

In WP2, the System requirements were gathered, analyzed and discussed by all participants. This lead to a requirements and use cases document. Based on these findings a system design was created by means of a hierarchical executable system model.

One of the main tasks where to identify the possible scenarios for using geographical load shifting. The first ideas with buildings and data centers where made. Also a new scenario, the usage of electric vehicles, was identified. The main task for Vienna TU was to elaborate the possibilities for load-shifting in data centers. The idea behind is, that tasks can be stored parallel but done only on one machine.

The methodology is like the following: The Servers a, b and c have a set of tasks. The tasks X32 and B32 are included in the set of their tasks. Assuming, the network is capable of synchronizing the results quickly to the other server, the place or the region where the task is computed is irrelevant. Taking into account that the servers are located in different regions, this can be used for geographical load shifting (See Figure 1 and Figure 2).

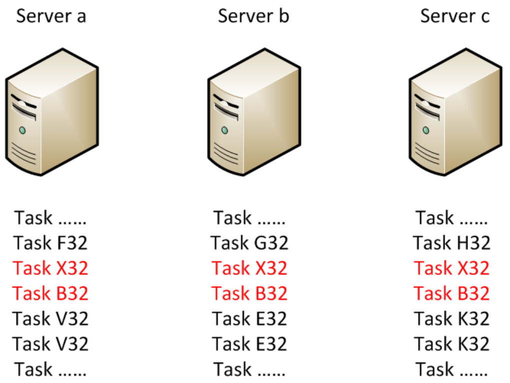


Figure 1 : Server infrastructure

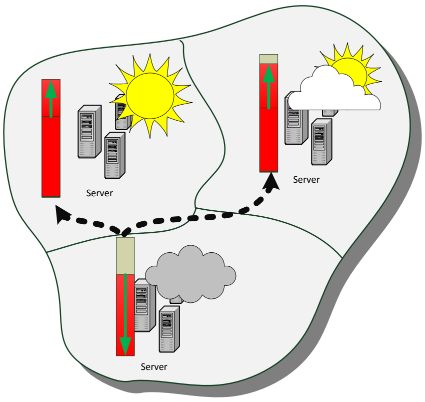


Figure 2 : Algorithm basics

2.2 Smart Grid and Moveable consumption

2.2.1 Coordination strategies and algorithms

In collaboration with AIT, TU Vienna developed a concept to include electric vehicles as moving loads. The first concept to reroute vehicles were withdrawn by the consortium, due to a possible lack of customer acceptance. Instead of that the TU evaluates the concept of using weather forecasts to explore a minimum of charge at the current location (when there is a lack of renewable production) and charging fast at the car's destination if there is renewable energy available. The main problem is to estimate the minimum charge at the current location. Two approaches will be analyzed:

1.) using fixed values. This idea is a straight forward approach and included two steps: A.) charge in any case to 50 %, also if there is no renewable production. B.) from 50…100% the charging can be varied and even stopped.

2.) an algorithm has knowledge about the trips of the vehicle and estimates the needed energy for this trips and charge the car slowly to this capacity if there is no renewable generation or charges fast if there is renewable generation.

For both approaches it is assumed that renewable production should be used locally if local production exceeds local demand.

2.2.2 Renewable Energy profiles:

Part of WP 3 was the generation of renewable energy profiles for the scenario simulated in WP6 proof of concept. The focus was on generation from solar and wind. For covering possible interdependencies or correlations between environmental temperature, wind speed and solar radiation, it was necessary to use a consistent data set for generating the corresponding profiles. The schematics of the method used for the generation of local renewable energy profiles are outlined in Figure 3:

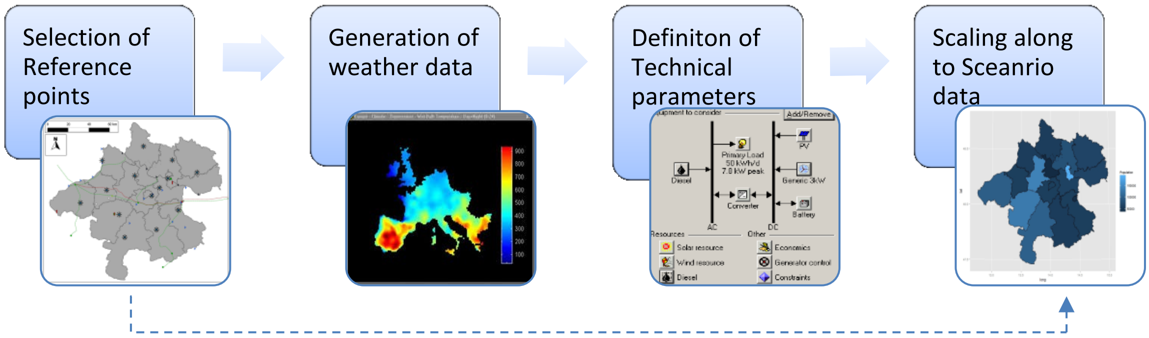


Figure 3 - Generation of renewable energy profiles

Several points with existing weather data metering stations were chosen around the scenario area. Based on historical measured data, the tool Meteonorm [1] calculates an individual data set for each district which contains environmental temperature, wind speed and solar radiation (direct and diffuse) for a whole year in 15 minute time steps. For getting energy profiles from weather data, the tool HOMER2 [2] was used for configuring relevant technical parameters of generation systems (PV, wind turbines) and scaling the profiles along the assumed installed nominal power per district. Besides the generation of energy profiles the weather data, specifically the temperature data was further used for calculating the energy consumption of moving electric vehicles, which differs depending on the temperature due to the usage of onboard heating and cooling systems.

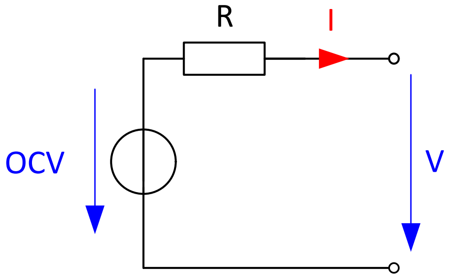
2.3 Infrastructure and Components

WP4 creates the component models for the electrical storage in electric vehicles, the thermal storage in buildings and the data center energy consumption.

2.3.1 Analysis of energy Storages in V2G

For integrating electric vehicles to the electricity network simulation, a model from the energy storage system from the vehicle is needed. The developed energy storage model and its application in the simulation environment are outlined in the following passages.

For analyzing the grid stability in G(e)oGreen, a simplified battery model consisting of a current-dependent voltage source with an internal resistance has been built, since the dynamic behavior representation of the lithium-ion battery is not relevant. With this basic battery model the parameters of the internal resistance and the non-linear voltage source has been configured to represent different high voltage battery systems of EVs available on the market. To reduce computational power and thus shorten the simulation time, only one instance of the battery model with scaled parameters, according to the different EV specifications, was used in the simulations. In Figure 4 the basic battery model is depicted.



OCV	Open Circuit Voltage
V	Terminal Voltage
I	Discharge current direction
R	cell impedance

Figure 4: Equivalent circuit diagram

As mentioned above the open circuit voltage (OCV) has a non-linear dependency from the state-of-charge of the energy storage, and thus depends on the battery current. Via the resistor R, the ohmic losses are modeled. The voltage V corresponds to the measurable terminal voltage of the battery cell. In summary, the model is based on the following equations.

$$\mathrm{SOC(t)} = \mathrm{SOC_{ini}} - \int_{t1}^{t2} \frac{\mathrm{I(t)}}{\mathrm{C}}\,\mathrm{dt} \tag{13}$$

$$\mathrm{OCV(t)} = \mathrm{f(SOC(t))} \tag{14}$$

$$\mathrm{V(t)} = \mathrm{OCV(t)} - \mathrm{I(t)} \cdot \mathrm{R} \tag{15}$$

$$\mathrm{P_{loss}(t)} = \mathrm{I(t)^2} \cdot \mathrm{R} \tag{16}$$

More detailed information is provided in the delivery document “D4.1 Simplified energy storage model for grid analysis”.

In the second project period the main focus was on performing a survey to identify suitable battery chemistries and cells for V2G use. Therefore this survey was divided into two important parts. The non-technical part deals with interviews of experts from V2G related fields. In total, nine expert interviews have been made that comprise three different target groups. Experts from charging station production, cell chemistry engineering and experienced EV user have been invited to a personal talk. The focus was to gather the status quo of V2G and to evaluate the future trend of this technology and its influences on the EV user. The technical side of the study was to simulate two different battery generations based on their availability in EVs on the market. In the simulation the batteries will be loaded with different current profiles to simulate vehicle movement and vehicle charging scenarios. To provide an expedient basis for this study also a literature analysis regarding the main aging mechanisms of Lithium Ion batteries was conducted. The aging mechanism as well as the battery model have been further developed and shown very realistic results in the end. The results on battery simulation and aging modeling have also been presented on different conferences.

V2G applications may contribute to grid stabilization or supporting stand-alone solutions for home application as the users and the industry see it positive. However the survey and the simulation suggest that more time will be needed before this strategy is ready for a broad application. On the one side the chargers available on the market are not prepared for bidirectional charging at the moment which indicates that there will be no market in the close future. Also the users, even if they are positive regarding the idea of V2G, set a lot of constraints for minimum remaining operational range, controllability, transparency of the model and other aspects limiting its applicability. The behavior of the users for plugging in their cars nearly all the time when not driving would speak in favor of V2G application as the cars would be available in principle.

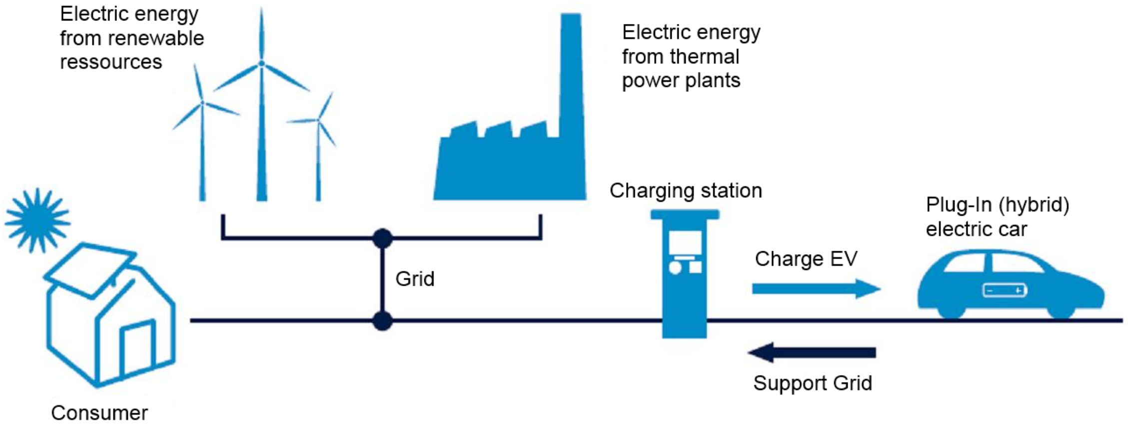


Figure 5: Principle of V2G service scenario

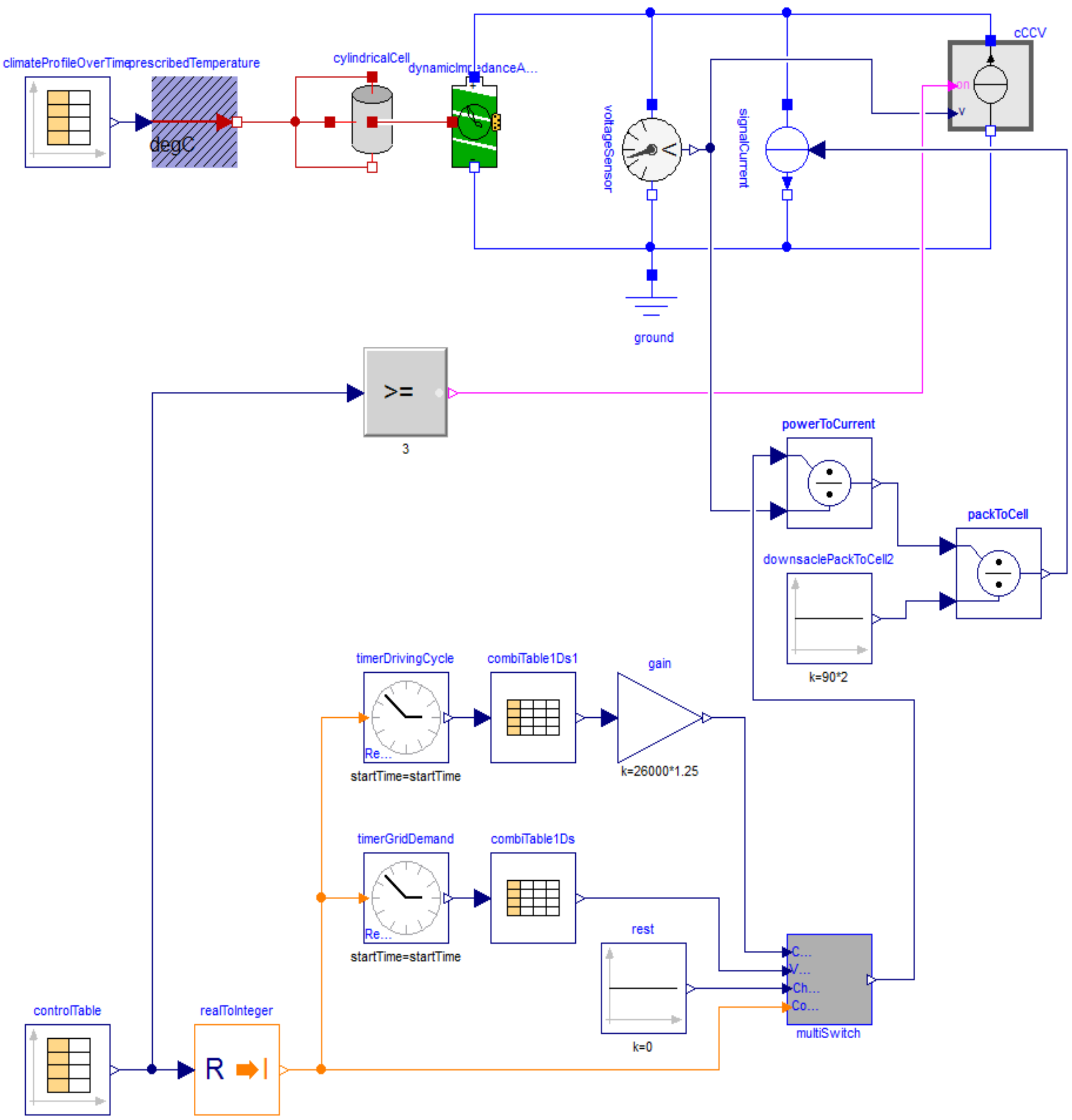


Figure 6: Full model for the V2G scenario simulations in Dymola

For the analysis of the different V2G scenarios for the survey in WP4 a Dymola [5] simulation model has been setup that includes the above mentioned battery model. The results of the simulation suggest that V2G is still demanding for today's batteries. Especially challenging are the profiles with high energy throughput as they lead to lots of additional cycles compared to driving reducing the lifespan of the cells significantly. High load profiles with shorter time lead to a better behavior than low load profiles with high energy demand. These results correspond also to recent findings that fast charging does not significantly influence the lifetime of the battery. A solution for the next future could be the controlled charge mode. The results show that the lifetime of the battery is higher than the lifetime for normal use due to the lower average SOC level. With controlled charge the user demands are still fulfilled while the grid can charge the cars in lower load phases leading to a more equal daily distribution of the load.

2.3.2 Analysis of energy Storages in buildings and building management control strategies

Buildings offer large thermal capacity and potentially also a large electrical capacity for load shifting. In the G(e)oGreen project geographical and time load shifting potential of buildings shall be analyzed. For the geographical aspects the G(e)oGreen system is working with different types of geographical cells. The smallest cell is the District Cell, it is also the most important for the load shifting potential caused by buildings. This cell covers an area of +/- 1 km^2 which can be used to assign charging points, data centers, energy generation devices, buildings, homes and local network load status. The boundaries in a District Cell are fixed and known.

To provide an electrical load shifting potential in a District Cell caused by buildings, a detailed thermal building simulation is not an option, as a best case solution. Therefore simple building models are necessary, which considers at least the losses and the gains in a building.

This document presents the solution of heat balance system, describing the heat losses and gains in a building to predict the indoor room temperature. The equations are solved for one building and later scaled up for n buildings of the same type. The sum of the load shifting potential of different building types is used to calculate the total potential in a District Cell. To keep the equation system simple but accurate enough the equations were simplified by introducing following restrictions.

The room heating is total or partly produced by electrical devices like heat pumps, combined heat and power plants or direct electric heating systems, if that isn't the case the load shifting potential in the grid is zero.

- Hot tap water production is not considered
- The electric consumption of ventilation systems is not considered
- Complex buildings with large variation in their usage need more advanced models (e.g. office and residential usage in one building).
- The influence of a storage tank is not considered

With these restrictions the dynamic heat load Q within a room or building can be expressed by the losses Q_{loss} and the gains Q_{source}:

$$\dot{Q} = Q_{loss} - Q_{source} \tag{1}$$

The equations can be reformulated for temperature using $T = \frac{Q}{c_p m}$ where cp is the thermal capacity of the walls, and m their mass. For Qsource = 0, the solution is.

$$T_{room} = (T_{start} - T_o) \cdot e^{-t/\tau_{cool(m_{inf}, T_o, U)}} + T_o \tag{2}$$

Time t starting from T_{start} till the room temperature falls to T_{min} (lower heating set point) with a given time constant τ_{col}.

$$-\ln\left(\frac{T_{min} - T_o}{T_{start} - T_o}\right) \tau_{cool} = t \tag{3}$$

Giving the cooling behavior of a building starting from temperature T_{room} (T_{room} usaually is between the lower and upper heating setpoint temperature T_{set},low/up) to an outside temperature $T_o < T_{set}$. For a large enough Q_{source}, there is a theoretical equilibrium temperature T_{end} > Tout which will be reached eventually, leading to the solution

$$T_{room} = (T_{end} - T_{start}) \cdot \left(1 - e^{-t/\tau_{heat(m_{inf}, T_o, U, q_{source,th})}}\right) + T_{start} \tag{4}$$

Figure 1 shows the principle scheme of the indoor temperature for cooling and heating in steady state conditions.

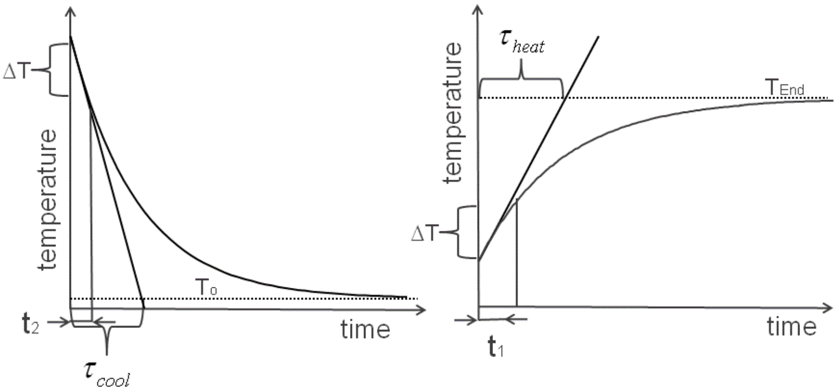


Figure 7 - Principle scheme of the indoor temperature for cooling and heating

time t starting from Tstart till the room reaches Tmax (upper heating set point) with a given time constant τ_{heat}

$$-\ln\left(-\left(\frac{T_{max}-T_{start}}{T_{end}-T_{start}}-1\right)\right)\tau_{heat}=t \tag{5}$$

The total electrical load shifting potential Q_{el} in each time step for a representative building ensemble can be calculated with equation 8, equation 6 calculates the thermal losses caused by ventilation and transmission (Figure 4).

$$Q_{heat}=\sum_{i=1}^{n}\left(U_i\cdot A_i+c_p\cdot m_{inf,i}\right)\cdot\left(T_{room,i}-T_o\right) \tag{6}$$

$$m_{inf}=V\cdot n\cdot c_p \tag{7}$$

$$Q_e=q_{source,th}\cdot A\cdot e\%\cdot a \tag{8}$$

e% represents the percentage of produced heat by electricity, for example buildings with a direct electric heating system have an e% = 1 and for buildings with heat pumps e% is equal to 1/COP, but only if the heat pump is providing 100 % of the energy. The variable a represents the stage of the heating system (on = 1 or off = 0).

For buildings which have a combined heating system e.g. hat pump or CHP plant plus back up system, e% can be calculated as follows

$$e\%=\frac{q_{th,CHP}}{q_{source,th}\cdot A}\cdot\frac{\eta_{el,CHP}}{\eta_{th,CHP}} \tag{9}$$

$$e\%=\frac{q_{th,HP}}{q_{source,th}\cdot A}\cdot\frac{1}{COP} \tag{10}$$

Figure 2 shows the indoor temperature of ten buildings, if no interaction (request from outside) is taken place. In this case only the building management system (BMS) is controlling the heating system. The band of the indoor temperature is set in all buildings between T_{set}/low (20°C) and T_{set}/up (22°C), but each building has a different indoor temperature.

Figure 3 shows the same buildings as in Figure 2, but from 7 to 10 a.m. and from 5 to 9 p.m. a request to consume less energy is coming from outside, during this time periods the heating system should be turned off.

Equation 11 calculates the critical temperature T_{min}. T_{han} means if the indoor temperature of a building is lower than T_{min} the building is not reacting on the request.

$$T_{min}=\frac{T_{low}-T_o}{e^{-t_{peak}/\tau_{cool}}}-T_o \tag{11}$$

The load shifting potential of a DistrictCell can be estimated as follows

$$Q_{e,DC} = \sum_{i=1}^{n} Q_{e,i} \tag{12}$$

This section shows findings of the control strategy of building along to the outdoor temperature (see Figure 8). Figure 9 shows the indoor temperature of ten buildings, if no interaction (request from outside) is taken place. In this case only the building management system (BMS) is controlling the heating system. The band of the indoor temperature is set in all buildings between T_{set}/low (20°C) and T_{set}/up (22°C), but each building has a different indoor temperature. Figure 9 shows the same buildings as in Figure 10, but from 7 to 10 a.m. and from 5 to 9 p.m. a request to consume less energy is coming from outside, during this time periods the heating system should be turned off. One interesting point in this simulation is the synchronization of the temperature after some periods. From this this simulation exact control strategies at the District Cell level can be derived. Following values are used in the simulation to define the buildings and the heating system:

A = 3763 m^2
V = 7814m^3
U = 0,58W/(m^2·K)
minf = 6560 kg/h
τ_{cool} = 152h
τ_{heat} = 25 h
q_{source} = 25 W/m^2
e% = 1-
T_{set},low/up = 20 / 22 °C

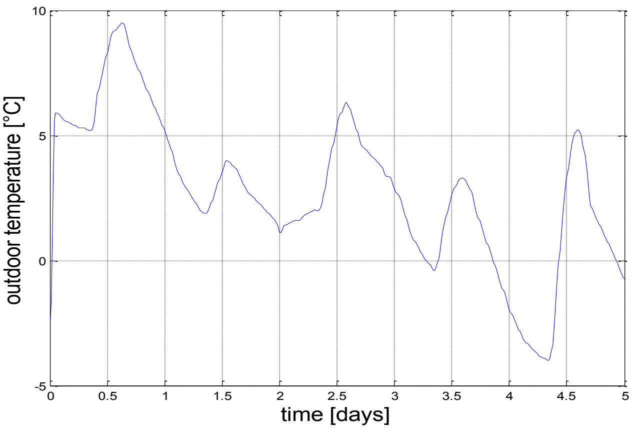


Figure 8 - Outdoor temperature during the simulation

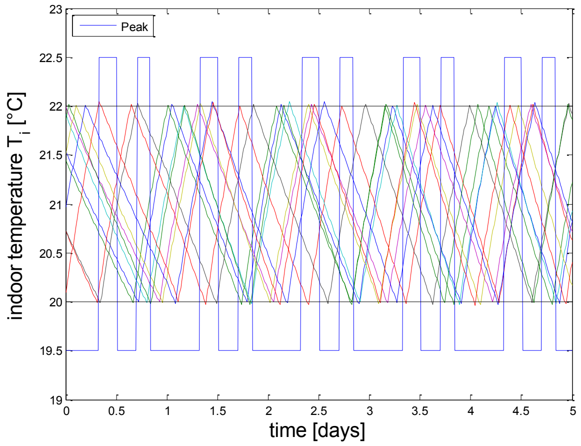


Figure 9 - Indoor temperature of ten buildings (T_{set}/low=20°C, T_{set}/up=22°C), the heating system is only controlled by the BMS

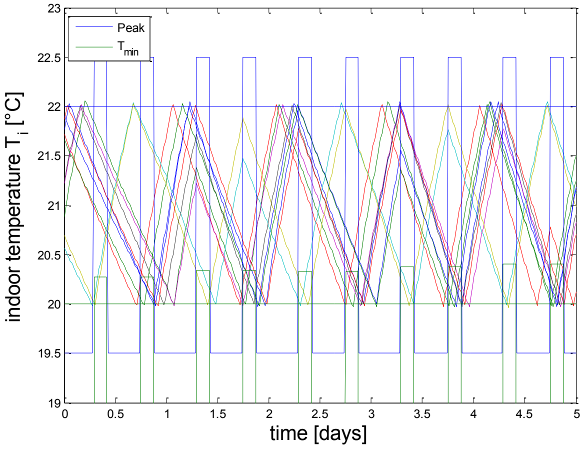


Figure 10 - Simulated indoor temperature of ten buildings if a request is coming from outside

Figure 12 shows the consumed electrical energy for the ten buildings without any control (red) and the consumed energy if the buildings are reacting on the request from outside. As shown in Figure 11 the simulation also includes internal losses caused by ventilation and transmission.

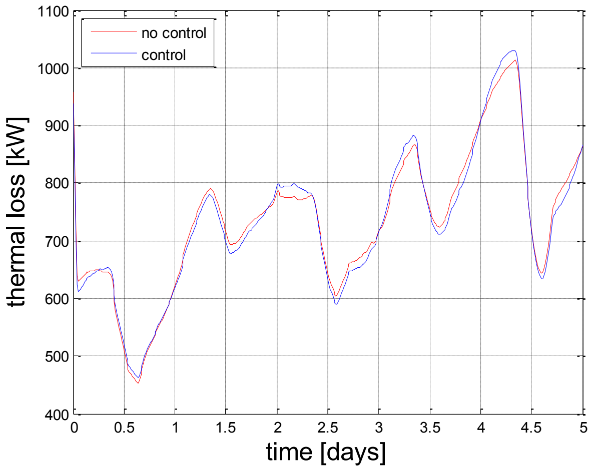


Figure 11 - Simulated thermal losses caused by ventilation and transmission

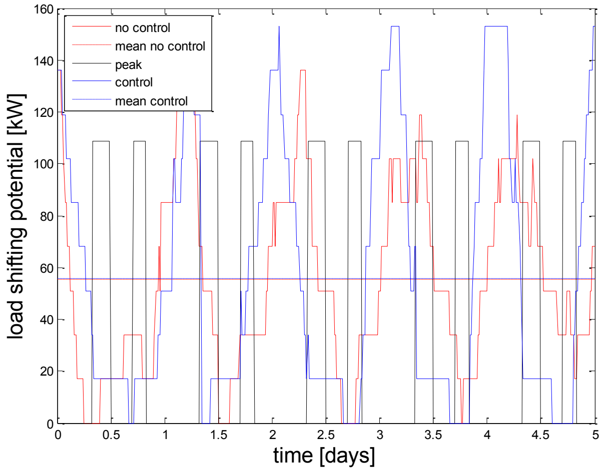


Figure 12 - Simulated load shifting potential for a building ensemble of ten buildings

2.3.3 Analyzing charging behavior of EVs

Additionally to the survey on charging and discharging activities of EVs, the charging behavior of existing EVs was measured and analyzed for its effects on the power grid. An existing test bed at AITs SmartEST laboratory was extended to enable measurements on electric vehicles. The aim of this task was to compare the assumed profile used in simulations with measured ones and to identify potential gaps. Further on, the measured profiles were expected to provide an outlook on possible effects to the power grid of controlled charging EVs (e.g. reduction of charging power). Figure 13 shows the schematics of the measuring setup. It can be seen, that each phase is measured individually. Different plug types for EVs are supported.

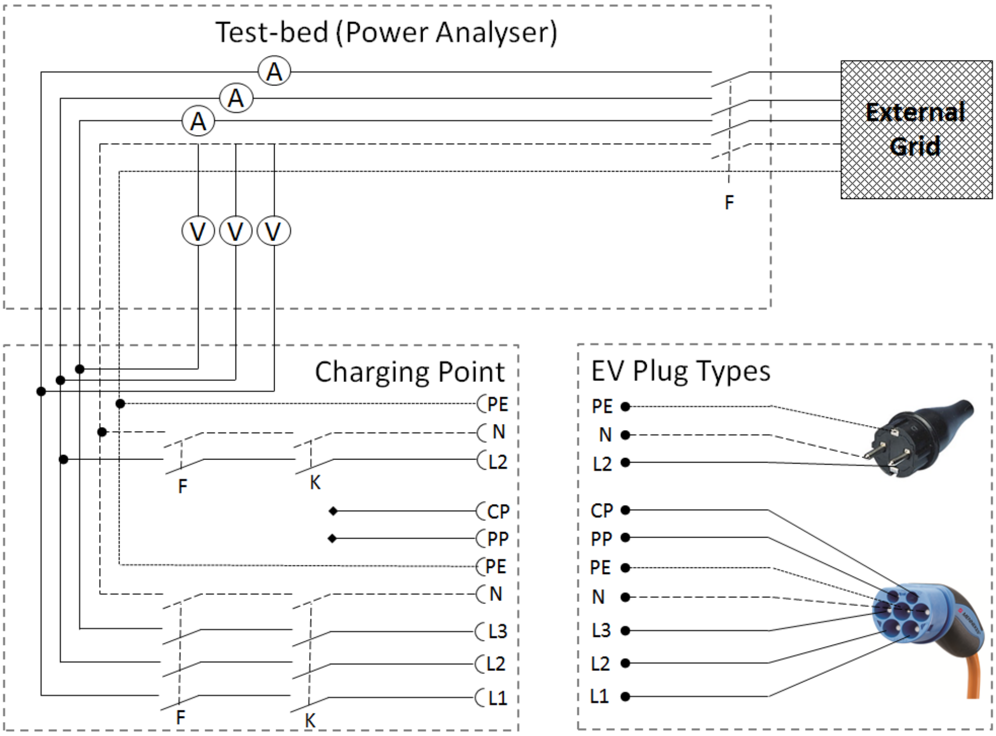
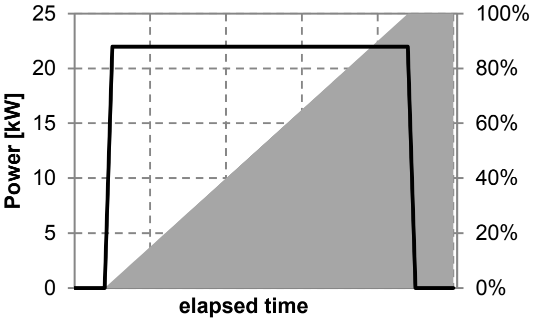


Figure 13 - Schematics of EV test bed

Additionally to Voltage and Amperage, real power (P) and apparent power (S) are captured and the related power factor calculated along to equation 17:

$$\text{Power Factor} = \frac{P}{S} = cos\varphi \tag{17}$$

Based on the findings of the measurements of charging electric vehicles (Figure 15) activities a simplified charging curve Figure 14 was considered to be sufficient for being used for the simulations to be done in WP6.



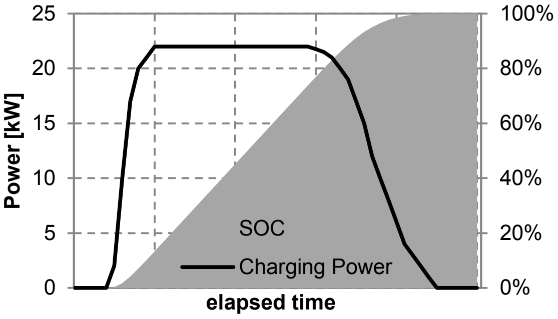


Figure 14 - Simulated charging power curve

Figure 15 - Measured charging power curve

Besides the analysis of the power curve of charging EVs, measurements covering several parameters were performed. Especially the findings regarding the behavior of the power factor during the charging processes should be mentioned here. Whilst charging with maximum power (e.g 22 kW) the power factor stays between 0.95 and 0.99. During the phase of charging when SOC is above 90%, the charging power is reduced by cell balancing reasons. In this final stage of the charging process, the power factor decreases along with to the reduction of charging power till 0.2 at the very low end.

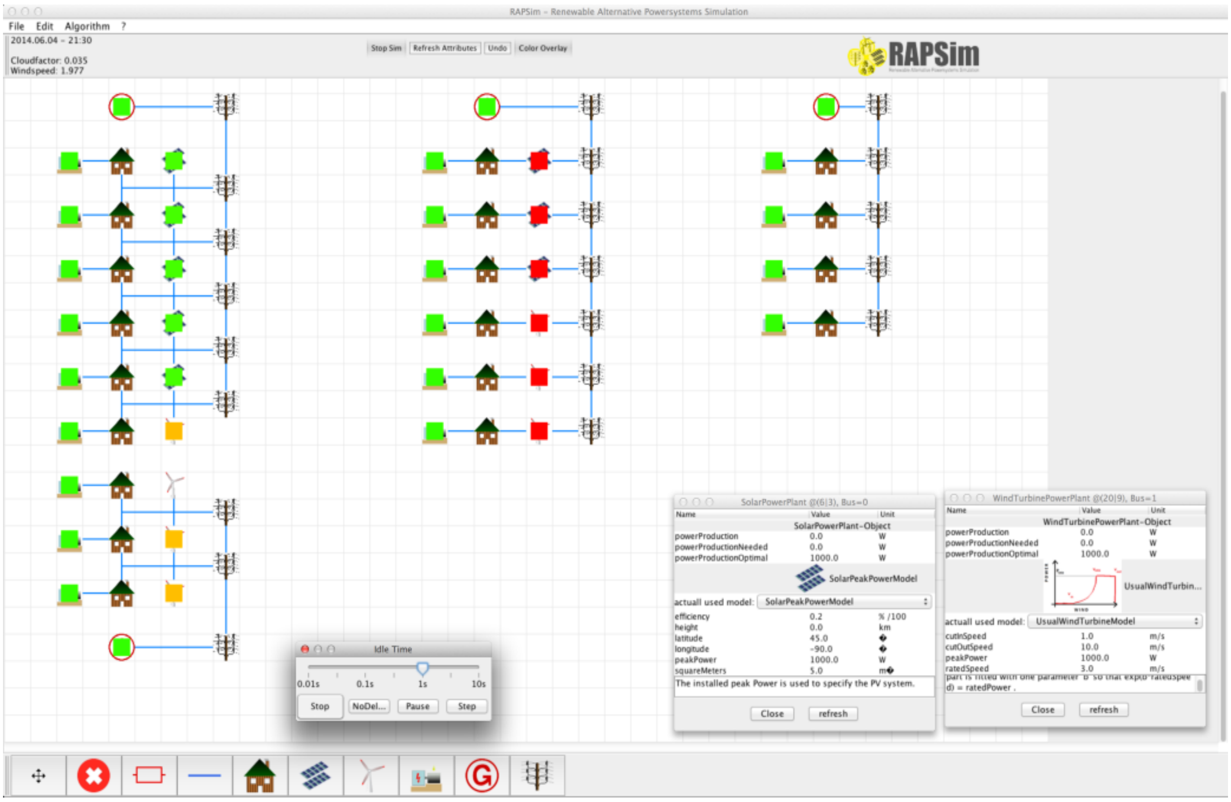
2.4 Proof of concept

2.4.1 Data Center Use Case

This proof of concept regarding a data center use case first looks at the state of the art of data centers capability and potential for shifting their power not just in time but also in space. After this grounding in today’s actual potential, a theoretical analysis of potentials was developed statistically. A simulated proof of concept showing the application of the statistical potential in a simplified model is given to show the workability of this theory. A real world application was not realized, but it is shown to be trivial for industry players deploying highly redundant data centers globally, since resynchronization is handled in a different layer by appropriate systems.

To prove the workability of the G(e)oGreen concept in simulation regarding the data center use-case, RAPSim [11] was chosen due to its properties matching G(e)oGreens demands right from the start. Especially the unique ability of RAPSim to calculate the power flow in its simulation of renewable energy sources was important for its choice to prove the workability of the G(e)oGreen concepts. RAPSim being applicable in simulations of household sized micro grids up to distribution grids on low and medium voltage levels as stated in [21], whilst factoring in changing weather conditions and a graphical easy to use interface made the decision straight forward. The open source license and the java based extendible libraries are going to become important in follow up projects, simulating definitive use cases of G(e)oGreen, for example to technically support economically viable business models or when helping to plan new infrastructure or making acquisition decisions for data center owners. Running in a commonly known IDE like eclipse, RAPSim is easy to adopt and its graphical user interface allows to quickly and intuitively prototype model designs.

As a proof of concept, a configuration of four micro grids or rather distribution grids around the globe were chosen. Data centers were modeled as buildings with a constant energy demand, and placed at a chosen real data center location from the scraped data center location data. During a simulation run, every time step is recorded in a comma separated values file together with the current weather conditions, and the net power production of each micro grid or distribution gird.



2014.06.04 - 21:30

Cloudfactor: 0.035
Windspeed: 1.977

SolarPowerPlant @(6|3), Bus=0

Name	Value	Unit
SolarPowerPlant-Object		
powerProduction	0.0	W
powerProductionNeeded	0.0	W
powerProductionOptimal	1000.0	W
SolarPeakPowerModel		
actuall used model:	SolarPeakPowerModel	
efficiency	0.2	% /100
height	0.0	km
latitude	45.0	�
longitude	-90.0	�
peakPower	1000.0	W
squareMeters	5.0	m�

The installed peak Power is used to specify the PV system.

WindTurbinePowerPlant @(20|9), Bus=1

Name	Value	Unit
WindTurbinePowerPlant-Object		
powerProduction	0.0	W
powerProductionNeeded	0.0	W
powerProductionOptimal	1000.0	W
actuall used model:	UsualWindTurbineModel	
cutInSpeed	1.0	m/s
cutOutSpeed	10.0	m/s
peakPower	1000.0	W
ratedSpeed	3.0	m/s

part is fitted with one parameter b so that exp(b ratedSpee
d) = ratedPower .

Figure 16 - Data Centers simulation environment and the proof of concept configuration

Figure 16 shows the graphical simulation environment and the proof of concept configuration. In the lower right corner a typical wind turbine profile can be seen. The randomly simulated wind weather generates dependent amounts of electricity. Left of this information window, a solar panel configuration can be seen, showing a chosen peak power model. RAPSim also offers a square meter model which can be more practical for designing after a real world use case specification. Since the resulting values of the simulation are not necessary for showing the proof of concept and the workability of the G(e)oGreen system, 1000 Watt peak were chosen for all installed panels. The last small information window shows the simulator speed and its ability to pause at any time step to perform data center load shifting. The green, yellow, orange and red overlay color spots display the absolute values changing during simulation and provide a glance overview of the overall system status: eg. solar panels receiving sunlight and producing energy not (red), a little (orange), average (yellow), or a lot (green).

2.4.2 Electric Vehicles Use Case (uncontrolled)

In order to test the proposed algorithm for electric vehicle charging in dependency of renewable generation in different locations, three simulation components had to be coupled, the simulation for electric vehicles, the simulation of the power grid and the G(e)oGreen algorithm. The simulation of the electric vehicles was provided by the AIT. In order to run the simulations, the EVSim program had to be adapted by the TU. Also an automatic configuration writer where implemented to get suitable simulations inputs. The writer where written in MATLAB© [6] and is feasible of providing input for a configured amount of vehicles with a random number of drives during a day. The amounts of drives during a day are calculated with a Gaussian distribution. The times of the drives are oriented on a typical week day in Upper Austria.

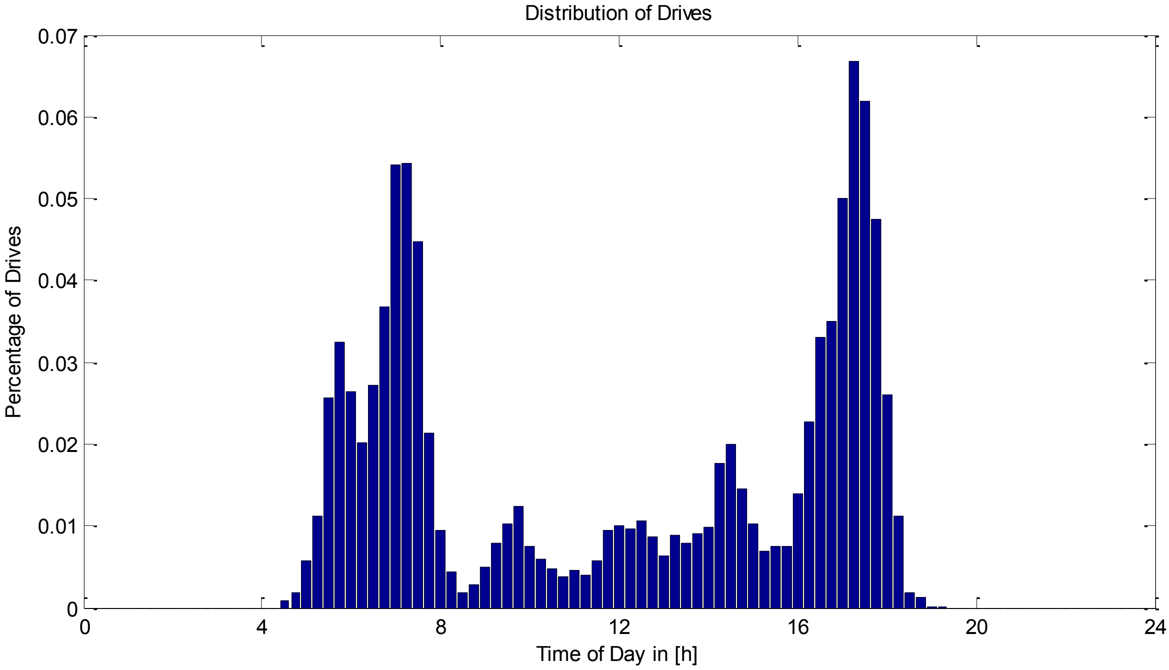


Figure 17 - Distribution of Drives during a Work Day in Upper Austria

- Defining Scenario (Upper-Austria)
- Generating renewable energy profiles
- Simulation of traffic and EV activities
- Measuring of EV charging activities

The simulation environment (as show in the schematics of Figure 18) for the proof of concept consist of several tools and aims for simulating a scenario covering a variety of suppliers and consumers of electricity. The co-simulation environment consist of the power simulation tool PowerFactory [10], the component simulation tool EVSim [8] and the G(e)oGreen optimization Algorithm. These tools are connected and synchronized via OPC [9] and a round-robin schedule. The traffic and mobility simulation was performed prior the co-simulation with a multi-agent simulation tool (MATSim). The output from the simulation with MATSim [7] is a detailed Agent plan (containing for example: origin, destination, times of arrival and departure, distance driven …) for each mobility agent and this information is further used as input for EVSim to simulate electric vehicles. The simulation environment is capable of simulating in different time-steps (e.g. 1-minute, 15-minutes …).

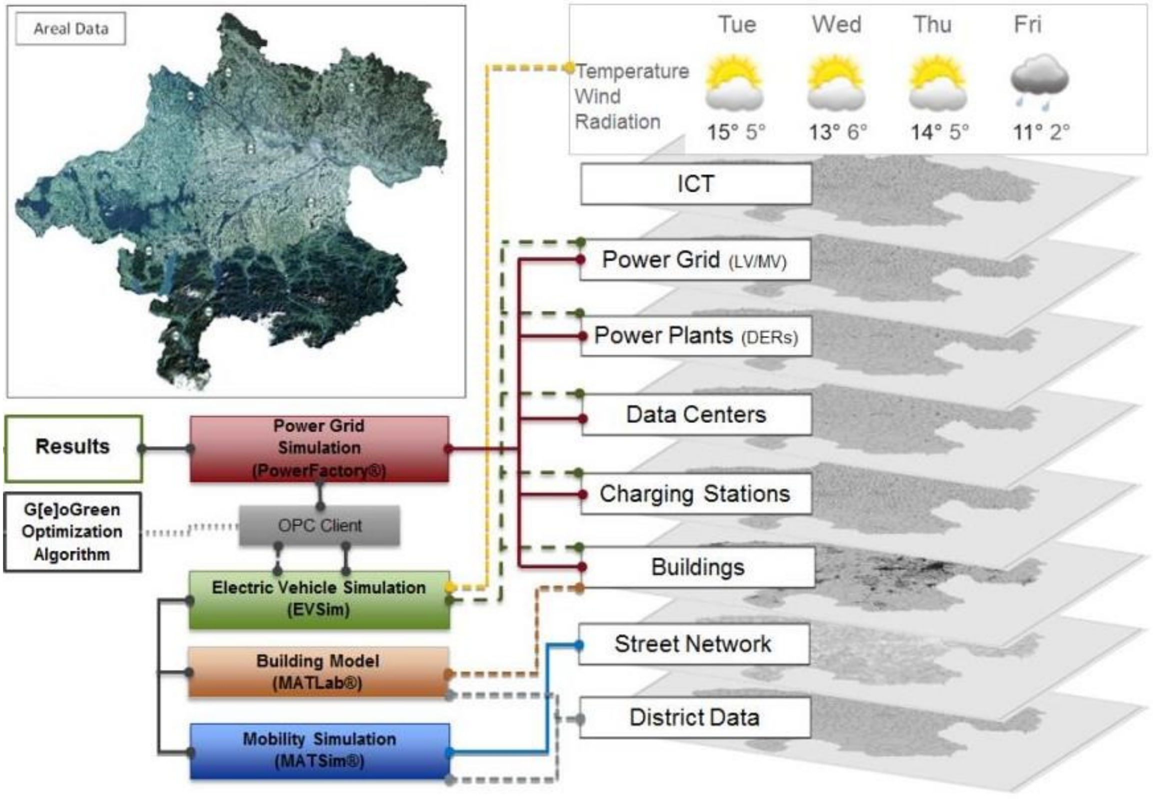


Figure 18 - G(e)oGreen simulation environment and scenario overview

Data from the component simulation is fed and linked via OPC to the specific node in the power grid. Figure 19 shows a power grid node representing a single G(e)oGreen cell with different types of loads (EVs, buildings …) and generators (Power plants, DERs …). During each simulation time step changes of values of every variable get actualized as well as values for the optimization (e.g. set value of max. charging power for EVs).

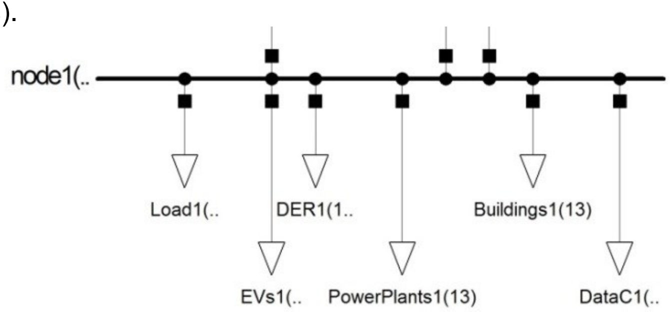


Figure 19 - Example of a power grid node of a single G(e)oGreen cell

For the proof of concept of the G(e)oGreen concept, the area of Upper-Austria was chosen as scenario. The 18 political districts of Upper-Austria were chosen to represent 18 individual G(e)oGreen cells. Based on available statistical data about the population [13], buildings [14] and mobility behavior [12] a use-case with an assumed number of EVs (based on real vehicle fleet data) and additional power plants of RES was created. Table 1 provides an overview of the main statistical figures of the area Upper-Austria and its districts. It is assumed that population and the car-fleet of Upper-Austria will stay on a constant level. In the use-case, a market-penetration of 100% EVs (more than 800.000 vehicles) is assumed. The maximal charging power in this use-case was set to 22kW[1].

---

[1] This represents the Mennekes 32A charging standard. EVs always charge with the highest possible power and are either limited by their on-board charger or the maximum charging power allowed by the charging pole.

Table 1 - Scenario data

District Nr.:	Population [22]	Power plants [MWpeak]				Consumers		
		Thermal [15][16][17]	**Hydro** [15][16][17]	**PV**[2]	**Wind**[3] [4]	**EVs** **[20]**	**Buildings**[4] [23]	**Data centers**[5]
0	38215	6	0	10	0	20281	364	1
1	56777	0	20	26	2	34381	351	0
2	65131	0	0	27	0	38857	187	0
3	65765	0	379	25	0	39496	336	0
4	81491	0	179	34	20	49258	347	0
5	56565	0	410	25	2	33821	355	0
6	58596	0	81	26	14	36169	624	0
7	98000	223	73	44	16	59173	425	0
8	130520	606	9	56	43	78351	470	0
9	99595	0	30	44	7	58965	604	0
10	55607	0	8	24	53	32955	376	0
11	58751	0	144	25	32	36001	349	0
12	139218	0	1	46	7	83574	377	0
13	62632	0	0	27	0	38826	187	0
14	190802	414	10	33	0	96835	603	3
15	31767	0	324	13	0	19907	125	0
16	58709	13	0	14	0	32967	769	2
17	67961	0	71	28	0	42124	391	0
Total	**1416102**	**1262**	**1739**	**528**	**196**	**831941**	**7240**	**6**

The power generation profile of the RES is based on the historical data from [23] and measured PV profiles, covering an average day (around 20°C). Both time lines were scaled to the particular installed peak power in each G(e)oGreen cell (shown in Table 1, Figure 22, Figure 24 and Figure 26). A pre-analysis about the shifting potential of EVs (battery capacity: 40kWh), data centers and buildings showed that EVs by far provide the highest potential for load shifting compared to the other two options. The fleet of EVs consist of different types of vehicles with individual parameters (size of battery, max. charging power, number of phases…), which are modeled after vehicles which are currently available on the market.

The use-case of uncontrolled charging of 100% EVs driving in total more than 1.6 mio. trips in 18 G(e)oGreen cell was simulated. An average working day in the year was chosen (around T=20°C), where EVs on-board devices (heating or cooling) do not rise energy consumption. In order to develop appropriate optimization algorithms for the proof of concept, a pre-analysis of the time lines of supply and consumption of electricity of this specific use-case under uncontrolled (non-optimized) conditions was done. Figure 20 shows the corresponding power curve of generation (PV and Wind) and uncontrolled charging EVs in all of the 18 cells.

---

[2] It is assumed that approximately 30% of the buildings in the districts are equipped with PV system of 5 kW$_{peak}$

[3] Additionally to the number of current installed wind power per district [3] a certain amount of wind power potential was assumed based on information from [4]

[4] Based on information from [23] buildings with direct electrical heating systems were selected for being controllable within this use-case

[5] Currently no data centres are located in the Upper-Austrian are. However for this proof of concept a number of centres was assumed to be located within the three largest urban areas.

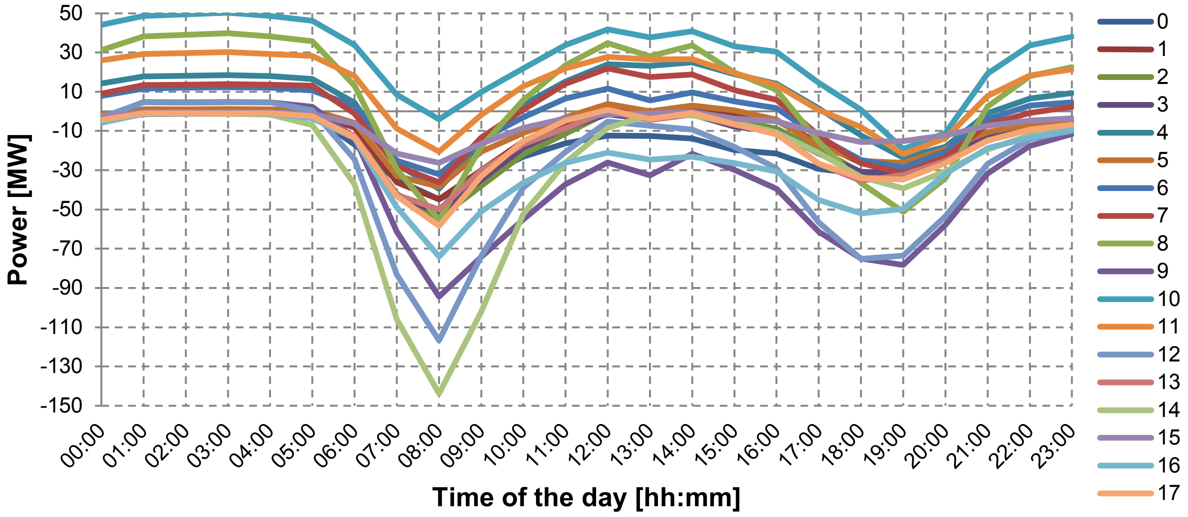


Figure 20 - Power curve of power generation from RES and consumption by EVs in each cell

Figure 21 shows the SOC of the simulated EVs after arriving at their destination and before starting charging. Around 2% of all EVs are not capable to perform their daily trip without running out of energy. In total, 68% of all EVs arrive at their destination with an SOC above 80%. 25% of all EVs have SOCs between 50 and 80% and the rest of 7% of all EVs ends up with SOCs lower than 50%.

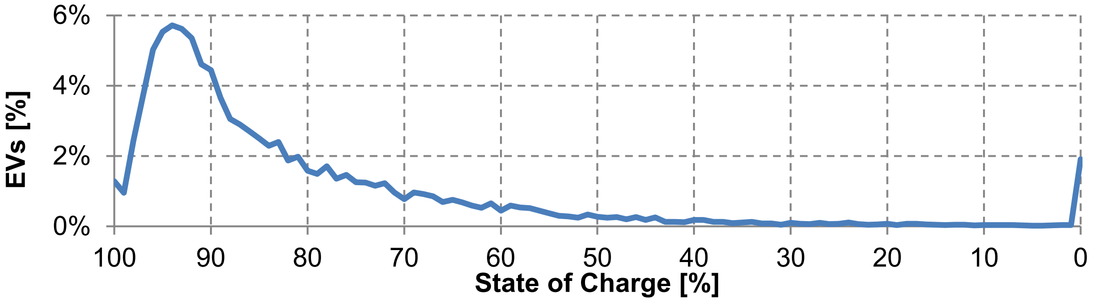


Figure 21 - Minimum SOC of EVs before charging

Between 22:00 and 06:00 of the simulated day, more power from RES would be available in most cells than is consumed by charging EVs. Especially in the hours from 06:00 till 11:00 and 17:00 till 20:00 in most cells the consumption of energy by charging EVs excels the generation from RES. During the noon hours (11:00 till 16:00) in most of the cells the consumption by EVs can be covered the generation from RES (especially from PV systems). In geographical terms (as shown in Figure 23), cell number 14, which represents the largest urban area in this use-case, shows the largest demand in power during the morning hours, whilst more rural cells (e.g. 10 and 11) are less frequented by charging EVs during this time. Table 2 provides (along with Table 1 from page 23) an overview of the main-specifications of the use-case and shows some geographical snapshots of the power balance within selected points of time. Figure 22 and Figure 24 shows the unbalanced distribution of RES in the different cells. Due to the limited size of urban areas these cells show lower amounts of installed RES than most of the rural areas. The power snapshots in Figure 23, Figure 25 and Figure 27 show, that imbalance between different areas exist and potential for geographical load shifting is given. This mainly applies for the urban areas in this use-case but also applies for specific rural areas where insufficient amounts of RES are installed and charging activities of EVs are high throughout the day.

Table 2 - Results of time-line analysis (at selected points in time)

Location and number of installed RES and EVs per G(e)oGreen cell

Snapshots of power supply (RES) and consumption (EVs) per G(e)oGreen cell

Figure 22 - Installed Wind power (MW)

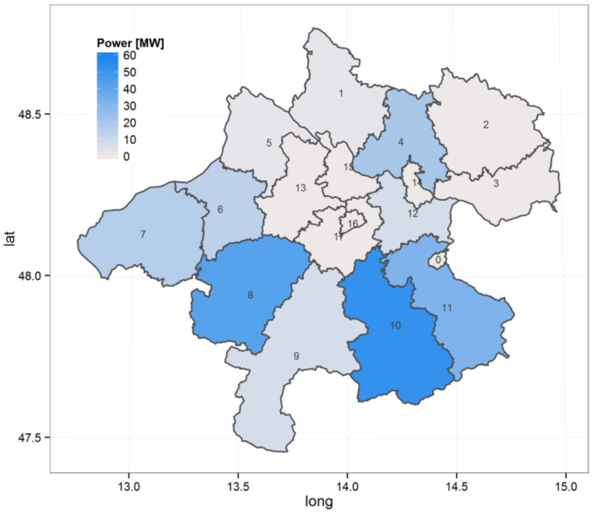


Figure 23 - Power Snapshot 08:00 (hh:mm)

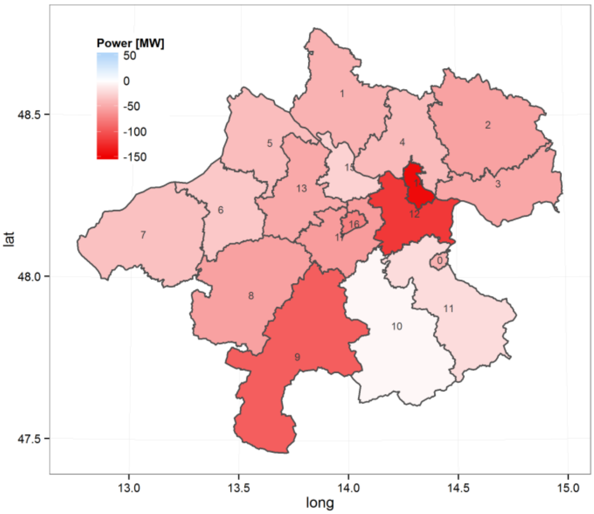


Figure 24 - Installed PV Power (MW)

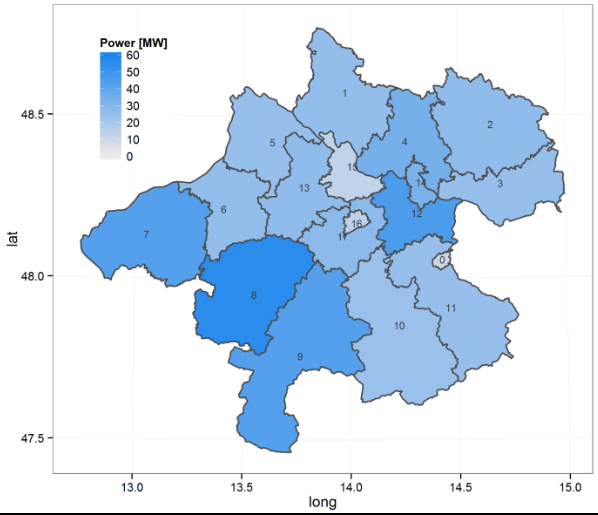


Figure 25 - Power Snapshot 12:00 (hh:mm)

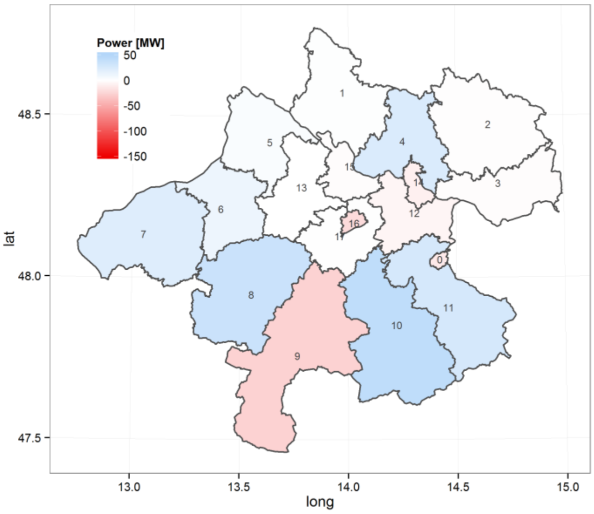


Figure 26 - EVs per G(e)oGreen cell

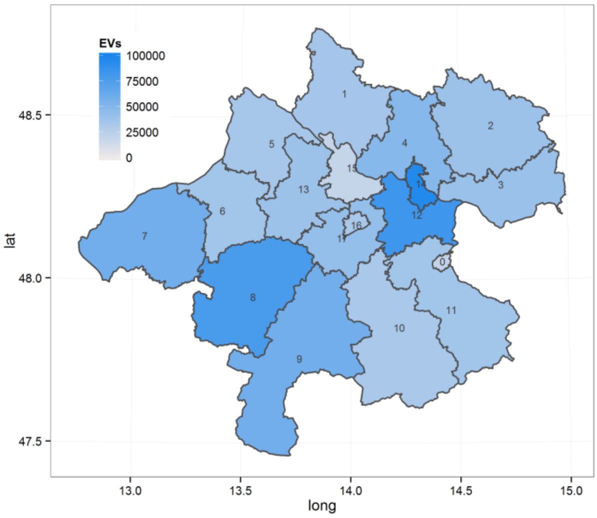
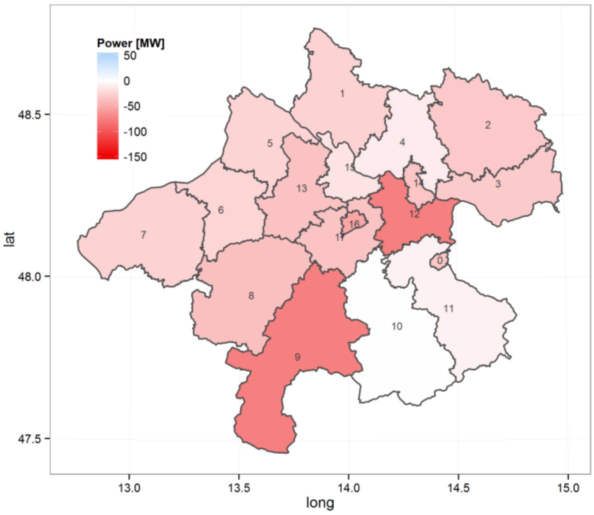


Figure 27 - Power Snapshot 18:00 (hh:mm)



2.4.3 Electric Vehicles Use Case (controlled)

Within the project a special case with 7 nodes (see Figure 28) and 30000 vehicles where simulated. The simulation of the vehicles was done by EVSim, developed by the AIT. The Vienna TU adapted the program to run faster simulations and getting input from an external algorithm. A so called G(e)oGreen algorithm was applied and reads all necessary values from the EVSim tool. It defines the charging speed of each car individually, depended on the voltage and the renewable energy generation. In DIgSILENT Power Factory a grid topology with seven nodes where modeled. The node where equipped with typical RES (Wind, Solar) production (see Figure 37 and Figure 38 at the end of the document) and H0 profiles (see Figure 39). In order to simulate geographical load shifting all RES profiles where slightly different from each other, to simulate different weather situations within the nodes.

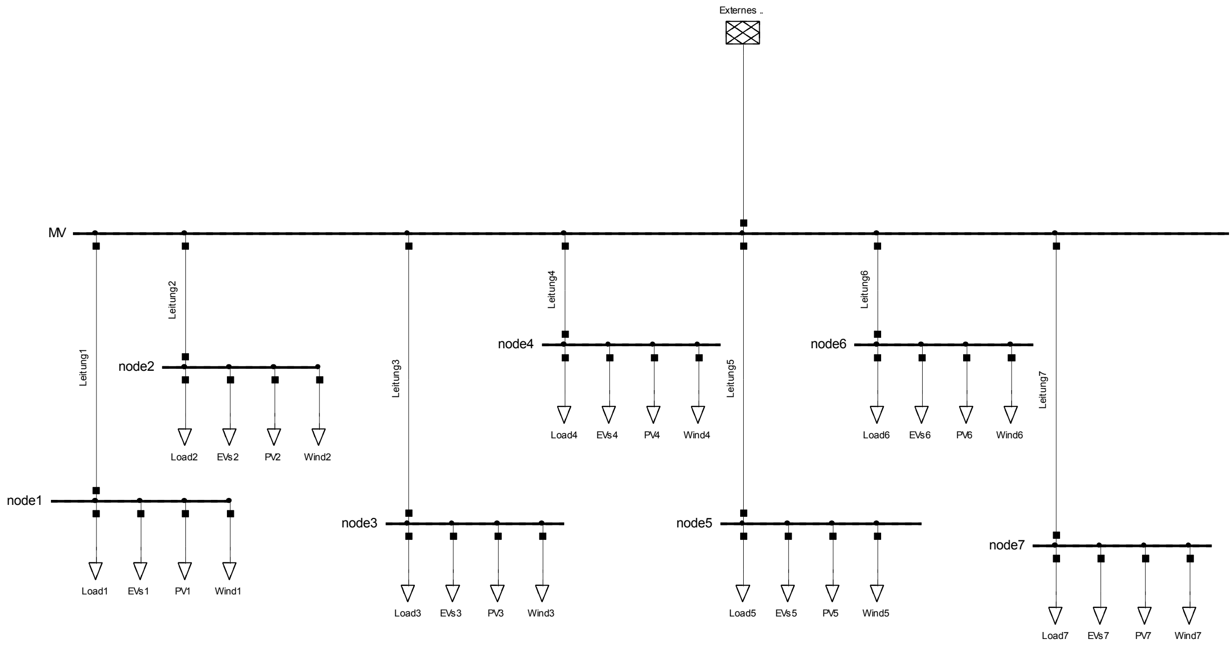


Figure 28 : Grid topology, modelled in DIgSILENT Power Factory

The optimization algorithms had knowledge about the cars properties, the RES forecast and the movements the vehicle will fulfill. The optimization goal of the algorithm was to load the car only when needed if no consumption is present and load as much as possible if consumption is present. As control variable, the voltage of the nodes where used. If the controller detects a voltage that is below a certain limit, it queues the cars resp. the charging stations. For queuing the cars are ordered by the next drive they will make (the car with the smallest timespan between the current simulation step and the next planned drive has the highest priority) and if there is possibly enough RES generation at the node it will drive to, to charge it for the next drive. As simulation step size, five minutes where chosen, and the simulation spans a complete day. The controller works with the following steps:

- Is the voltage higher than 98 % of the nominal voltage; Charge all Cars with the maximum power.
- Is the voltage below 98 % of the nominal voltage; Charge the cars in order of the calculated priority with a fixed amount of power.

The downside of this method (because there is no knowledge of the algorithm about the topologies of the grid) it can be possible that the charging will fluctuate between the two states (see Figure 29).

The results show, that with this approach, the voltage stays, after an adjusting phase, in between the levels and all cars can be charged (see Figure 30). In comparison without the control of the G(e)oGreen algorithm, the voltages drop in some nodes for longer time.

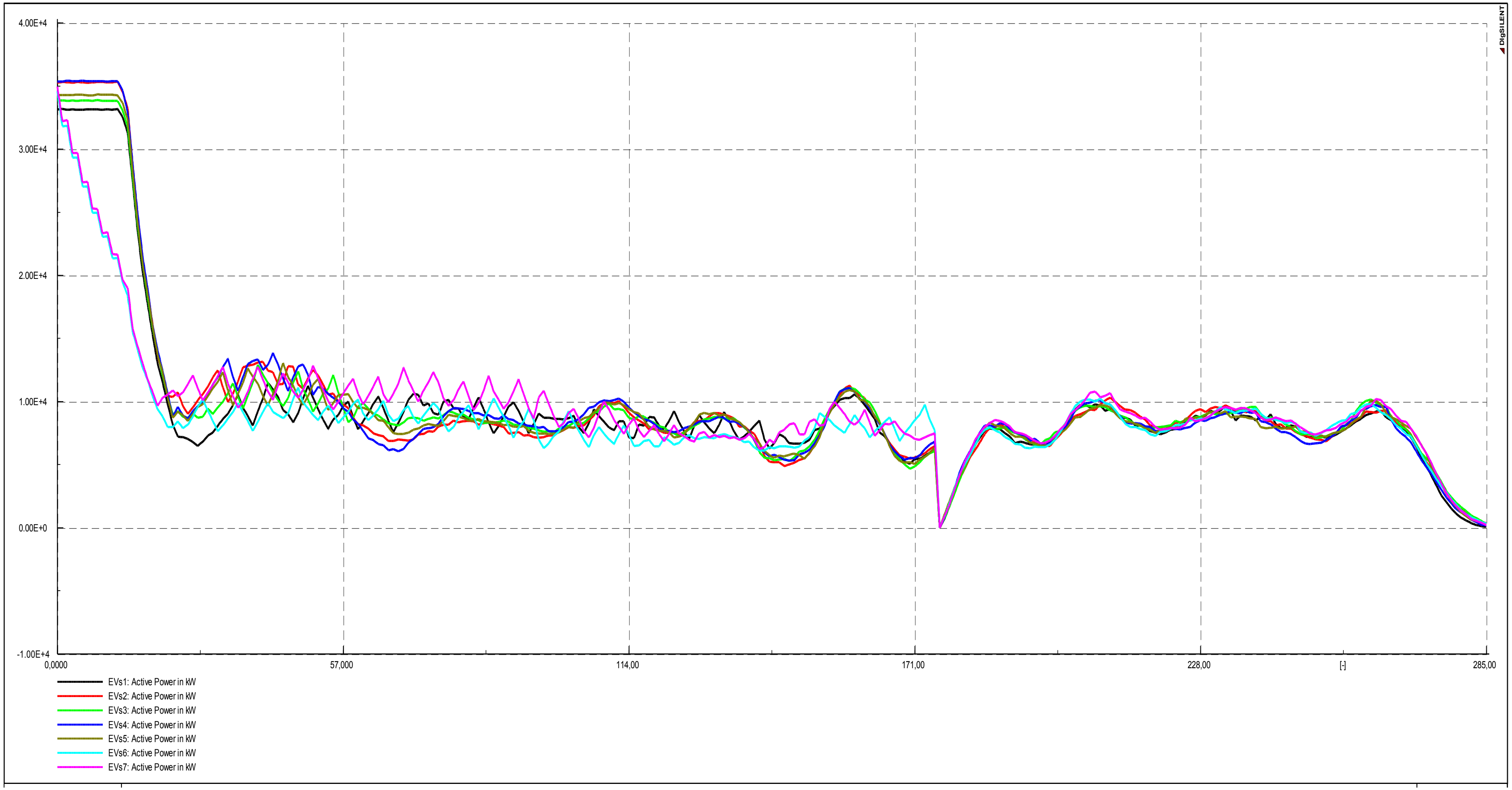


Figure 29 : Power demand of the electric vehicles summed by the node the vehicle was charging, with the G[e]oGreen algorithm activated

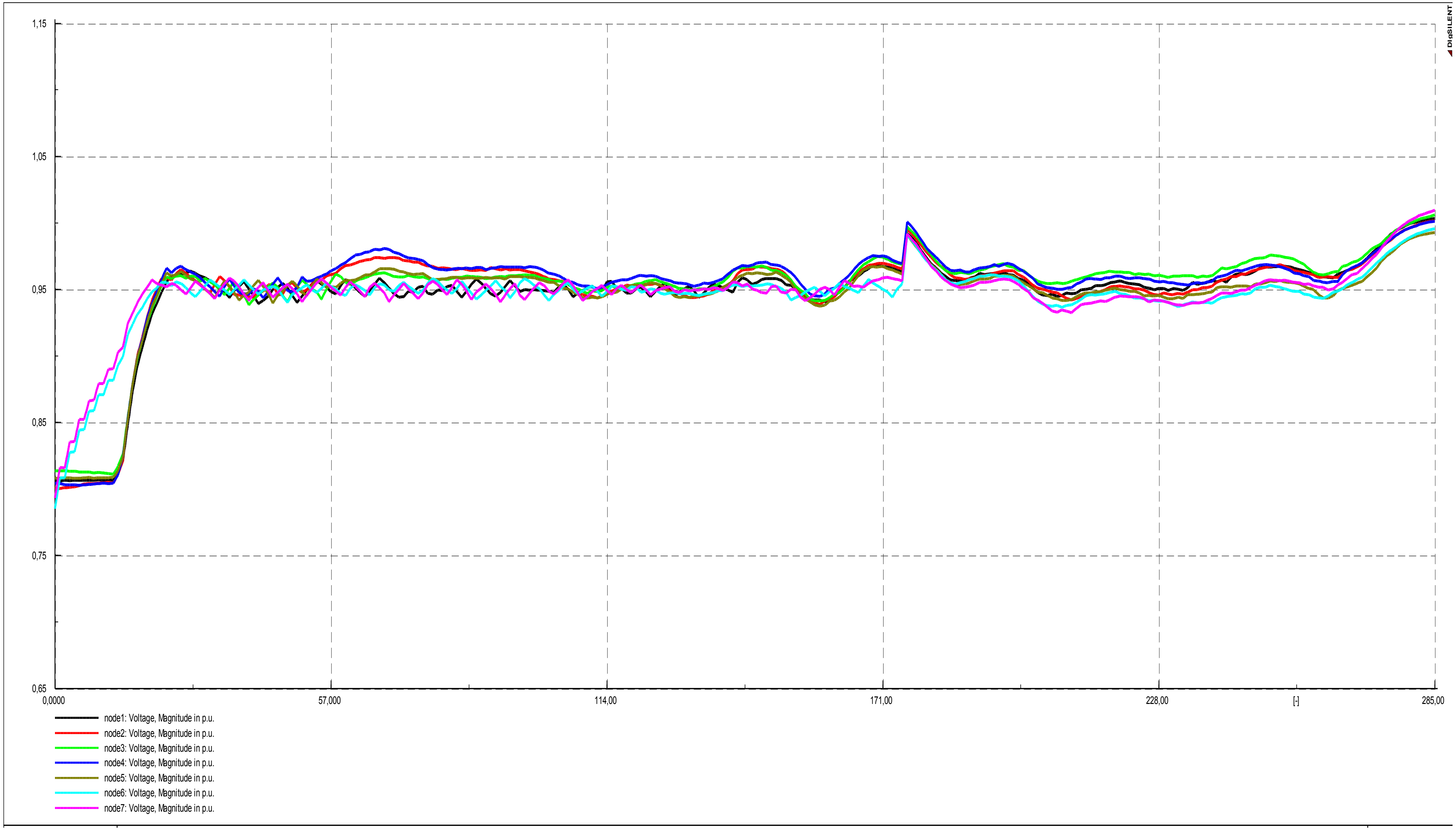


Figure 30 : Voltage simulation of the node voltages, generated by DIgSILENT Power Factory, with the G(e)oGreen algorithm activated

3 Ergebnisse und Schlussfolgerungen

The following section of this report provides conclusions regarding the main findings and the project outcome. Due to the different aspects and objectives of the individual parts of the project, this section addresses certain conclusions regarding to specific results individually. As a general conclusion of the results and finding out of project it can be stated, that an agent based approach combined with the G(e)oGreen cell concept is a suitable approach for addressing the requirements of the objectives of this project. However, as it can be seen throughout section 2 of this report, that different methods and approaches are necessary for addressing individual entities for optimization properly. Due to the variety of different objectives of each entity (EVs, buildings, data centers) which partly have to be met in front of the optimization process a hierarchical and agent based process of the optimization seems to be a feasible approach for addressing multiple objectives.

Especially in the use case of managing data centers within a G(e)oGreen system it is necessary to look at the topic at a broader view. In a scenario, starting from a Balancing Responsible Party (BRP), a day-ahead schedule is calculated every 15 minutes and the necessary load modifications request sent to data centers. They in return respond to the grid with their offered potential in using more or less energy through moving tasks to a different data center in a different balancing region with a surplus in energy.

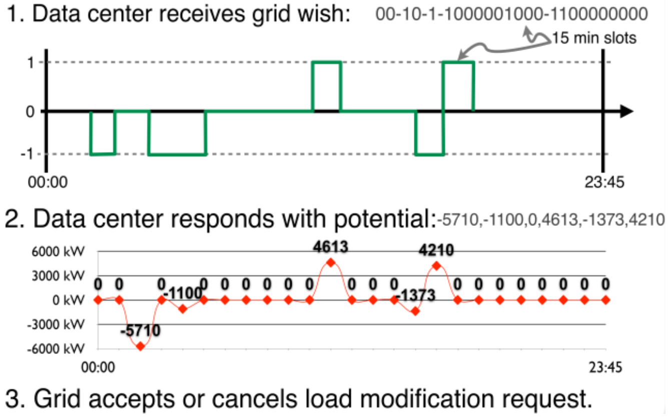


Figure 31 - Minimized protocol example grid

Figure 31 shows a minimized protocol example grid with 15 minute time slots indicating where energy is needed and where too much is available. The data center responds with its potential in all relevant slots. All data center responses are collected, aggregated and selected at the BRP on used and rejected data center potentials to create a partitioned day-ahead schedule. This process repeats every 15 minutes (see Figure 32).

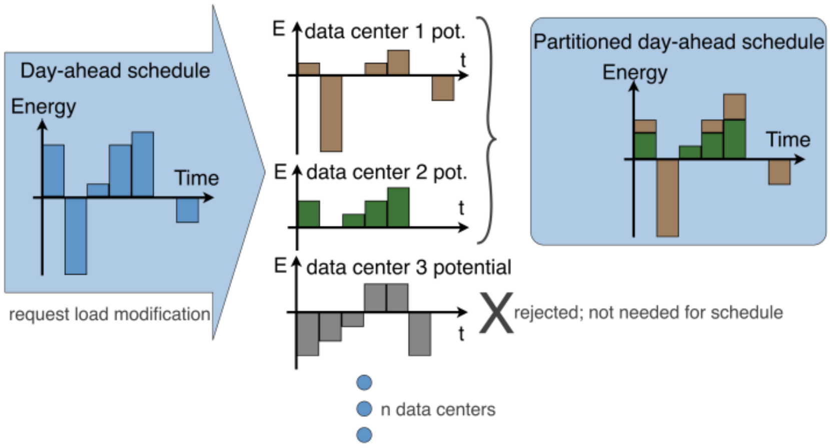


Figure 32 - Data center respond process

As described in the G(e)oGreen Cell Concept, a data center can be modeled together with buildings as a special kind of building, reacting faster and more powerful. Taking this approach, a system overview could look like Figure 33.

The approach of introducing a Smart Grid Controller and different kinds of specialized agents (buildings, data centers, etc.), can allow for horizontal and vertical scaling, as well as third party aggregation scenarios. A building agent manages one building, a data center agent one data center and handles all load modification requests whereas the smart grid controller receives day-ahead schedules, requests the load modifications, aggregates one's agents and can be an agent itself.

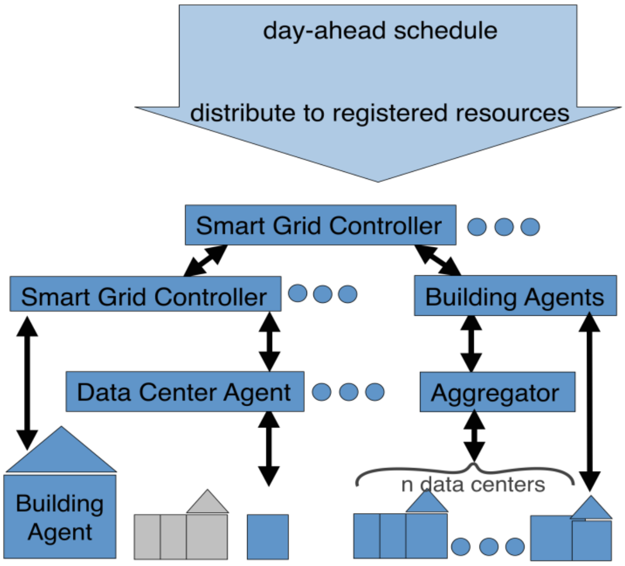


Figure 33 - Schematics of system approach

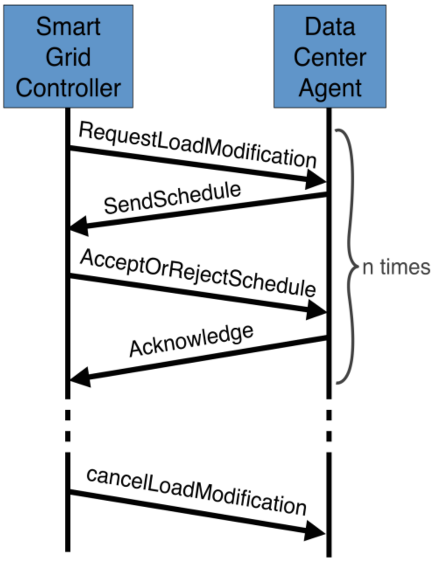


Figure 34 - Sequence diagram of communication protocol

Figure 34 shows the sequence diagram of a simple communication protocol that can be used between a smart grid controller and data center agents. This is the minimal granularity needed still with no resilience against lost packets, but only very little communication is needed. In this protocol capacities are aggregated by layer. For example openADR XML standards can be used to implement this in further work.

Further work also needs to be done at the point of the BRP, where offered data center capacities are chosen. There are different ways statistical data can be used to arrive at a decision:

- Normal distribution of load capacities within a data center
- Random distribution of possible load shiftable data centers
- Pareto distribution of building capacities over country
- Merit based remembering behavior of past requests

All methods can also be tested in simulation, providing results for field studies.

Simulation Aspects

The Simulation done in this project with RAPSim is not taking into account real grid structures or potentials but solely a generic one for each one of the micro grids around the globe. Also the settings chosen for renewable generation were not considered relevant for the proof of concept of G(e)oGreen, but can play a crucial role when calculating business models and detailed numbers.

It is unknown to the authors, how large a simulation RAPSim can handle. If for example all data centers around the world could be simulated in their respective micro grids in one simulation. It would be enough though, to simulate all assets of one globally acting data center company additionally to the respective national grids and mix of renewables. Whereas the movement of the sun around the globe in RAPSim was realized through latitudinal and longitudinal geo-positioning, different weather profiles for different regions or even the import of historic measured data are not yet possible and could be extended.

General Aspects

A more exact calculation of the shifting potential can be achieved simply by eliminating variables:

- Exact data center locations and sizes in terms of electricity consumption
- Exact power potential and load profiles of data centers connected

Ceph is an open source object storage solution which offers everything for physical layer replication control. It allows to specify replicas not being connected to the same power out-let, or across multiple data centers. It even manages the hard case in which it is just 2 data centers (more is easier because of voting being possible). In further work, Ceph can be used to practically test G(e)oGreen concepts described in a real, in use software, outside of simulation, as one step before implementing it in the data center industry.

One aspect not covered by the simulations, but measured at the test bed was the characteristic of the reactive power during the charging process. The findings of the measurements show, that current models of EVs are not specifically designed for avoiding negative effects during the charging process. Whilst the charging power stays close to its maximum (e.g. around 22 kW) the power factor stays within expected limits (0.95 – 0.99). During the phase of the charging process, when charging power is reduced due for cell balancing purposes (starting around 90% of SOC), the power factor decreases to 0.2 at the lowest. Due to the reduction of charging power, for charging from 90% to 100% SOC it takes proportionally a long period of time, which means that the considerable consumption of reactive power affects the power grid. Envisioning scenarios with mass introduction of EVs which show this specific charging behavior might be a considerable problem for the electricity network in future. This especially applies for scenarios where modulation of charging power according to specific charging strategies should be performed. It has to be noted that this findings are based on measurements on a few different models of EV and does not claim to be representative for EVs in general. More measurements on different EV models from a variety of OEMs have to be performed.

4 Ausblick und Empfehlungen

The cell concept developed during this project provides prospering features and options for future work. Especially the applicability of the concept within the European area would provide an ideal base for the further development of optimization algorithms and control strategies. Its modular and hierarchical approach would also allow and embrace agent based concepts which gain increasing attention from the scientific community.

Based on the findings regarding the measurements of charging activities from specific EVs activities for the future can be derived. Besides a general evaluation of effects of charging EVs to the power grid, especially the decreasing power factor during charging phases where power is reduced has to be investigated further more. More measurements on different EV models from a variety of OEMs have to be performed and analyzed. With the measurements and the developed battery model, different EV agents can be parameterized to simulate diverse EV models. As a consequence they will show a different charging behavior as this depends on the integrated battery technology of the EV. Thus the accuracy for load management investigations can be enhanced as the results are more realistic.

The next step regarding to the data center use-case will be to evaluate the four most promising future demand response scenarios in detail together with focus groups and expert surveys of decision makers, financiers, and manufacturers. Especially ecological, technical, social, and economical factors need to be analyzed as a multidisciplinary phenomenon in order to identify barriers and starting points for future implementations in every step. Further work also needs to be done at the point of the BRP, where offered data center capacities are chosen. There are different ways statistical data can be used to arrive at a decision:

- Normal distribution of load capacities within a data center
- Random distribution of possible load shiftable data centers
- Pareto distribution of building capacities over country
- Merit based remembering behavior of past requests

All methods can also be tested in simulation, providing results for field studies.

Regarding the future development of optimization algorithms, the project G(e)oGreen provided insight, that an optimization approach focusing mainly on one objective might be not feasible in the real world. Due to the different nature of individual entities (in this case EVs, buildings and data centers) a multi objective approach might be addressing the various requirements better. The basic concept of G(e)oGreen seem to be able to embrace such a optimization scheme.

Based on the experiences and findings gained during the work on the proof of concept, the development of the simulation environment and the EV scenario, the existing simulation environment will be revised. The future approach regarding the simulation environment abandons the traffic simulation tool and focus on generic method for creating an agent population for specific scenarios based on identified mobility patterns and probabilities. The advantage of this approach would be an increased performance and flexibility for simulating areas which lack of necessary data. Findings from project G(e)oGreen will be used for reference and validation purposes.

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6 Anhang

6.1 G(e)oGreen Project Structure

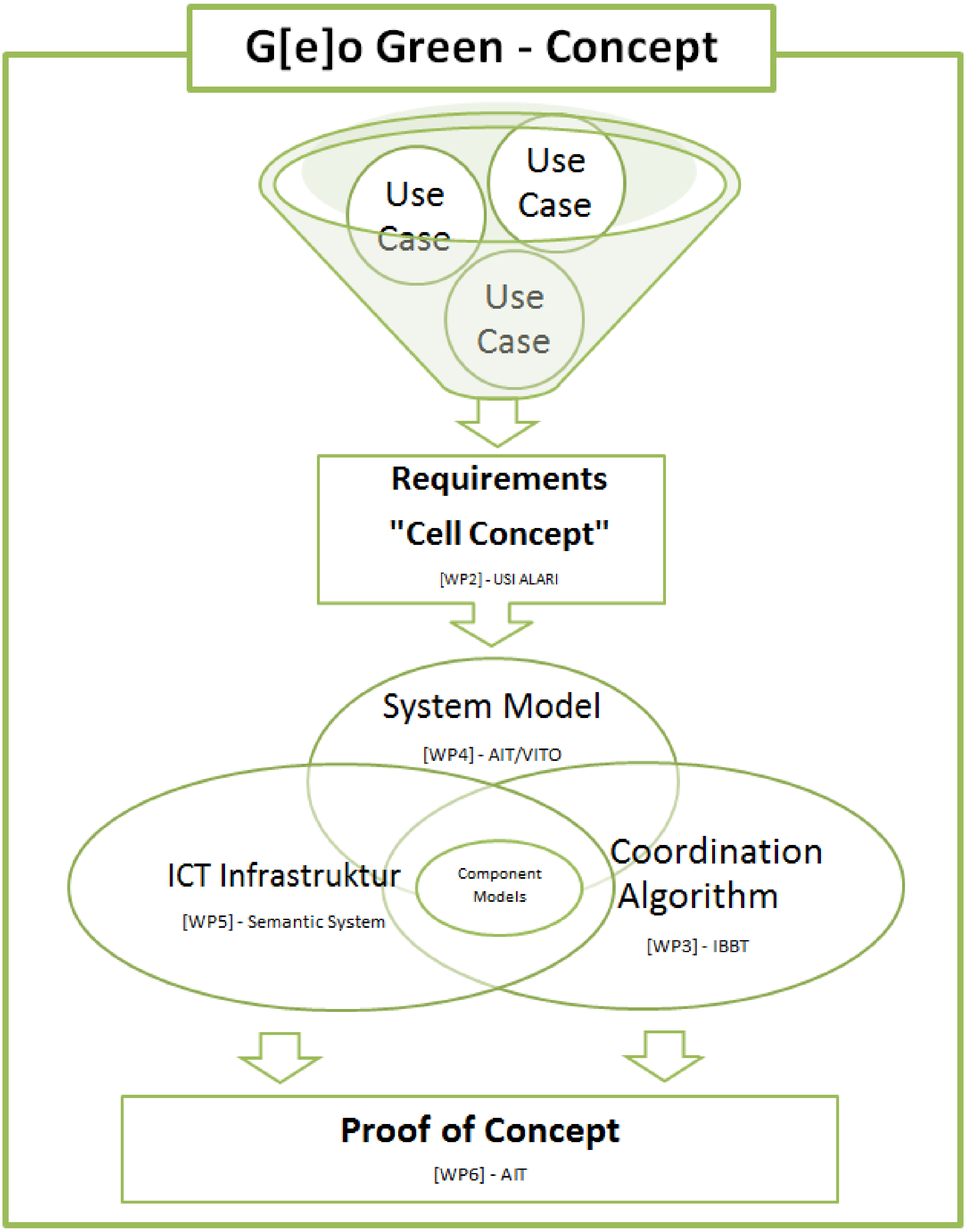

Figure 35 - Project Structure

6.2 G(e)oGreen Work Package overview and description

WP1: Project management (lead = VITO)

The project is led by VITO (Vlaamse instelling voor Technologisch Onderzoek).

WP2: System Requirements and Design (lead = ALaRI-USI)

T2.1: Requirements and Use-Cases

The requirements and Use-cases (general, smart charging and datacenter use case) were defined in cooperation with the whole G(e)oGreen Project team.

T.2.2: System Modeling

A hierarchical set of models was created. The methodology is based on UML (Unified Modeling Language).

WP3: Moveable consumption (lead = IBBT with assistance of VITO)

T3.1: Coordination strategies and algorithms

Mathematical modeling of energy efficient scheduling with geographical shifting; definition of simulator extensions for geographical shifting.

T3.2: Renewable energy profiles

Profiles for PV systems and wind turbines were generated out from statistical weather data from the Upper-Austrian area. The data set also contains temperature data which will be used for WP6.

T3.3: Grid stability

For grid stability analyzing purposes, a simplified electricity network for the simulated use cases and scenarios in WP2 and WP6 was defined.

WP4: Infrastructure and Components (lead = AIT with assistance of TUV ICT)

T4.1: Analysis of energy storages in V2G

Based on a survey of electrical energy storages used in automotive applications, simplified models were defined and built for the purposes in WP6. Furthermore a survey on future technological trends in energy storages for the automotive sector has been performed and their suitability for V2G applications investigated.

T4.2: Analysis of storing energy in buildings

A methodology and a model for simulating (in WP6) and analyzing the potential of storing energy in buildings were developed.

T4.3: Building Management control strategies

A methodology for controlling clusters of buildings without violating customer constrains was developed (based on T4.2).

WP5: ICT architecture (lead = Semantic Systems)

AIT and TU-Vienna take no part in this work package and its tasks.

WP6: Prove of concept (lead = TUV ICT with assistance of AIT)

T6.1: Workability of the system

The results of previous work packages were plugged together in the G(e)oGreen simulation environment. Models and parts of the profiles are set in place.

T6.2: Requirements for demonstration

Based on the use case definition in WP2 a scenario was defined. The area “Upper-Austria” and a simplified model of its medium voltage grid is used for this.

6.3 G(e)oGreen Basic Cell concept

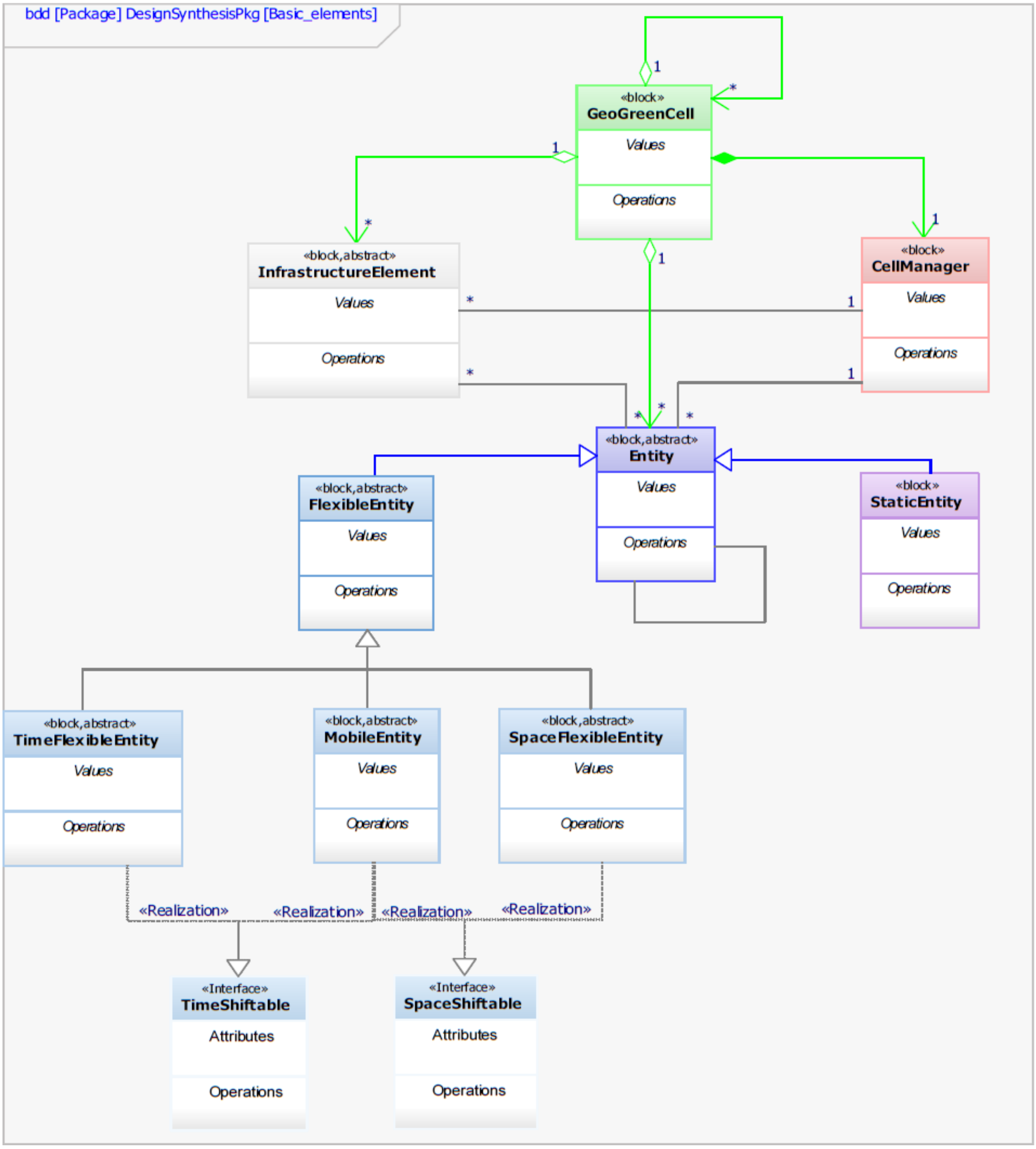

Figure 36 - G(e)oGreen Cell Concept

6.4 PV, wind and housholds profile diagrams

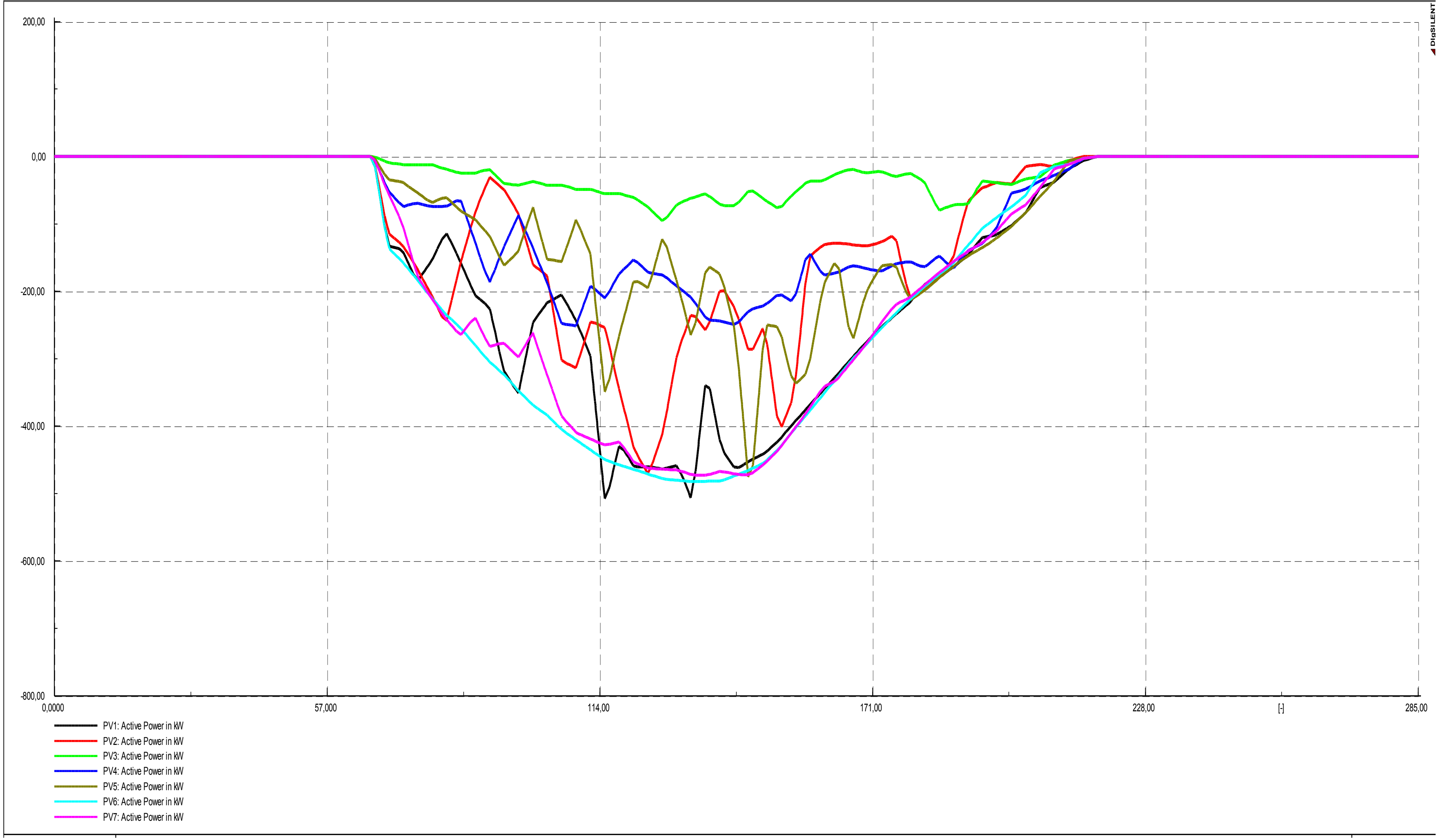

Figure 37 : Solar generation profiles for the node 1...7

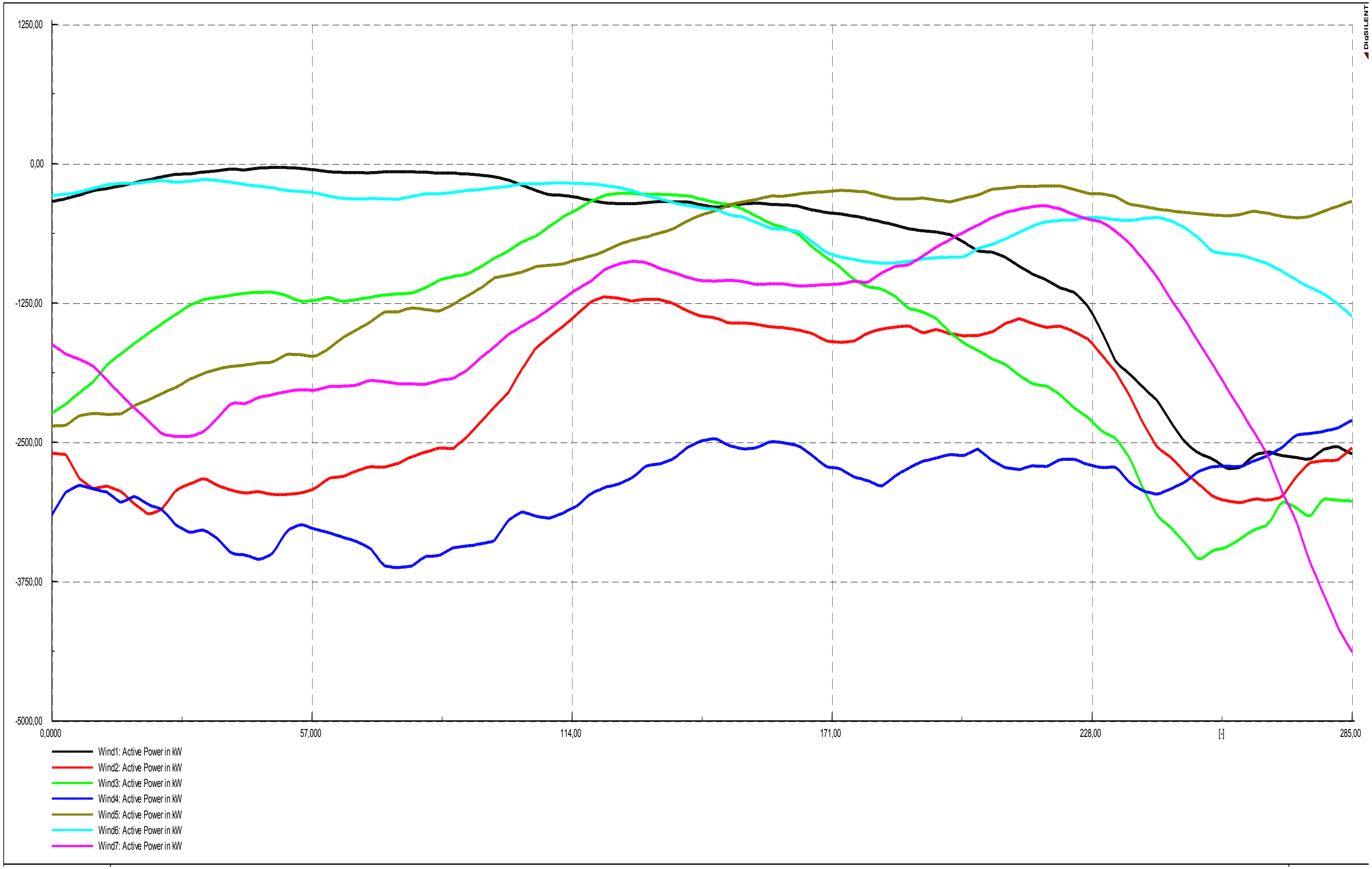

Figure 38 : Wind profiles for the nodes 1...7

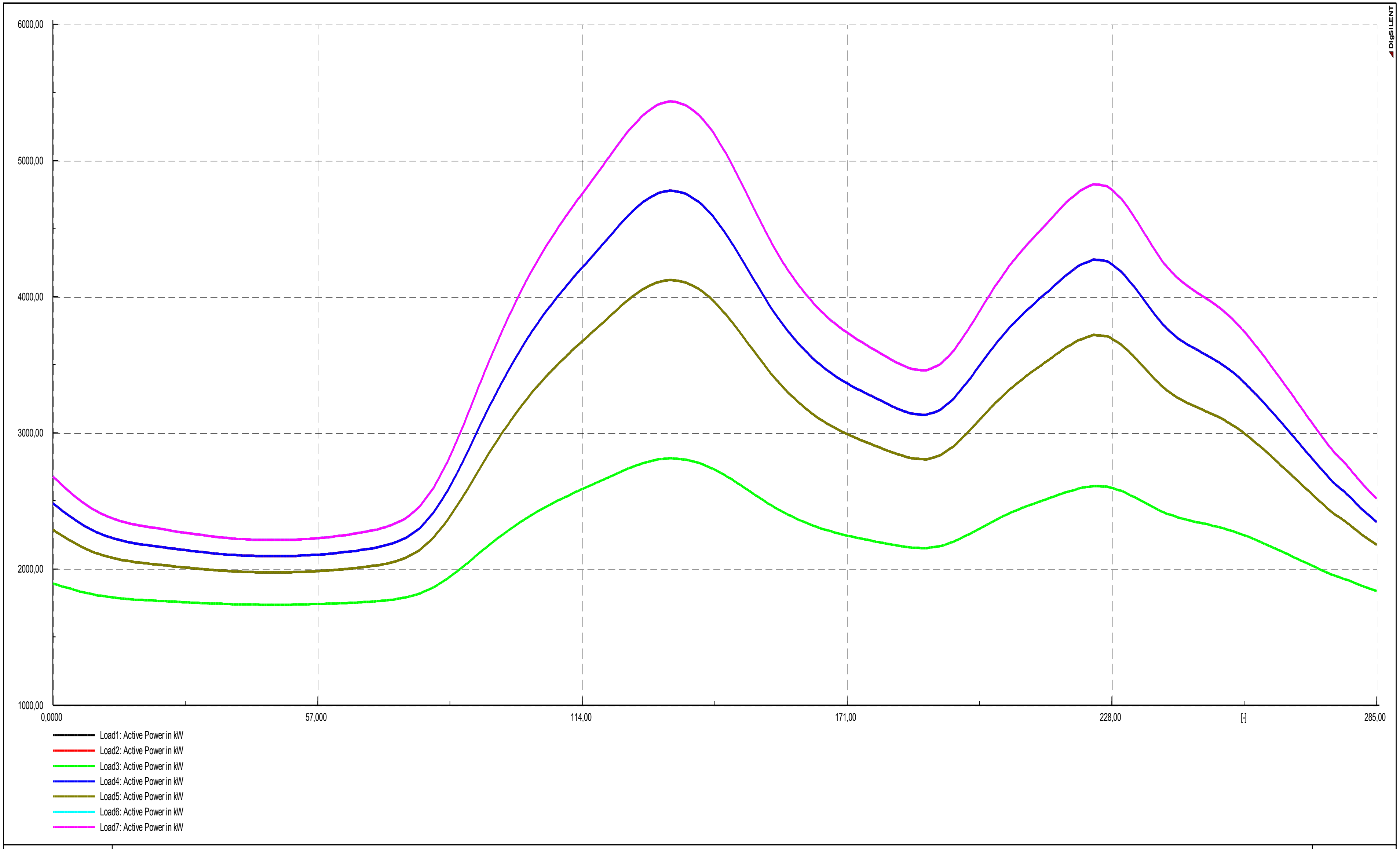

Figure 39 : The H0 loads that are applied to the nodes