D5.3
Description of implemented toolset for aggregator

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EcoGrid 2.0 is a research and demonstration project funded by EUDP (Energiteknologisk Udviklings- og Demonstrationsprogram). The 9 partners in the project are:

Main Authors:

Name/Partner	Email
Peter Buhler/IBM	bup@zurich.ibm.com
Dorothea Wiesmann	dor@zurich.ibm.com

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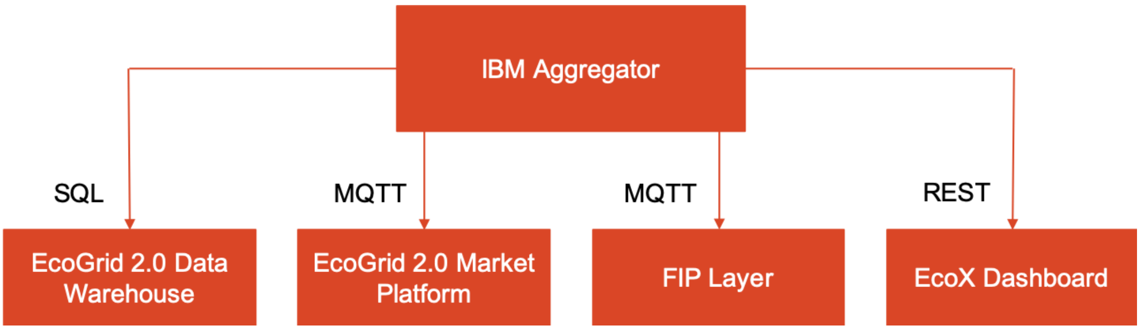
1 Aggregator Architecture

An aggregator is controlling the Distributed Energy Resources (DERs) and is offering their combined flexibility towards the EcoGrid 2.0 market platform. It is a bridge between the households and the power system; this new actor pools flexible power consumption from hundreds of households and sells it on the electricity market. The goal of an aggregator is to maximize the value of the flexibility provided by the DERs while respecting the specified participant requirements as user comfort, etc. The IBM aggregator is a software system connected to the EcoGrid 2.0 data warehouse maintaining all household data, to the EcoGrid 2.0 Market Platform or flexibility trading, to the Flexibility Interoperability Platform (FIP) providing interfaces to control the heating systems of the households, and to the EcoEx repository maintaining the status of the planed and performed experiments.

The flexible aggregator architecture with clearly defined external dependencies allows for an efficient deployment in the private cloud as well as in the public cloud environment: the deployments in IBM Public Cloud (Bluemix) and IBM Private Cloud were performed and tested during the project. In the demonstration period of the heating season 3 the IBM aggregator software was deployed on IBM Private Cloud which allows extensive monitoring of the execution of all aggregator components; the services required by the aggregator software package were accessed through secure communication interfaces using the authorization credentials of the EcoGrid 2.0 system components.



IBM Aggregator Interfaces

1.1 Control of Flexibility and Forecast

The EcoGrid 2.0 data warehouse offers a SQL interface to access the stored data. For the information about the managed households the aggregator is using the following tables of the data warehouse: eg_household, eg_household_log, eg_ecosphere_installations, eg_participants_survey. For each participating household the records of these tables provide the aggregator with information on the type of the household, the type of its heating systems (Heat Pump, Electric

Heating), the type of the installed control infrastructure (Green Wave Reality, Siemens), etc. They also specify the product selected by the household (Basic, Economy, Environmental) and by which aggregator the household is currently managed (IBM Aggregator, Insero Aggregator, Insero Replication Aggregator). The information on electric energy consumption and generation resides in the eg_lg_meter_data table. For weather data meteoblue_weather table is used, for carbon intensity data electricity_co2 table is used, for electricity price data the electricity_prices table is used. The aggregator reads all the available data in the setup phase to build up its knowledge base. Afterwards, the knowledge base is updated daily by retrieving new and changed data from the data warehouse.

1.2 Trading on the Market Platform

For trading of the flexibility of the managed households the aggregator uses the MQTT publish/subscribe communication interface of the EcoGrid 2.0 market platform. The market product interfaces are specified through JSON data structures which makes the exchanged messages readable and easy to understand, the market interfaces and products are defined in the deliverable D3.1.2 Marketplace Interface Specification. The use of standards as MQTT protocol and JSON data representation format enabled effective integration of market interfaces. The aggregator subscribes on the MQTT broker used by the market platform to receive notification messages on the opened TSO (AsyncBlockBid) and DSO markets.

The aggregator offering strategy defines at which point of time the available flexibility of a household is used in the offers for the market requests. Furthermore, the offering strategy defines how to prioritize the market request and determines the pricing of the offered services. In the heating season 3 the aggregator strategy tool performed the coordination of TSO and DSO market requests as well as the activations of the environmental CO_2 reduction aggregator product and manual tests.

For an opened market the aggregator evaluates its available flexibility resources in the requested activation time periods and takes a bid/no-bid decision based on its bidding strategy. To send an offer to the market the MQTT publish interface of the market platform is used. If an aggregator offer is accepted by the market, it receives a contract message from the market platform which initiates the flexibility activation planning for the contracted service.

1.3 CO_2 Reduction Product

The environmentally friendly CO_2 product is targeted for household customers with a high priority on the environment. This product contains the basic features (the flexibility of the household will be uses for balancing of demand / response) as well as the optimization of the energy consumption based on CO_2 emissions. The level of energy production that comes from renewable energy depends on the weather conditions such as wind and sunshine. At times with a low energy production from renewable sources, a larger percentage of the energy is produced by traditional powerplants leading to a higher CO_2 emission. This level fluctuates during a day.

The aggregator provides an environmental product focused on CO_2 emission reduction; for the households registered for this product the aggregator regularly performs activation planning of the CO_2 reduction service. The CO_2-Intensity forecast data for Bornholm was used to plan the activations. This data is retrieved from the electricity_co2 table stored in EcoGrid 2.0 data warehouse. Every day the CO2-Intensity forecast for the coming day is obtained from EcoGrid 2.0 data warehouse by the aggregator. The resolution of the available CO_2-Intensity data is one hour. The activation of the product is planned for a period of one hour reflecting the resolution of the forecast data. The aggregator schedules the product activation for an hour of high CO_2 intensity ideally followed by an hour of low CO_2-Intensity to accommodate for rebound following the response of a load reduction.

1.4 Load Reduction Scheduling

The aggregator manages the repository of scheduled load reduction requests (Load Reduction Request Queue); a registration of such a request is initiated as a result of an accepted TSO market offer, an accepted unconditional DSO market service, a CO_2 product activation, or a manual test plan. The aggregator executes the scheduled load reduction request at the specified point of time by switching-off the heating systems of the specified set of households; after the activation period the heating systems are switched-on to automatic again.

The lifecycle status of each planned flexibility activation needs to be registered on the EcoEx platform: https://ecoex.ecogrid.io. EcoEx is a service built to coordinate experiments during EcoGrid 2.0 testing and operation. It provides a RESTful HTTP API to manage experiments, and a dashboard to show the lifecycle status of the experiments. An EcoGrid 2.0 experiment is represented by a JSON data structure specified in the EcoEx API specification. The aggregator uses this interface to provide detailed information on each planned flexibility activation (households used by the service, start time and duration, expected response and rebound volumes, etc.) as well as to update the lifecycle status of a scheduled flexibility activation, which can be planned, started, stopped, or cancelled.

To execute the flexibility activations, the heating systems of the households needs to be controlled by the aggregator. The services to switch off/on a heating system and to retrieve its current state are provided by the Flexibility Interoperability Platform (FIP). The FIP is a system built for EcoGrid 2.0; it provides interoperability between aggregators and home energy management systems, also called distributed energy resources (DERs). It enables aggregators to talk to DERs managed by Green Wave Reality and Siemens using the EcoGrid 2.0 interoperability protocol. The FIP interface is based on MQTT publish/subscribe communication and JSON data representation format: to issue commands to DERs the aggregator publishes FIP MQTT messages with JSON payload specifying the commands to be performed, to receive the responses from FIP the aggregator subscribes to the FIP MQTT messages.

1.5 Conditional Load Reduction

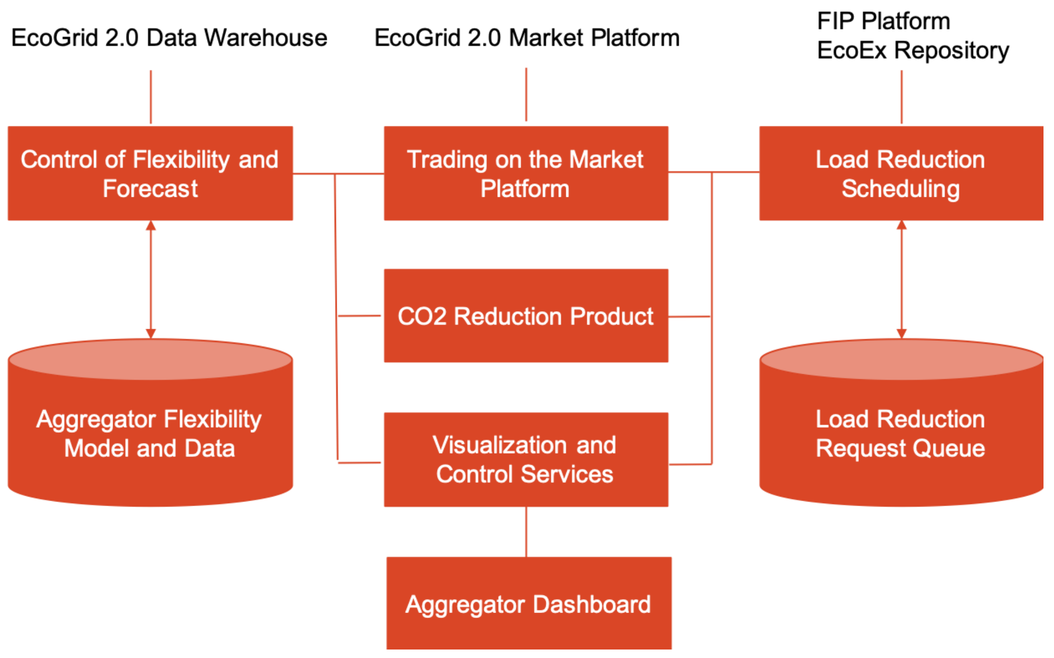
EcoGrid 2.0 introduced the concept of conditional services which are bought in advance but need to be explicitly activated before schedule if they are needed. The aggregator manages the repository of conditional load reduction services. A conditional load reduction service request is generated based on an accepted conditional DSO market service. It will be scheduled for execution if the aggregator receives from the market platform the corresponding activation notification message; in this case this service will be treated similarly to a scheduled load reduction and executed at the specified point of time.

1.6 Visualization and Control Dashboard

The aggregator software package contains an HTTP server to provide an interactive HTML based graphical user interface for visualization of its data and operations as well as for its configuration management. This dashboard interface is used to visualize the knowledge base of the aggregator, its derived household consumption flexibility models, and the information on the performed and planned flexibility activations. Many of the configuration parameters for the aggregator setup and operation can be controlled through the dashboard. Furthermore, the dashboard interfaces offer functionality to manually plan and execute load reduction activations on a selected set of households.

1.7 Aggregator Functional Components

The figure below shows the major aggregator functional components and its external interfaces. This set of closely integrated components compose the aggregator software package which is interfacing the following EcoGrid 2.0 services: EcoGrid 2.0 Data Warehouse, EcoGrid 2.0 Market Platform, EcoGrid 2.0 FIP Platform, and EcoGrid 2.0 EcoEx Repository.

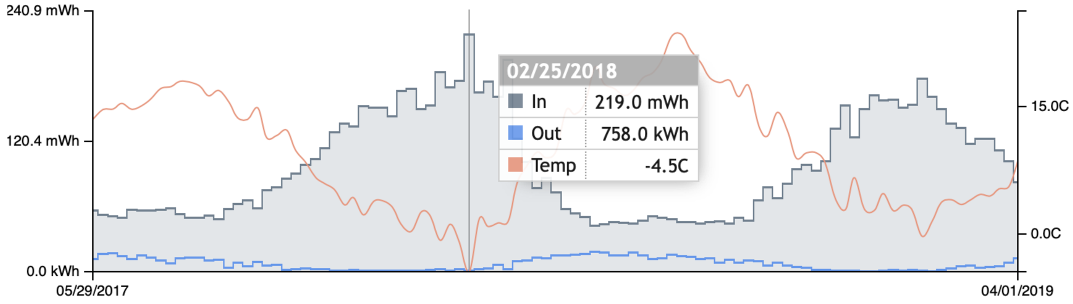


Aggregator Functional Components and External Interfaces

2 Aggregator Model Setup

2.1 Aggregator Data Sources

In the setup phase the aggregator reads and processes the information on managed households and on power consumption and generation of these households stored in the EcoGrid 2.0 data warehouse as well as the temperature and the weather forecast data for the region. This information is used to build and refine a model of power consumption for each individual household managed by the aggregator. The electricity consumption models for heating season 3 were built based on about 32 GB of measurement data collected starting from October 2016.



Electricity consumption and generation of EcoGrid 2.0 households and temperature data.

The figure above shows the electricity consumption of all EcoGrid 2.0 households since June 2017: grey filled area in MWh with one-week resolution. The blue line shows the output power generated by these households and the red line the average outside temperature on the Bornholm island. In this picture one can clearly see the correlation between outside temperatures, sunshine, and energy consumed and generated. The difference in energy consumption in winter and summer is mainly due to the electricity consumption of the heating systems.

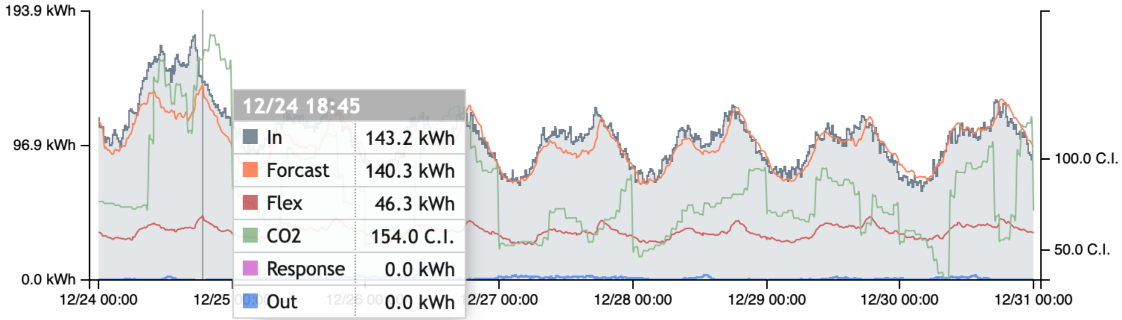
2.2 Aggregator Forecast Generation

Following the data cleansing step inspecting the measurement data to remove incorrectly captured and incorrectly recorded values, the aggregator autonomously learns the behavior of registered households and estimates the amount of electricity consumption flexibility an individual household can potentially contribute at any point of time depending on the past household consumption patterns and outside temperature; for heating season 3 the aggregator only used these two data sources to forecast the consumption flexibility of a household. A number of statistical and machine learning methods are used in this data driven process.

The methods developed and evaluated in heating season 2 for households with heat-pump heating systems [Mueller, F. L., & Jansen, B. (2017). Autonomous estimation of the energetic flexibility of buildings. *American Control Conference* (pp. 2378-5861). Seattle: IEEE] were deployed, extended, and complemented with methods for households with electric heating. The more historic data for a household is available the better model can be developed. The models are validated and tuned based on samples of historical consumption data reserved for the validation purpose. The current model is using a small set of data sources (electricity consumption and outside temperature) and provides a reference for development and validation of extended models utilizing additional household related information.

The aggregator creates a model of energy consumption for each individual household based on historical household electricity consumption patterns and outside temperature. This model is used to estimate the amount of flexibility an individual household can contribute at a specific point of time depending on the weather forecast. To deliver a service to the market the aggregator combines the flexibility forecasts from the available households. The results show that accurate flexibility estimations are performed by the aggregator for a larger set of households; the average load reduction can be predicted accurately with a median error of 6.7%.

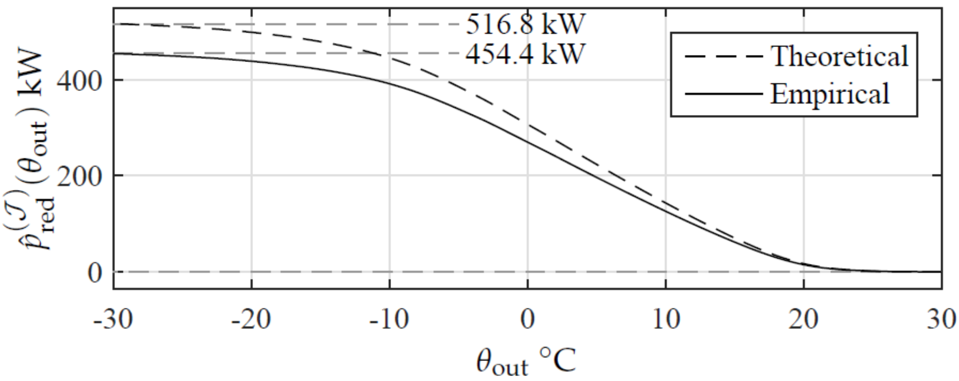
In the EcoGrid 2.0 demonstration setup, the households managed by an aggregator are using heat pumps, electric heating, or both. In many cases alternative heating methods are also used at the same time additionally. Many of the households are furthermore equipped with electricity generating equipment. Taking all this into consideration makes an accurate estimation of flexibility that an aggregator can obtain from controlling only one major heating system in a household very challenging. On the other side, such a setup requires minimal intervention and installation of infrastructure in the participating households. One key goal of the experiments performed in heating season 3, from the aggregator toolset development perspective, was to validate to which level the estimated electricity consumption flexibility of a set of households corresponds to the actual response obtained from controlling the major heating system in these households continuously over longer period of time.



Aggregator forecast data

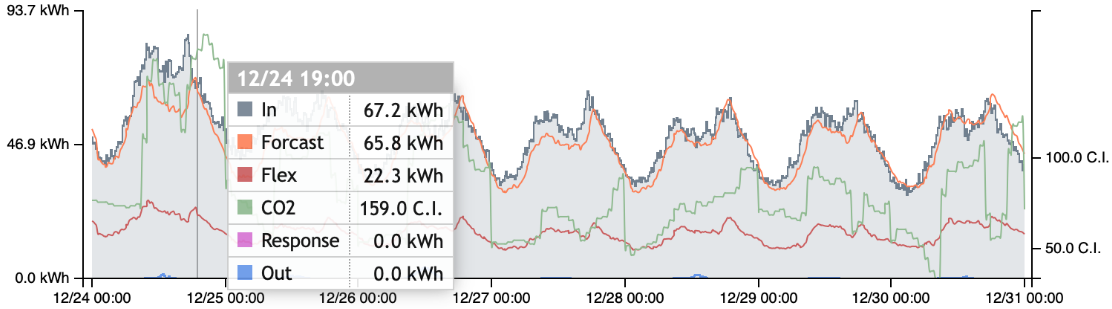
The figure above shows the aggregator generated forecast and measurement data for 229 resident households managed by the IBM aggregator for the week from 24.12.2018. The filled grey area shows the overall measured electric power consumption of these households in kWh with 15 min resolution and the blue line shows the measured output power generated by the households. The orange line shows the forecasted power consumption for these households computed by the aggregator model at the time of planning based on historical electricity consumption data and weather forecast; the red line shows the model based estimated power consumption flexibility of these households. As the aggregator also provides the environmental product focused on CO_2-reduction, the forecast data of CO_2-Intensity (C.I.) for Bornholm is shown by the green line. There were no activations during this week and the forecast matches the actual power consumption sufficiently for regular days. The model was not configured to consider special situations on days like Christmas (the first day in the graph above) when the electricity consumption significantly differs from regular consumption of the households.

The private households managed by an aggregator are very diverse in terms of size, isolation, electric power generation capabilities, heating system characteristics, requirements regarding indoor temperature, etc. These all strongly impacts the amount of flexibility a heating system of an individual private household can contribute. There are large households with high indoor temperature requirements which provide high flexibility; many resident households belong to this category. There are households with negligible flexibility, they use only very small amount of electricity for heating and thus only small savings can be achieved by switching-off their electrical heating system. This is the case for many of the summer cottages. The figure below illustrates the theoretic and empirical total load reduction that can be achieved by a population of 209 resident households equipped with heat-pump heating system for different outdoor air temperatures at a certain point in time. This set of households can deliver 348 kW at -5°C, 267 kW at 0°C, and 190 kW at 5°C. This means that at a particular point of time an average household of this set delivers a load reduction of 1.66 kW at -5°C, 1.27 kW at 0°C, and 0.91 kW at 5°C.



Expected load reduction from 209 heat-pump households at different outdoor temperatures

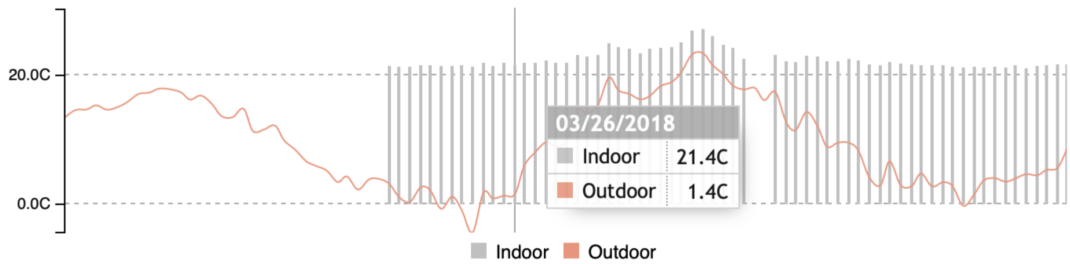
The electricity consumption of a household heating system and thus the amount of flexibility depends on the day of week and the time of day. The figure below shows the aggregator generated forecast and measurement data for 132 resident households with electric radiators for the week from 24.12.2018. The filled grey area shows the overall measured electric power consumption of these households in kWh with 15 min resolution and the blue line shows the measured output power generated by the households. The orange line shows the forecasted power consumption for these households computed by the aggregator model at the time of planning based on historical data and weather forecast; the red line shows the model based estimated flexibility of these households. One can clearly see that particularly the time of day has a strong influence on the flexibility provided by the private households. The temperature at 19:00 on 24.12.2018 was around 0°C, at this temperature this set of 132 households can deliver 89.2 kW of load reduction. An average household with electric radiator of this set can deliver around 0.87 kW at -5°C, 0.68 kW at 0°C, 0.50 kW at 5°C and at this point of time.



Expected load reduction from 132 electric heating households

2.3 Indoor Temperature Data

The aggregator also processes the indoor temperature of the managed households, if available, to identify the specific indoor temperature ranges for the households and then to validate whether the indoor temperature of a particular household remains in the acceptable range during the flexibility activations. The gray area in the figure below shows the weekly average indoor temperature of one sample resident household since June 2017; the red line shows the average outside temperature in the region. The indoor temperature measurements for the household are not available for all the weeks; however, they are available for the previous heating season and for the heating season 3. In both heating seasons the average weekly temperature of this household, equipped with an air/water heat pump and GWR control infrastructure, was always above 21 °C.



Weekly average indoor temperature of a household

3 References

WP3: EcoGrid 2.0 Marketplace Interface Specification

WP5: EcoGrid 2.0 EcoEx API Specification

WP5: EcoGrid 2.0 FIP (Flexibility Interoperability Platform) API Specification

WP8: EcoGrid 2.0 Data Warehouse Tables Structure

Mueller, F. L., & Jansen, B. (2017). Autonomous estimation of the energetic flexibility of buildings. *American Control Conference* (pp. 2378-5861). Seattle: IEEE

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