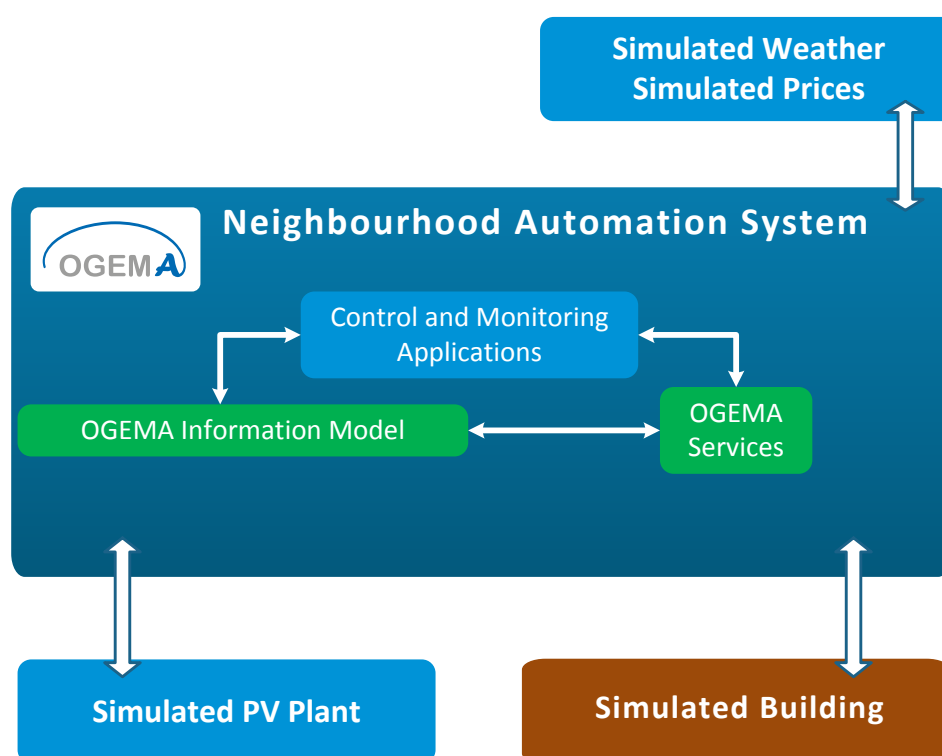


Laboratory Prototype



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Table of contents

1. Publishable executive summary	4
2. Introduction.....	5
2.1 Purpose and target group.....	5
2.2 Contributions of partners	5
2.3 Baseline	5
2.4 Relations to other activities.....	6
3. Laboratory Prototype Architecture	7
4. Specification of the Laboratory Prototype Applications.....	9
4.1 Simulated Weather.....	9
4.2 Building Simulation.....	9
4.3 Simulated Prices	9
4.4 OpenWeatherMap Connector.....	10
4.4.1 The Administrative Interface	10
4.4.2 The Location Interface	11
4.4.3 Retrieving OpenWeatherMap Data.....	11
4.4.4 Solar Irradiance Calculation.....	12
4.5 oBIX Connection Application	12
4.6 Load Prediction	12
4.7 Validation	13
5. Conclusions	16
5.1 Summary of achievements	16
5.2 Relation to continued developments.....	16
6. Acronyms and terms.....	17
7. References	18

1. PUBLISHABLE EXECUTIVE SUMMARY

This report provides documentation of the implemented EEPOS Laboratory Prototype, an extension of the Neighbourhood Automation System (NAS) developed in T2.1 and T2.3. Like the NAS, the Laboratory Prototype is based on the OGEMA framework, which provides a hardware-independent system for energy management software applications. This Deliverable is intended to provide stakeholders and other interested parties with an overview of the individual applications that form the Laboratory Prototype, as well as give suggestions for future extensions made possible by the modularity of the system.

The overall architecture and the necessary data flows of the system are summarized in Section 3, showcasing how the laboratory prototype differs from the base NAS system and the field demonstration setups. Section 4 describes the individual applications that were developed for the prototype, fulfilling the following tasks:

Generating simulated information for setups when external data sources are not available, including:

- Weather forecasts for temperature, wind speed, and solar irradiation
- Consumption forecasts for individual households
- Price information for time-variable electricity prices

Furthermore, OGEMA applications were developed to retrieve external data from the following sources:

- Weather forecast data from the publicly available website OpenWeatherMap
- Data from oBIX servers like the server used in the Finnish field demonstration (T5.2).

The load prediction application which aggregates both electricity consumption and generation for a whole neighbourhood and provides vital information for the optimal load shifting application developed for T2.3 is also detailed.

Additionally, the earlier studies of the impact of the load shifting application that were part of T2.3 have been extended to examine the impact of time-variable electricity prices and the potential cost benefit of load shifting.

2. INTRODUCTION

The purpose of the Laboratory Prototype is to provide a testbed system where simulations of neighborhood-level energy management can be performed without connections to external systems. This system has been successfully installed and run on a server operated by the Fraunhofer IWES (formerly called the "Pool-BEMI", a now obsolete term). The individual applications that make up the Laboratory Prototype are all based on the OGEMA framework and either were initially developed for the Neighborhood Automation System in T2.1 and T2.3, or were new additions developed during this task, providing either simulated data generated locally or accessing additional external data sources.

2.1 Purpose and target group

The purpose of this report is to provide an overview of the requirements needed for an autonomous Laboratory Prototype and detail the additional applications developed for it. It is intended to provide stakeholders and other interested parties with insight into this sample setup, impress upon them the modularity and easy extendibility of the system, and provide inspiration for future extensions for both simulation setups and use in various real world applications.

2.2 Contributions of partners

DERlab e.V. is the lead contractor and responsible for this report. The entirety of this report was written by DERlab.

2.3 Baseline

While ultimately, all energy management systems must prove themselves in the field, each field demonstration requires significant investments, time, and effort. For this purpose, testing energy management systems in a laboratory prototype setup will help identify problems that can be difficult and expensive to compensate for when the system has already been installed in the field. A modular setup for such a laboratory prototype is particularly useful, as each component used in the field can be developed and tested independently and replaced step by step by physical counterparts after the simulations have validated the concept.

Furthermore, not all field demonstration sites have the same range of possibilities. Sometimes, some data sources needed for the overall field demonstration concept are unavailable at a particular site, which can be especially disastrous if this only becomes clear late in the project. In such a case, simulated components can take the place of real components – while not ideal, this can nevertheless prevent overall failure of the field demonstration in question as the components which are available in the field can be combined with simulated versions of the components which aren't.

Finally, this modularity also opens up further possibilities for commercial applications. A commercial product which must invariably contain specific components to work will have a much more limited customer base than one where individual components can be replaced by simulated counterparts – again, while this will perhaps not provide the optimal results, it will often still be better than having no working energy management systems at all.

2.4 Relations to other activities

Primarily, the work in this task was based on the Neighbourhood Automation System specified and developed in Tasks 2.1 and 2.3, and readers are encouraged to refer to the respective Deliverables. Care was also taken to integrate the system with the ongoing work in WP 5 (“Demonstration”). Finally, the User Interface was improved based on feedback gathered during the Usability Study in Task 5.1.

3. LABORATORY PROTOTYPE ARCHITECTURE

While the NAS applications developed in Tasks 2.1 (“EEPOS automation and energy management platform” and 2.3 (“Supervisory and Predictive Control Methods and Applications”) are sufficient to provide adaption requests for the specified field demonstration system, the laboratory prototype must be able to operate independently of the external data sources available for the field demonstration. For this reason, the NAS platform was extended for the laboratory prototype by including a number of new applications that simulate external data sources. Figure 1 shows the architecture and data flows needed for the complete laboratory prototype.

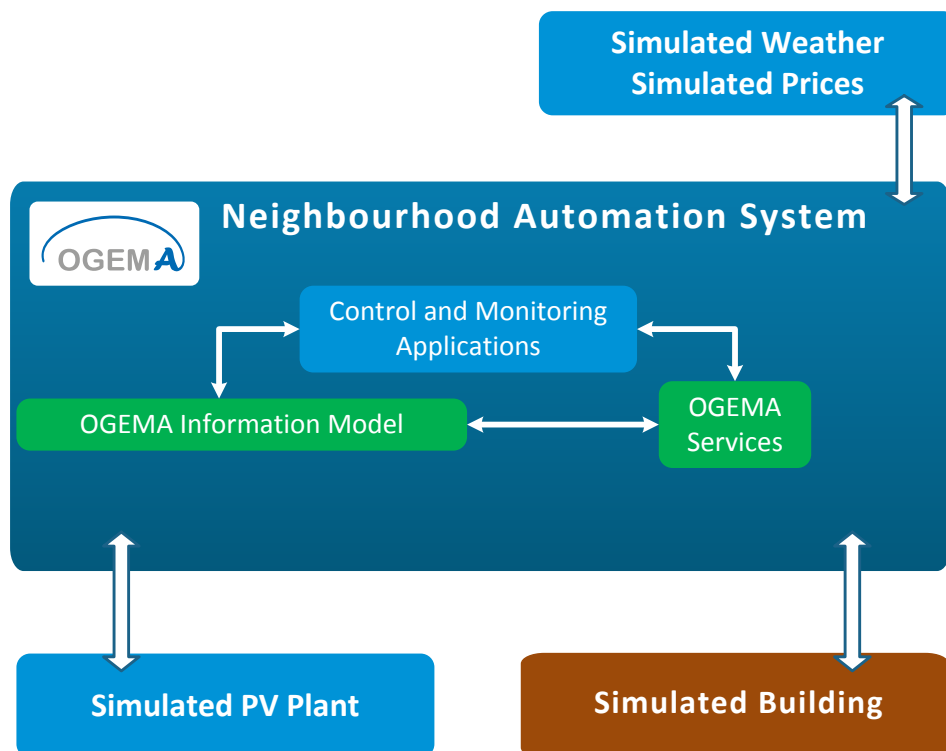


Figure 1. EEPOS Laboratory Prototype architecture and data flows.

In comparison to the architecture of the original NAS platform (compare and contrast with Chapter 3 of D2.1), the following applications were added:

- **Simulated Weather:** As weather data from the field test location is not available, this application simulates outside temperature, outside wind speed, and outside solar irradiation and provides forecast schedules for each.
- **Building Simulation:** Instead of real consumption data from individual households and buildings, this application generates consumption data for a virtual building. Additionally, it can provide a consumption forecast.
- **Simulated PV Plant:** Based on available weather forecast data for solar irradiation and temperature (real or simulated) as well as technical specifications and alignment of the “virtual” PV plant, this application generates a forecast for its electricity generation. The algorithms for this application were described in Section 4.1 of D2.3.

- **Simulated Prices:** As the Optimal Load Shifting Planning Application (described in Section 4.2 of D2.3) can also take variable electricity prices into account in order to optimize energy consumption for times low electricity prices, this application simulates variable prices throughout the day. As currently the only variable price systems available for private electricity consumers are simple, static day/night price differences, the application only generates those. However, if more complex electricity price tariffs become available in the future thanks to the proliferation of smart meters, for instance by taking renewable energy generation forecasts and load prediction into account and calculating new hourly electricity rates for each day in order to optimize load shifting.

Thanks to the modularity of OGEMA, each of the applications can run independently of any other and be added or removed from the system depending on the precise requirements of the system, whether for laboratory demonstration purposes or uses in the field. All that is required is that the various applications make use of the same OGEMA Resources specified in Section 9 of D2.1 (“Appendix 1: Data Models related to NAS Communication”). Some possibilities:

- In a field demonstration setup or in a commercial application, individual households might be unwilling to share their own electricity consumption data out of privacy concerns, or because the households are not equipped with smart meters that can provide detailed information on their consumption patterns. In this case, the Building Simulation application can replace this information, using past load profiles for the whole neighbourhood as a basis for its load prediction schedule.
- If an electricity provider generates its own flexible, frequently changing tariffs and makes these tariffs available via an internet-based interface, these could be imported into OGEMA and used instead of the Simulated Prices application.

Likewise, other data sources could be replaced by their own specialized apps for individual applications. Two such applications were developed during this Work Package:

- **OpenWeatherMap Connector:** This application can replace the Weather Simulator. It allows the import of weather data from the public website OpenWeatherMap[1]. The administrator can set a town and country as well as the local time zone, and the application will retrieve the forecast for temperature, cloud cover, and wind speed, and derive a forecast for solar irradiation.
- **oBIX Connection App:** This application allows retrieving information from and submitting information to oBIX servers, such as these used at the Finland demonstrator.

Finally, the following application is described here:

- **Load Prediction:** This application keeps track of all electricity consumers and producers in the neighbourhood, and aggregates the information into presumption forecast schedules that are used by the Optimal Load Shifting Planning Application (see Section 4.2 in D2.3).

4. SPECIFICATION OF THE LABORATORY PROTOTYPE APPLICATIONS

All OGEMA applications listed here make use of the data models and OGEMA resources listed in Section 9 / Appendix 1 of D2.1 (“Data Models related to NAS Communication”).

4.1 Simulated Weather

This application creates OGEMA resources for the outside temperature, wind speed, and solar irradiation in the form of forecast schedules and fills them with data from CSV files packed with the application bundles. For the demonstrator, temperature values from 2012 Kassel and average solar irradiation and wind speed values for Germany were used, although of course the CSV files can be swapped for any other weather data with the same format. These generated OGEMA resources and the data stored within them can then be used by other OGEMA applications with the appropriate access rights (which are all other EEPOS applications, in this case.) The OGEMA resources have the following names:

- TemperatureSensor
- WindSensor
- SolarIrradiationSensor

The term “Sensor” is a generic OGEMA term for any information about the physical world, and does not imply the presence of an actual sensor connected to the running system. The reason for this is that in some cases the information might come from a physical sensor, and in some cases might be merely a simulated or derived value. However, other applications using this information – such as the optimal load shifting planning application described in D2.3 – should work whether or not the information comes from a real or virtual source. All that matters for the purpose of the application is that the resource is available within the OGEMA Framework and follows the right data model.

4.2 Building Simulation

Upon initialization, this application first searches for buildings created by the central management application. For each detected building, a simulated building object is created. In turn, a simulated “electricity meter” (“ElMeter”) is attached to each simulated building, which is filled with a forecast schedule for the electricity consumption for that building. A standard load profile is used to fill the consumption schedule.

4.3 Simulated Prices

This application generates an “ElPrice” Resource for the entire neighborhood containing the individual buildings of the Building Simulation. For the demonstrator, two different prices are used for day and night tariffs. However, due to the modular nature of OGEMA and its applications, it would be no problem to introduce more complex tariff systems – including flexible tariffs that change daily depending on forecasts for electricity consumption and production. The other applications that depend on the price data (in particular the load shifting planning application described in D2.3) could use such complex pricing systems as well without malfunctioning, thanks to the standardized data models and data schedule system of OGEMA.

4.4 OpenWeatherMap Connector

This application is intended to retrieve weather data from any location in the world. As part of the Usability Study (Task 4.5), the interface of the OpenWeatherMap Connector received significant overhaul in order to improve its user friendliness.

4.4.1 The Administrative Interface

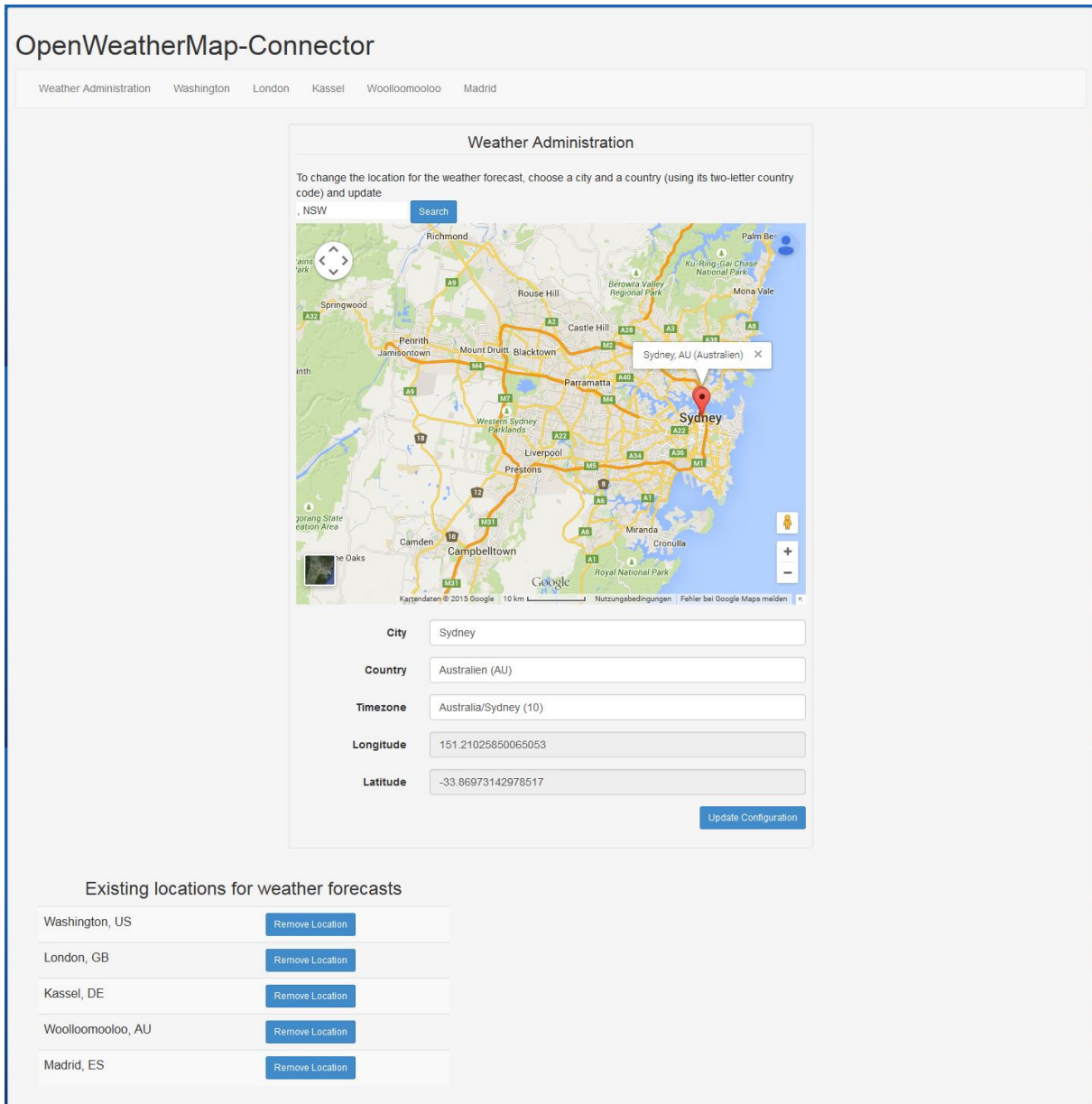


Figure 2 - Weather Administration interface of the OpenWeatherMap-Connector

For adding a new location, administrators can either type in the city and country for the location, or choose a spot on a world map. This map is based on the Google Maps API, and thus retrieves the map information online. Additionally, the user has to pick the time zone for the location (as automatically detecting the time zone would have been too complex to implement within the context of the project). From this input, the latitude and longitude of the location are automatically derived, which are used to retrieve the weather data from OpenWeatherMap.

Furthermore, the administrative interface shows a list of locations already submitted to the system, as well as the option to delete them.

4.4.2 The Location Interface

The Location interface displays current and forecast information for each location currently subscribed to by the OpenWeatherMap-Connector. Each subscribed location has its own tab. The interface shows the current temperature, windspeed and direction, cloud cover, pressure, humidity, time of sunrise and sunset for the current day, geographical location, sun elevation, and solar irradiation (a derived value, not one retrieved from OpenWeatherMap), and shows forecast information for cloud cover, irradiance, windspeed, temperature, and sun elevation.

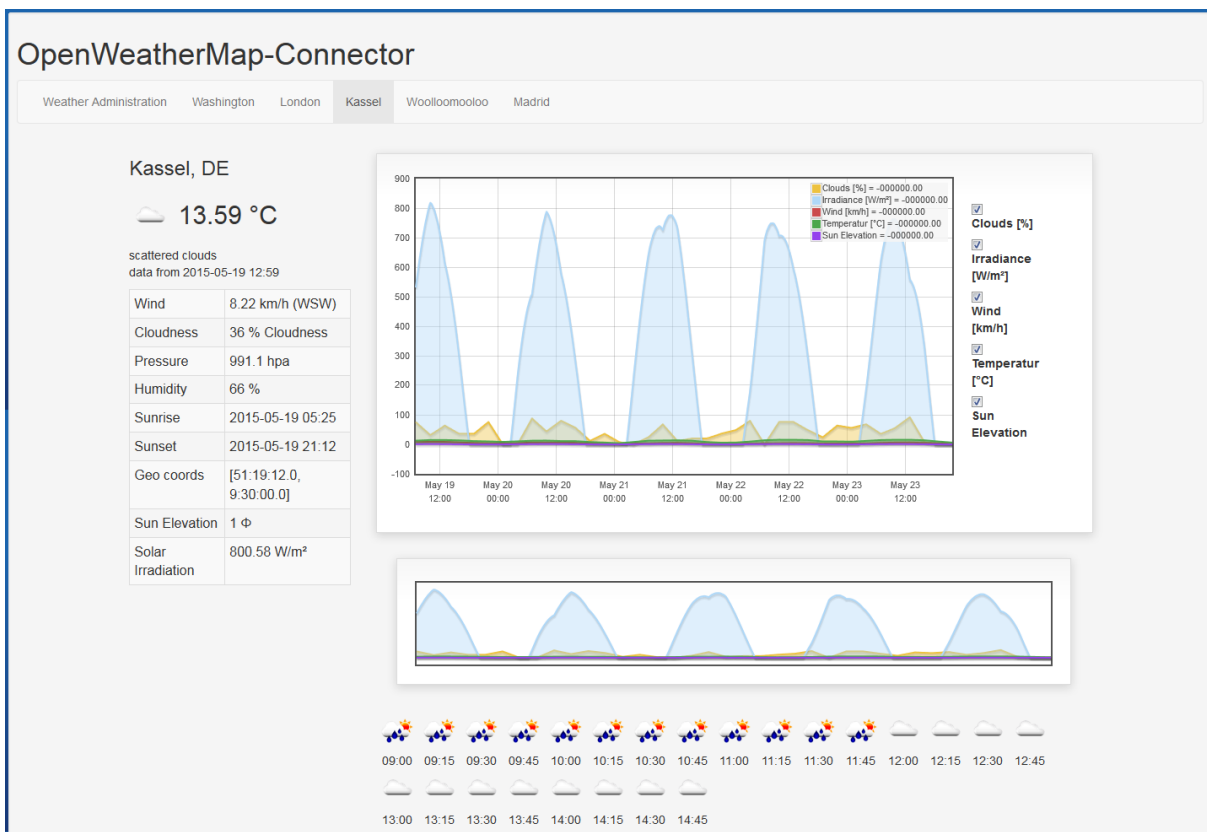


Figure 3 - Location Interface of the OpenWeatherMap-Connector.

4.4.3 Retrieving OpenWeatherMap Data

Data from OpenWeatherMap can be retrieved via the OpenWeatherMap API[2], which makes weather data available via a simple Internet-based interface. For instance, the following URL would provide current weather data for Langenfeld, Germany:

[HTTP://API.OPENWEATHERMAP.ORG/DATA/2.5/WEATHER?Q=LANGENFELD,DE](http://api.openweathermap.org/data/2.5/weather?q=Langenfeld,DE)

and return data for the current weather in the following format:

```
{ "COORD": { "LON": 6.95, "LAT": 51.1 }, "SYS": { "MESSAGE": 1.5615, "COUNTRY": "DE", "SUNRISE": 1430366782, "SUNSET": 1430419945 }, "WEATHER": [ { "ID": 501, "MAIN": "RAIN", "DESCRIPTION": "MODERATE RAIN", "ICON": "10N" }, { "BASE": "STATIONS", "MAIN": { "TEMP": 280.914, "TEMP_MIN": 280.914, "TEMP_MAX": 280.914, "PRESSURE": 1002.73, "SEA_LEVEL": 1024.78, "GRND_LEVEL": 1002.73, "HUMIDITY": 100 }, "WIND": { "SPEED": 2.79, "DEG": 262.504 }, "CLOUDS": { "ALL": 92 }, "RAIN": { "3H": 4.5625 }, "DT": 1430421220, "ID": 2881085, "NAME": "LANGENFELD", "COD": 200 } ] }
```

while the following URL will provide a forecast schedule for the same location

[HTTP://API.OPENWEATHERMAP.ORG/DATA/2.5/FORECAST?Q=LANGENFELD,DE](http://api.openweathermap.org/data/2.5/forecast?q=Langenfeld,DE)

The OpenWeatherMap Connector app retrieves this information and saves it as OGEMA Resources. While only geographical location ("COORD"), temperature ("TEMP"), and cloud cover ("CLOUDS"), and time ("DT") are needed for the current laboratory prototype, the other information is stored in OGEMA as well to facilitate future expansion – for example, wind speed and angle ("WIND": "SPEED"/"DEG") could be used to create wind power generation forecast apps similar to the current Simulated PV Plant application and factor this into load shifting adaption requests as well.

4.4.4 Solar Irradiance Calculation

In order to calculate the solar irradiance for any geographical location based on the time and cloud cover, the sun elevation angle β_{sun} must be calculated first. The process for this is described in Section 4.1.1.2 of D2.3.

As the approximate maximum solar irradiation at the ground level while the sun is at its zenith is equal to 1066 W/m², and full cloud cover reduces this to 752 W/m², the following approximation was used for the irradiation ($S_{Surface}$) forecast:

$$S_{Surface} = (1066 \text{ Wm}^2 - \text{cover} * 314 \text{ Wm}^2) * \sin \beta_{sun}$$

with “cover” being the cloud cover percentage.

4.5 oBIX Connection Application

The Finnish demonstrator stores information via an oBIX-based server, which can be accessed via a secure login. The OGEMA oBIX Connection app can execute this login and retrieve data to which the login account has been granted access. oBIX data is retrieved in an XML format:

```
<OBIXLIST>
  <LIST OF: /DEF/OBIXLISTENTRY>
    <OBJ NAME="141812460000" IS="/DEF/OBIXLISTENTRY">
      <STR NAME="QUALITY" VAL="GOOD"/>
      <ABSTIME VAL="2014-12-343T11:30Z"/>
      <REAL NAME="VALUE" VAL="-1.0"/>
    ...
  </OBJ>
```

This data is retrieved by OGEMA and stored as OGEMA system resources. Likewise, data from OGEMA can be stored on the remote oBIX server.

4.6 Load Prediction

This application generates lists of all buildings and all PV plants in the neighborhood – both simulated and real, as field setups might require using both, and the Resource data models of both are identical. These are kept up-to-date by OGEMA and are appended whenever a new building or PV plant is registered or an old one is removed.

From these lists, power consumption and production lists for the entire neighborhood are created. These are then retrieved by the Optimal Load Shifting Planning Application (detailed in Section 4.2 of D2.3) in order to identify electricity shortages and times of electricity abundance so that adaption requests can be made for load shifting purposes.

4.7 Validation

To recap the validation studies described in section 4.2.2 of D2.3 (Supervisory and predictive control methods and applications), five scenarios for load shifting were examined that shave times of peak production and consumption depending on the available load shifting capacity. The load shifting capacity ranged from 0% in Scenario #1 and increased by 2.5% in each successive scenario, up to 10% in Scenario #5.

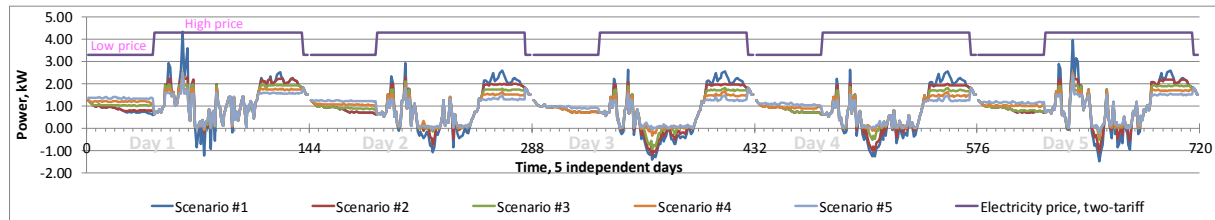


Figure 4- Residual load shifting and electricity price

As described in the Deliverable, the Optimal Load Shifting Planning Application also takes variable electricity prices into account. For these studies, a simple day-night tariff model was chosen (reflecting tariff systems offered by some German electricity providers), with a “high” day time tariff for the period from 6:00 to 22:00, and a “low” night time tariff from 22:00 to 6:00.

Not yet discussed were the actual price levels of the day time and night time tariffs. These price levels are of critical importance since they provide the incentive for the consumers to agree to participate in load shifting in the first place, as even fully automated energy management systems will require additional effort for electronics and software management, and manual management will require some sort of compensation for the added inconvenience of delaying consumption of electricity to different time periods.

For this reason, the effects of four different price levels were studied. Tariff #1 represents a tariff model currently in use in Germany, with a night tariff of €0.25/kWh and a day tariff of €0.30/kWh. For each subsequent tariff, the price difference between day and night periods was increased by €0.06:

	Day Tariff in €/kWh	Night Tariff in €/kWh
Tariff #1	0.30	0.25
Tariff #2	0.33	0.22
Tariff #3	0.36	0.19
Tariff #4	0.39	0.16

Table 1 - Variable electricity pricing for grid users

It was also assumed that each household had its own PV panels (as described in D2.3) and made use of a feed-in-tariff of €0.13/kWh (2014 values for Germany).

The following figure shows how the different tariffs show different average daily electricity costs for the grid users, depending on the load shifting capacity as outlined in the various scenarios described earlier:

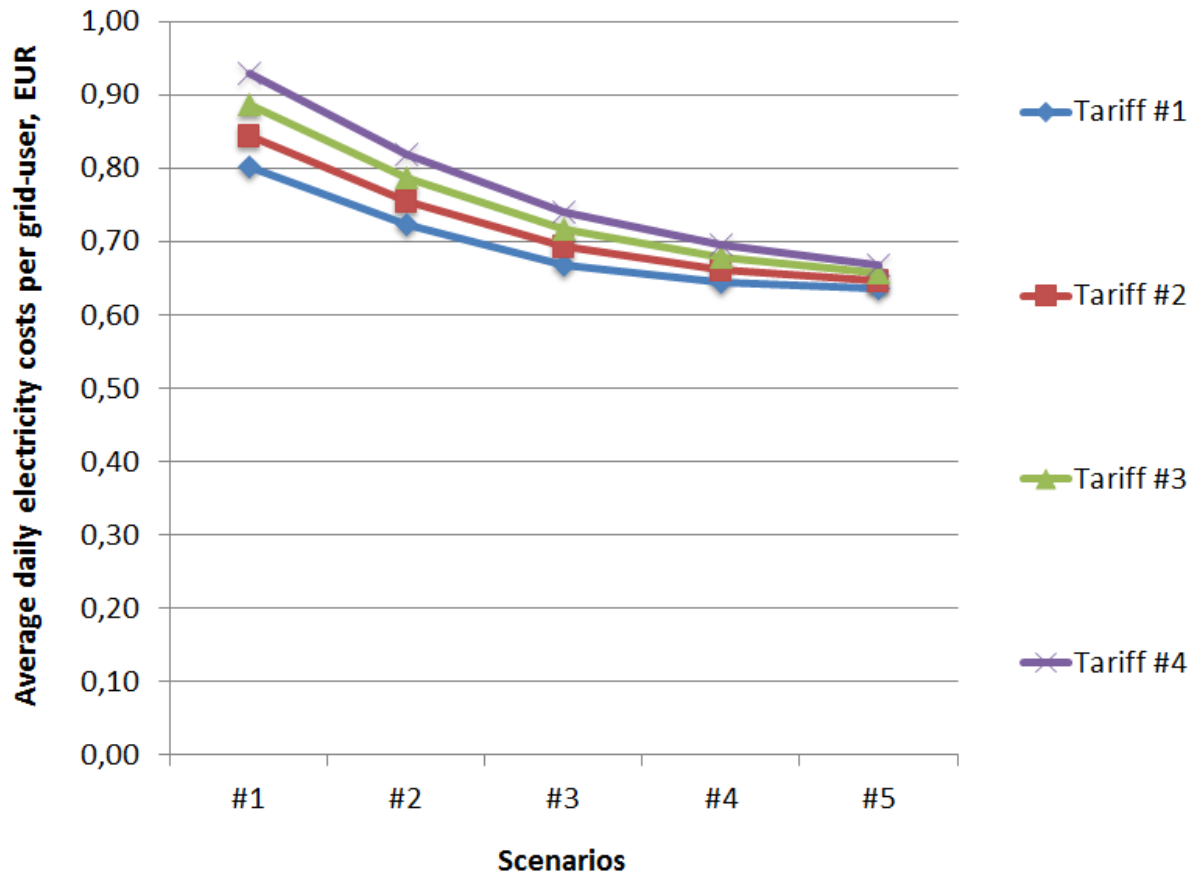


Figure 5 - Average daily electricity costs depending on tariffs and load shifting scenario, with PV production

Even a small amount of load shifting capacity can result in a large percentage reduction in the electricity cost – Scenario #2 in combination with Tariff #1 reduces the daily electricity cost from €0.80 to €0.72. A further increase in load shifting capacity leads to diminishing returns, however, with Tariff #1 reaching a minimum of €0.63 per day for 10% load shifting capacity (Scenario #5).

If the day and night tariffs diverge more, the potential savings derived from load shifting become greater. For Tariff #4, the daily cost plummets from €0.93 for zero load shifting to €0.67 for 10% load shifting. The individual daily costs can be seen in the following table:

	0% load shifting	2.5% load shifting	5% load shifting	7.5% load shifting	10% load shifting
Tariff #1	€0.80	€0.72	€0.67	€0.64	€0.64
Tariff #2	€0.84	€0.75	€0.69	€0.66	€0.65
Tariff #3	€0.89	€0.79	€0.72	€0.68	€0.66
Tariff #4	€0.93	€0.82	€0.74	€0.69	€0.67

Table 2 - Daily electricity costs based on load shifting and variable tariffs.

While the percentage savings can be significant, the total amount of savings must be taken into account – since energy management systems will cost money, the savings accumulated through automated load shifting must be large enough to compensate for the cost. Likewise,

the savings accumulated from manual load shifting by the individual users must be large enough to be worth the added inconvenience. The use of smart meters could allow for more complex pricing systems, such as increasing prices during short-term electricity production shortfalls while drastically reducing prices during times of excess production instead of the simple two-tariff system used here. However, given the scale of the savings described above, such smart meters must be either fairly cheap to purchase and install or be in use for a long time before there is a financial benefit to the user.

5. CONCLUSIONS

The Laboratory Prototype provides an extension of the Neighbourhood Automation System platform which can work independently of external input. Moreover, the modularity of the OGEMA framework makes it possible to switch individual applications of both the NAS and the Laboratory Prototype in and out, thus allowing for field demonstrations and commercial applications to work even when specific external data required for the base NAS setup are unavailable.

Furthermore, earlier studies were extended to show the financial impact of both load shifting and time-variable electricity prices, indicating that the price differences between day and night tariffs should be maximized to provide financial incentives for load shifting.

5.1 Summary of achievements

In this deliverable, several applications have been developed which can generate simulated data replacing external data required for the base NAS setup:

- Simulated Weather application
- Building Simulation application
- Simulated Prices application
- Load Prediction application

Furthermore, two applications have been developed which provide optional external data from two further sources:

- OpenWeatherMap Connector
- oBIX Connection application

Finally, earlier studies were extended to study the impact of a simple time-variable tariff system on the cost savings for individual households.

5.2 Relation to continued developments

The OpenWeatherMap connector will provide weather information for the field demonstration version of the NAS in WP5. The simulation applications also provide data for the field demonstrations where local measurement data was not available

Furthermore, a server running the laboratory prototype has also been used to provide adaption requests for WP5 has also been used for the Usability Study in T4.5. The feedback received from the Usability Study has been used to improve the administrative interface of the Neighborhood Automation System, including the laboratory prototype version.

6. ACRONYMS AND TERMS

- EEPOS.....Energy management and decision support systems for Energy POSitive neighbourhoods
- NAS.....Neighborhood Automation System.
- oBIX.....Open Building Information Xchange
- OGEMA.....Open Gateway Management Alliance
- Pool-BEMI.....Server running an installation of OGEMA which can exchange data with external systems. Obsolete term.

7. REFERENCES

- [1] <http://openweathermap.org/>, retrieved on April 30, 2015.
- [2] <http://openweathermap.org/api>, retrieved on April 30, 2015.
- [3] <http://www.obix.org/>, retrieved on April 30, 2015.