Evaluation of Aggregator Tool and Demand Response

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IBM

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TABLE OF CONTENTS

1 Aggregator Overview 7

2 Aggregator Operation 9

2.1 TSO Market Participation 9

2.2 DSO Market Participation 9

2.3 Aggregator Flexibility Activation Planning 10

3 Aggregator CO_2 Reduction Product 11

3.1 CO_2 Reduction Product Overview 11

3.2 CO_2 Reduction Product Operation 11

4 Aggregator Demonstration Results 13

4.1 Aggregator Response Validation 13

4.2 Aggregator Rebound Validation 14

4.3 Aggregator Indoor Temperature Validation 14

1 Aggregator Overview

Executive summary

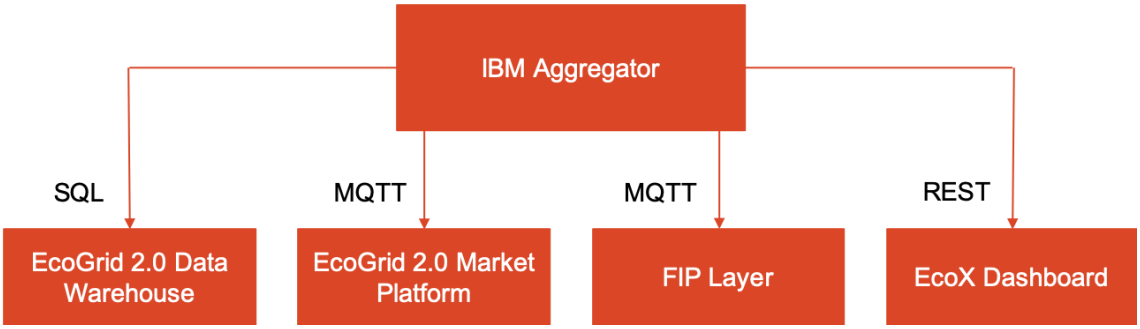
An aggregator is controlling the Distributed Energy Resources (DER) and is offering their combined flexibility towards the EcoGrid 2.0 market for flexibility. The aggregator reads and processes the information on managed households and on power consumption and generation of these households. It combines this data with temperature and the weather forecast data to build and refine a model of power consumption for each individual household. The IBM aggregator participates in TSO and DSO markets for balancing of demand / response as well as delivers functionality for consumption optimization to reduce CO_2 emissions. In the demonstration period of heating season three we showed that:

- The aggregator can control the flexibility from private households and deliver services to TSO and DSO markets as well as optimize consumption leading to savings of CO_2 emissions
- The aggregator can trade the available flexibility of its managed households on the market platform.
- The aggregator can successfully execute scheduled load reduction on the specified set of households.
- The aggregator can successfully execute conditional load reduction on the specified set of households.

An aggregator is controlling the Distributed Energy Resources (DERs) and is offering their combined flexibility towards the EcoGrid 2.0 flexibility market. 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

- EcoGrid 2.0 data warehouse maintaining all household data
- EcoGrid 2.0 flexibility clearing-house market platform for flexibility trading
- Flexibility Interoperability Platform (FIP) providing interfaces to control the heating systems of the households
- 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

2 Aggregator Operation

From the third week of 2019 the aggregator started its full operation with offering its flexibility in TSO and DSO markets as well as with performing CO2-reduction product activations. Furthermore, the aggregator participated in the manual long duration power reduction tests activating all of its managed households. The aggregator was active in five working days of the week with some of the days reserved for manual activations and other tests. The activations planed by the aggregator were for no longer than for one hour and the minimum period between two subsequent activations for a household was set to five hours most of the time to ensure that the inside temperature does not significantly drop, and the comfort of the participants is maintained.

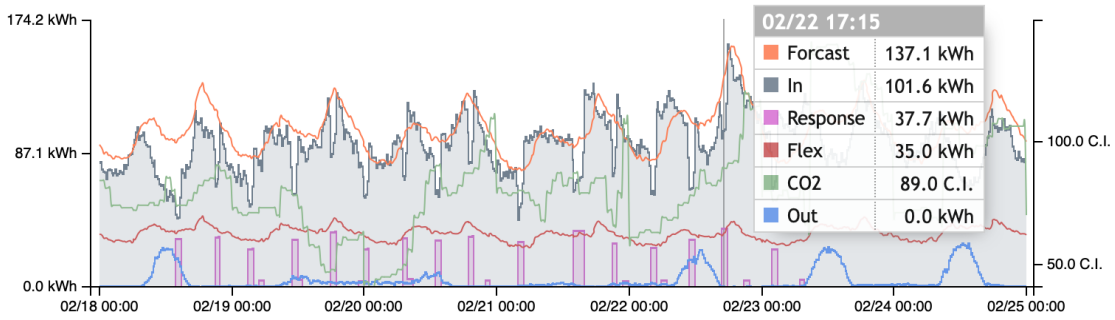
2.1 TSO Market Participation

Every hour, through its market platform MQTT connection, the aggregator received a new TSO market request (AsyncBlockBid) with the balancing period of two hours beginning in the next following hour. Overall it responded with a bid to 232 of these market requests using the estimated flexibility of available resident households; the response duration of the aggregator offers into the AsyncBlockBid markets was always one hour with natural rebound duration of one hour as well. 103 of the issued bids were accepted by the market platform and the associated flexibility activations were successfully performed by the aggregator in the time period specified in the contract received from the market platform. The flexibility volumes of scheduled CO2 product activations were also accounted and used to additionally accommodate TSO market requests; this combination was helpful for the aggregator to offer higher volumes in its bids for TSO markets.

2.2 DSO Market Participation

During the demonstrations in heating season 3 the aggregator received 12 DSO market open requests from the market platform. The DSO requests were generally received at the beginning of the week and requested services from the specified set of households in a region with activations in the coming working days of this week, which requires longer term resource planning from the aggregator. The aggregator responded with offers to 11 of these requests using the available flexibility of resident and holiday households specified in the DSO market open notification message. 6 issued DSO service bids were accepted and scheduled for unconditional activations (50%) and conditional activations (50%) in the specified periods. For conditional activations the corresponding activation notification messages from the market were processed. The flexibility activations of the scheduled enabled services were successfully performed by the aggregator in the specified time.

2.3 Aggregator Flexibility Activation Planning



Aggregator activations planning

The figure above shows the planned aggregator activations and measurement data for 229 resident IBM managed households from 18.02.2018. The filled grey area shows the overall measured 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 without flexibility activations 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. The estimated response volumes of planned service activations for TSO markets, DSO markets, and CO_2-reduction product as well as for one two hours long duration test in this week are shown by the pink filled areas.

3 Aggregator CO_2 Reduction Product

3.1 CO_2 Reduction Product Overview

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.

3.2 CO_2 Reduction Product Operation

The environmentally friendly product focused on CO_2 reduction was activated in week 3, 2019 by the IBM aggregator. Overall 41 households were registered for the CO_2 product until the end of the demonstration period at the beginning of April. 28 of these households were resident and 13 were holiday or summer households. Particularly the holiday households offer very little flexibility as the heating of these households is often limited. Many of the households which selected the CO_2 reduction product are equipped with energy generating equipment which makes an accurate estimation of their flexibility by the aggregator more challenging.

The product was activated on 40 working days during the demonstration period of heating season 3. Overall 112 product activations were performed weekdays during January, February and March; on average about 11 CO_2 product activations were performed in one week during the demonstrations period. The CO_2-Intensity forecast data for Bornholm was used to plan the activations. Every day the CO_2-Intensity forecast for the coming day was 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 was planned for a period of one hour reflecting the resolution of the forecast data. The aggregator scheduled 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 an activation. The minimum period between subsequent product activations for a household was set to five hours to ensure the comfort of the participants is maintained. The scheduled CO_2 product activations were also accounted and used to additionally accommodate TSO market requests; this combination was helpful for the aggregator to offer higher volumes in its bids for TSO markets. The overall response volume of all CO_2 product activations during the demonstration period was around 980 kWh; this aggregated power consumption of households was shifted from hours with higher CO_2-Intensity to hours with lower CO_2 Intensity.

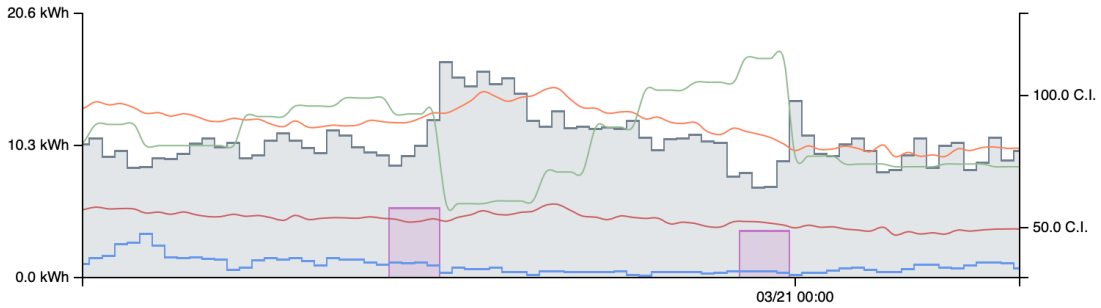


Figure showing two CO_2 product activations.

The figure above shows two CO_2 product activations on 28 resident household. The filled gray area shows the overall measured 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 forecast of the power consumption for these households in kWh computed by the aggregator at the time of planning based on historical data; the red line shows the estimated flexibility of these households at a point of time. The forecast of CO_2-Intensity (C.I.) is shown by the green line and the volume of a planned activation by the pink filled area. As demonstrated by the figure, the CO_2 product activations reduce the power consumption during hours with high CO_2-Intensity while the rebound following the activations lies the time of lower CO_2-Intensity. In this example the period between the two activations is exactly five hours.

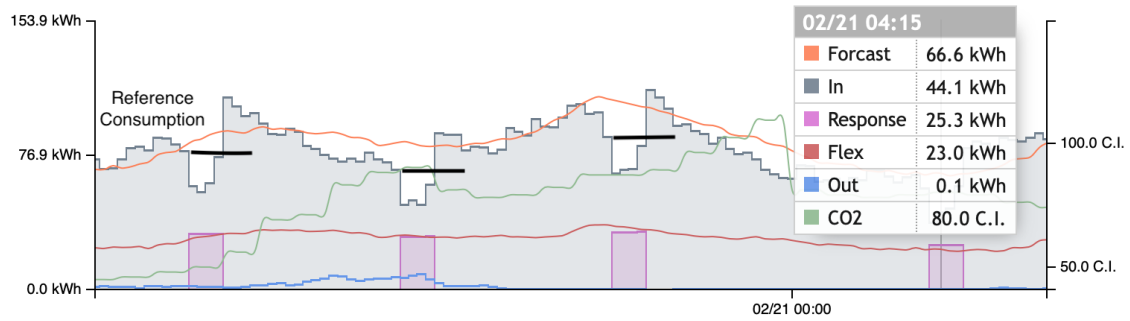
Based on CO_2 intensity definition, moving power consumption of 1 kWh into a period with CO_2 intensity lower by 1 C.I. saves 3.6 g of CO_2. The first activation shown in the figure moves approximately 8 kWh from an hour with CO_2 intensity of 93 C.I. to an hour with 59 C.I. which saves 979 grams of CO_2 emission. The second activation in the figure moves approximately 7 kWh from an hour with 114 C.I. to an hour with 77 C.I. which saves 932 grams of CO_2 emission. Overall, the 112 activations of the CO_2 reduction product on 28 resident households during the 40 days in the HS3 demonstration period resulted in savings of approximately 62 kilograms of CO_2 emission.

4 Aggregator Demonstration Results

The size of the drop area of the measured power consumption corresponding to an activation period shows the actual response of the managed households to the flexibility activation commands sent by the aggregator through the MQTT FIP Layer interface. These comparisons allow to validate and to continuously adapt the household flexibility forecast models used by the aggregator. In EcoGrid 2.0 project setup, the difference of expected and measured response for a larger set of households depends on many changing factors such as power generation volume of the households, problems in delivery of control commands to switch on/off the equipment, non-responding households due to temporary deactivation of the heating control functionality, usage of alternative heating systems, etc.

4.1 Aggregator Response Validation

To determine the amount of the actual response delivered during an activation period, an assumption is required regarding the reference energy consumption in this time period, if no flexibility activation would take place. The quality of the determined reference consumption volume, the electricity baseline, obviously directly impacts the quality of the response delivery validation. For reasonably short activation periods, one simple method is to assume that without a flexibility activation the electric power consumption would not significantly change and stay more or less constant for that period. The figure below illustrates this simple method. It illustrates the reference electricity consumption as a straight black horizontal line.



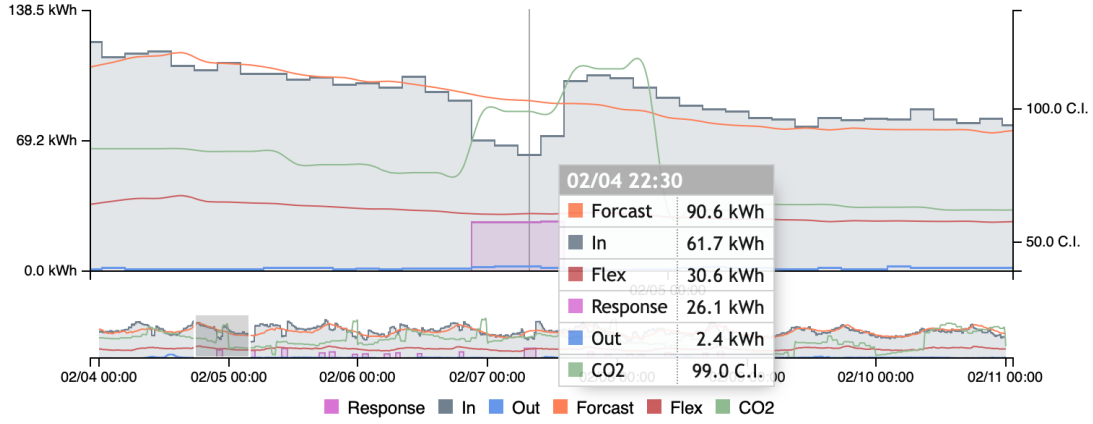
Aggregator flexibility model validation

The aggregator provides functionality to validate and to configure its flexibility planning estimations. In this case it is mainly based on this simple method, in order to illustrate the process. This validation can be performed as soon as the actual measurement data becomes available in the EcoGrid 2.0 data warehouse. Surely, a more accurate electricity baseline model would be beneficial and will be integrated into the aggregator; the data collected during the heating season 3 and the methods developed during the EcoGrid 2.0 project provide a good basis for such enhancements. The aggregator allows ongoing statistical validation of the aggregator flexibility models and provides information to adopt the models according to the changing behavior of the managed households. Looking at the data week by week, the results based on the simple reference consumption model show that the sum of all delivered response in a week was between 99% to

66% of the sum of the planned response volumes; on average it was around 77% and was generally decreasing from the first week of demonstrations. This difference, which among other factors depends on changing ability to actually control the households used in the planning process at the time of activation, can be easily accounted for by continuous adaptation of the aggregator model.

4.2 Aggregator Rebound Validation

The aggregator performed no special rebound shaping and all the collected data can be used for evaluation of the rebound behavior which is naturally following the response of a flexibility activation. The assumption is that a flexibility activation only shifts the electricity consumption but results in no electricity savings; the amount of the consumed electricity stays the same, it will only be consumed later and thus generate a rebound, the shape of the consumption curve will change due to an activation. The figure below illustrates the validation of the natural rebound following a flexibility activation. The gray filled area shows the electricity consumption of 200 resident households managed by IBM with the basic product on 04.02.2019. One can see that without the flexibility activation shown by the pink filled area the actual electricity consumption would be sufficiently similar to the aggregator forecasted consumption for this time period shown by the orange line in the graph. This graph illustrates a general observation that the response volumes of one-hour activations of a set of households with diverse mix of different heating systems are often compensated by not as high but longer rebound periods.

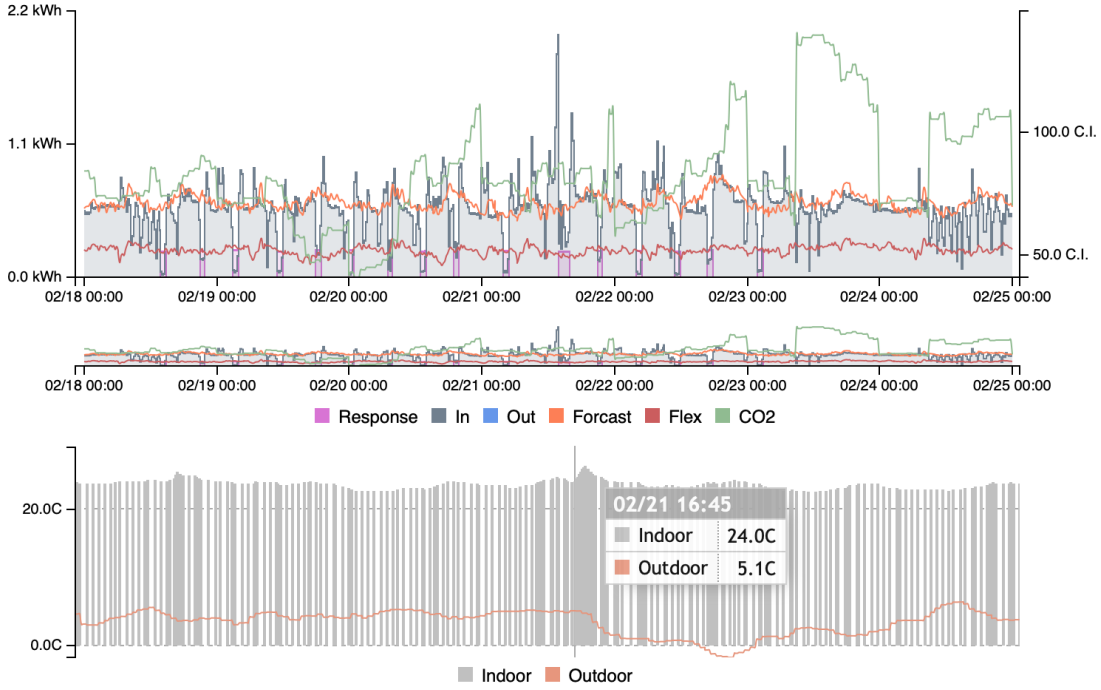


Aggregator rebound validation

4.3 Aggregator Indoor Temperature Validation

For the households with available indoor temperature measurements the aggregator performs the evaluation of the impact of the flexibility activations on the indoor temperature. The figures below demonstrate the data used for this validation: the first graph shows the electricity consumption data of a household and the flexibility activations; the second graph shows the indoor temperature measured by one installed sensor. The heating system of this household is a heat pump controlled by a GWR installation. The figure on top shows the electricity consumption data for the week from 18.02.2018. The filled grey area there shows the measured power consumption of the household in kWh with 15 min resolution. The orange line shows the forecasted power

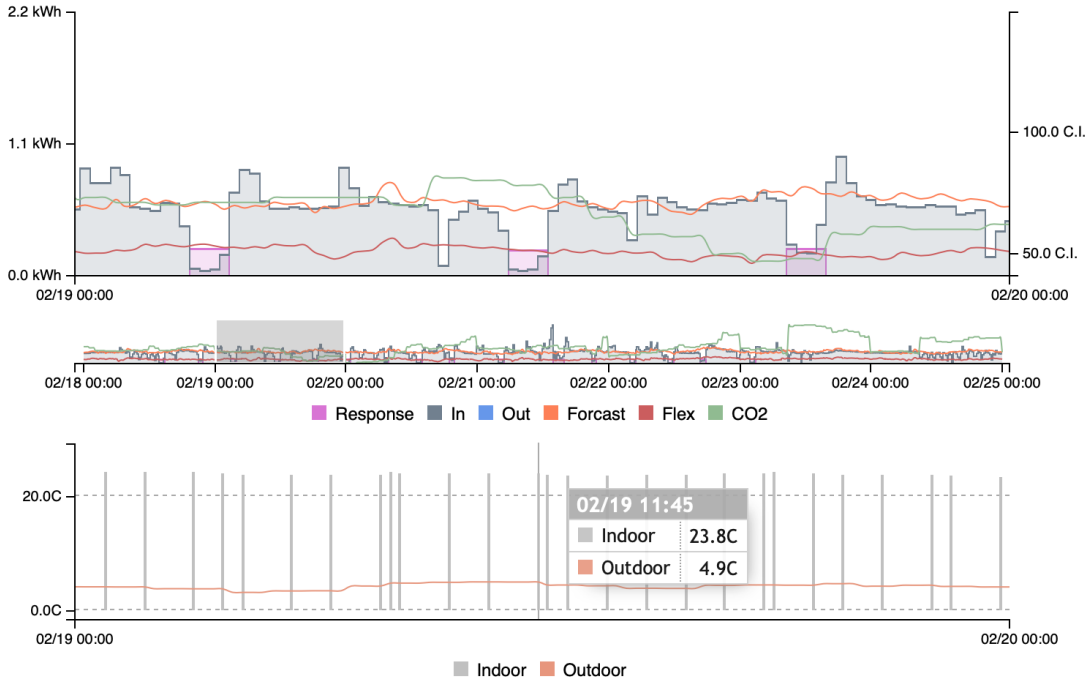
consumption for this household without flexibility activations computed by the aggregator model at the time of planning based on historical data and weather forecast; the red line shows the model based estimated flexibility of this household. The forecasted consumption generally comes close to actual household consumption when no flexibility activations are taking place and the rebound periods are over.



Flexibility activations and indoor temperature of a household

One can clearly see that the heat pump of this particular household directly reacts to the control signals. The next figure below zooms into the data from 19.02.2019 to visualize it in more detail. The electricity consumption of the household sharply drops to a very low value at the start of the flexibility activations shown by the pink filled areas and sharply increases at the end of the activations; the rebound after the flexibility activations can be clearly seen in this example.

The lower graphs in both figures show the measurements of the indoor temperature of the household. In this example the temperature does not significantly change during the activations. The indoor temperature data was only available for a subset of EcoGrid 2.0 households; for these households the demonstration results show that the flexibility activations of one-hour duration used by the aggregator in HS3 generally do not lead to the drop of the indoor temperature outside of the normal temperature range determined for the household.



Flexibility activations and indoor temperature of a household: 19.02.2019

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