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Trial Results

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Abstract:

This document describes trial results obtained within WP3 including trial results on usage of Generic Enablers and FIWARE, on B2B Energy Balancing and on simulation of scaled up trial scenarios.

Keyword list:

Integrated, Trial Architecture, Energy Balancing, Smart Factory, Cross-Border, Virtual Power Plant, Simulation of Electrical Grid, Visualisation Framework

Disclaimer:

All information provided in this document reflects the current stage of the WP3 trial at the time of writing and may be subject to change.

Executive Summary

The Aachen/Cologne B2B energy eco-system trial site interlinks industrial demand-side management and a cross-border Virtual Power Plant (VPP). Trial site infrastructure is enhanced by integrating FPL (FINESCE Presentation Layer) and FISFEPS (Future Internet Smart Factory Energy Planning System) that provide additional capabilities and functionalities of the trial.

The objective of this document is to describe achievements and contributions of the Aachen/Cologne trial site during implementation and operation of the B2B Energy Ecosystem framework based on FIWARE Generic Enablers. The document includes a section dedicated to trial results on usage of Generic Enablers (GEs) and FIWARE. The resultant B2B Energy Ecosystem services architecture demonstrates the feasibility, usability and suitability of FIWARE and GEs for Smart Grid applications. In particular, we have successfully applied FIWARE technology to interlink a cross-border VPP with a Smart Factory based on an energy balancing mechanism. Additional focus is put on comparison to alternative technologies, lessons learned from the use of FIWARE and recommendations for further development.

The document presents trial results on B2B energy balancing approach that is the core of the trial site and a result of successful integration of all parties. A comprehensive visualisation of B2B Energy Ecosystem, referred to as FINESCE Presentation Layer (FPL), is designed and implemented within WP3. The FPL provides a rich set of functionalities needed in both design of the applications and an efficient visualisation during the application runtime. Detailed descriptions of FPL components, namely Data Broker, Visualisation Framework and Visualisation Widgets, are provided in the document. Furthermore, functionalities of two FPL Web applications, Smart Factory and Virtual Power Plant, are described and illustrated.

Principles of the energy balancing mechanism enabling B2B Energy Ecosystem are described. The benefits and impacts of the balancing principle on electrical grid operation are evaluated in a simulation framework. Integration of a smart factory as a flexible load is detailed including clarifications for the chosen interaction strategy between VPP and Smart Factory. The advantages of adopting FIWARE for demand side management implementation, in particular for wide-scale deployment, are highlighted. Furthermore, trial results on simulation of scaled up trial scenarios extend results on trial finding with respect to benefits of the energy balancing mechanism in terms of electrical grid operation.

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1. Introduction

The overall goal of the trial sites in Cologne and Aachen is to show the integration of a cross-border Virtual Power Plant (VPP) with different distributed energy resources (DERs) with a Demand Side Management (DSM) at a discrete manufacturing facility, i.e. a smart factory. This goal was achieved by a two-sided approach. Firstly, there is a plan-driven balancing of energy demand and supply in the system through the mutual exchange of energy consumption and production forecasts. Secondly, an intra-day communication of changes and deviations from those forecasts is performed with an event-oriented architecture allowing for fast response times.

In order to run the energy generation as well as the demand side efficiently, it is essential to precisely plan both. Prerequisite is a forecast of energy generation as well as the targeted energy consumption of the manufacturing plans. The energy balancer then identifies the most suitable manufacturing plan, translates this into energy consumption and provides this info to the VPP as well as to the Factory.

Spontaneous deviations from the forecast of factory energy consumption are handled within the same architecture. The energy balancer identifies when the power consumption deviation exceeds a given threshold and informs both factory and VPP.

The communication between the factory and VPP as well as the decisions for choosing the most balanced course of consumption all happen automatically in the system's back end. However, the human users are always involved in the process, assessing the status of each side of the balancing, learning from the past occurrences and making high-level decisions. For them, the trial results include a visualisation stack complete with the end-user web applications integrated on top of the trials.

This document gives insights into the results within the Cologne/Aachen trial of FINESCE. Following aspects are covered and described in detail:

- Results on Usage of Generic Enablers and FIWARE: One critical result of WP3 is to validate the feasibility of GEs and FIWARE for such an energy ecosystem. This chapter therefore goes into detail on the technical trial architecture, and also gives a brief comparison of deployed FIWARE technologies and alternative solutions in the market. Furthermore, lessons learned from the use of FIWARE are presented and recommendations for further development are given with respect to the requirements of B2B energy balancing.
- Results on B2B Energy Balancing: Goal of the trial was to demonstrate the feasibility of B2B energy balancing between a VPP and a demand side. This chapter shows first the impact and role of a consistent and understandable visualisation across all parties for such an environment. Second, the mechanisms of balancing such an ecosystem are detailed. Third, the impact of the VPP operation on the grid is investigated based on simulation framework and, fourth, aspects of the demand side management in terms of large-scale adoption are described.
- Results on Simulation of Scaled Up Trial Scenarios: The third chapter gives an outlook into the impact of scaling up and extending the trial scenario to investigate technical aspects of higher penetration of renewables, multiple factories and B2B energy balancing system operating in multiple areas.

2. Trial Results on Usage of Generic Enablers and FIWARE

2.1 Integrated Architecture

The Figure 1 illustrates the architecture of the WP3, highlighting the placement and the relationships between components, GEs and DSEs. Particular domains in the figure correspond to the deployment of each subset of the components. To establish connections between domains, we used the GE Publish / Subscribe Context Broker Orion and the GE Complex Event Processing PROTON in most cases. In the rest of the cases, we used the specific trial's API to provide data to components higher in the architecture.

The number and placement of the GEs in our services shows that the FIWARE catalogue offered a great basis for our implementation work. The good fit was already apparent from the descriptions of the GEs in the catalogue and from the details in the documentation. Through the implementation we were also able to evaluate the suitability of the GEs in practice, further proving their usability.

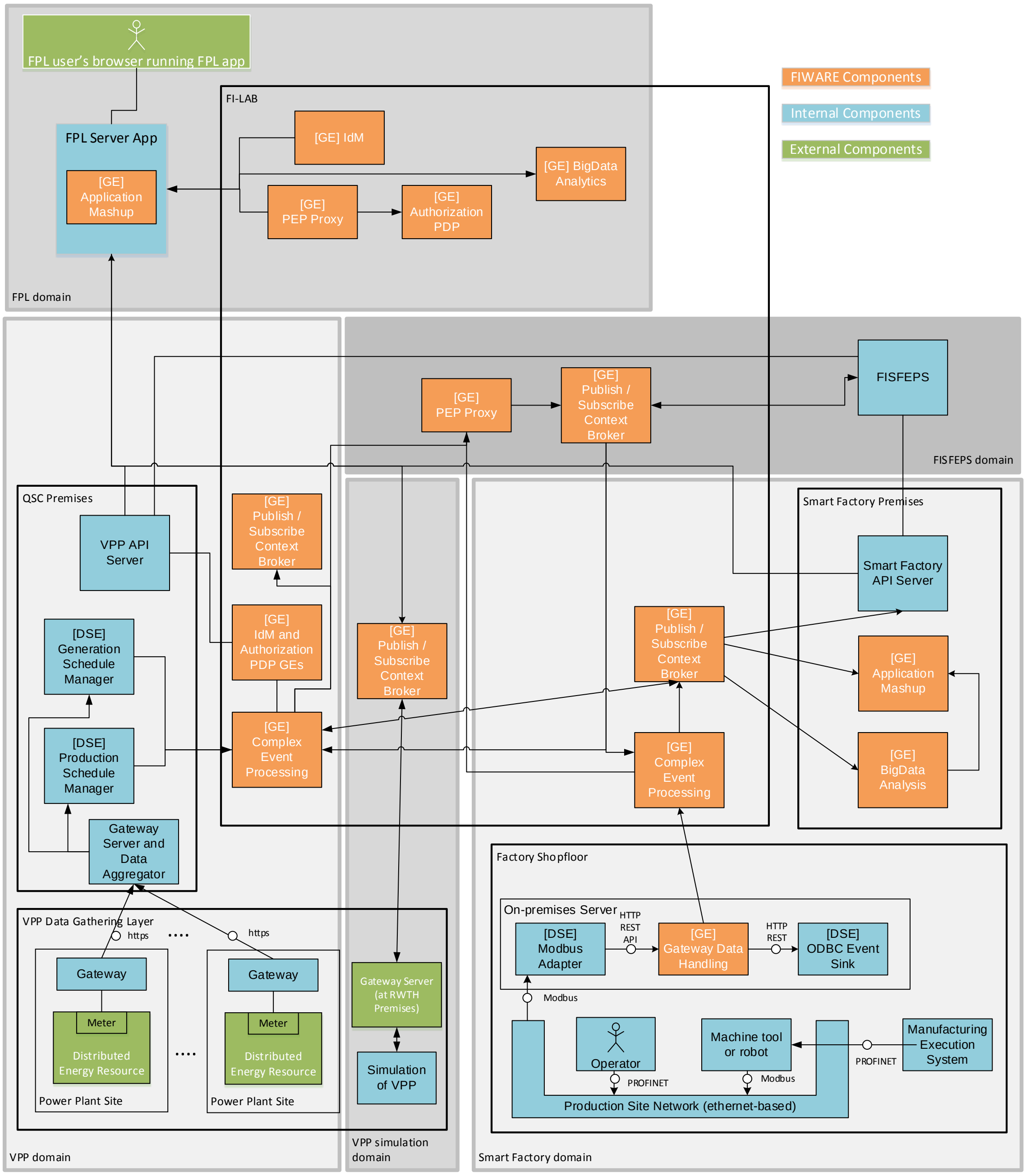

Figure 1: Architecture of the B2B Energy Ecosystem services, DSEs and FIWARE GEs

At the time of writing, the integration with the GEs has been stabilised, and our usage has transitioned into a continuous use of the GEs in the trial. The installation of each group's private instances has become persistent, as they have proven to require very little maintenance. This includes the GE Publish / Subscribe Context Broker Orion instances, which we share across teams and institutions. We found their operation to be reliable and therefore suitable to be used in projects that are beyond simple prototypes.

The trial currently exhibits a moderate load of the data being exchanged, but the setup including the GEs comfortably handles metering updates every minute arriving from 1000 units. The messages carrying the metered values are passing through GE Gateway Data Handling, GE Complex Event Processing and GE Publish / Subscribe Context Broker. This shows that the GEs can take a high number of volume even before needing to consider scaling up of the system deployment.

2.2 Comparison to alternative technologies

2.2.1 Alternatives to the GE Publish/ Subscribe Context Broker

The Orion Context Broker is an implementation of a Publish/Subscribe Context Broker GE belonging to the Data Management and Context Management chapter. To our knowledge, there is no single solution comparable to what Publish/Subscribe Context Broker - Orion has to offer: a combination of a key-value store and a publish/subscribe messaging service. The implementation of the NGSI-9 standard provides the functionality of a service (data source) directory, which in general is a functionality of key-value stores such as Memcached[1], Riak[2], Scalaris[3] and others. Instead of being a general solution, however, Publish/Subscribe Context Broker - Orion has a focus on metadata describing data providers and consumers. The data provider who creates an entity in a Publish/Subscribe Context Broker - Orion instance declares a key - a name of the entity - and provides the value - the address of the service providing entity's data.

In the NGSI-10, the implementation also provides brokerage of the actual data emitted by each registered entity. This, again, can be likened to a key-value store that uses a prescribed structure of the values. The key here is the name of the entity, while the value is a collection of attributes and attribute metadata as well as additional information on the entity prescribed by the NGSI-10 standard. Updating the entity's attribute values in the GE overrides any previously set values of the attribute, while querying for the entity's attributes retrieved the most recently set values. This is a normal behaviour of the key-value stores.

In both standards, the functionality of having data at rest at the broker is extended with the ability to push the changes to the registered services given the conditions for triggering the push are met. This is a functionality that could be provided with solutions such as the Java Message Service (JMS)[4] or one of the Advanced Message Queuing Protocol (AMQP)[5] (e.g., RabbitMQ[6]).

Similarly to the message bus implementations, the Publish/Subscribe Context Broker - Orion GE offers a loosely coupled communication between a data producer (e.g., a power meter) and data consumers (e.g., a status display in a web application). The message buses use topic names to name the channels to which the data producers send the messages. The data consumers subscribe to the topic names to receive the messages. In the Publish/Subscribe Context Broker - Orion GE implementation, the topic name is the same name of the entity as it was used to create or update the entity's context. This mostly caters for the IoT applications, where entities emit, more or less regularly, data on their attributes.

As demonstrated in this trial, however, the developers are free to involve this GE in other, more complex use cases, such as notifying the Energy Balancing services of new or deviated plans, so that it then returns the optimal result through the same channel. All it takes is that administrators deploy the GE, making it readily available to accept entities and context updates. This is in contrast to competitor solutions, which would require custom implementations before they could be used in the suggested way.

The use of open standards, namely the FIWARE NGSI-9 and NGSI-10 has further advantages. Rather than using a binary protocol that requires its specific set of libraries to communicate with the message bus, any client capable of making HTTP calls over the network can be used as either the data producer or the data consumer. The data exchanged is humanly readable, which is important during the development and debugging of an application. By complying with the open standards, any part of the architecture is also fully interchangeable, and this includes the Publish/Subscribe Context Broker - Orion GE which may be exchanged to another possibly more efficient GE implementation. The services can be deployed across networks, as long as their endpoints are reachable from each client end, which is not always possible without additional message bus bridges when using JMS or RabbitMQ.

[1] Memcached: http://memcached.org/
[2] Riak: http://basho.com/riak/
[3] Scalaris: https://code.google.com/p/scalaris/
[4] Java Message Service: http://www.oracle.com/technetwork/java/index-jsp-142945.html
[5] Advanced Message Queuing Protocol: http://www.oracle.com/technetwork/java/index-jsp-142945.html
[6] RabbitMQ: http://www.rabbitmq.com/

The choice of using the GE Publish/Subscribe Context Broker in FINESCE has proven valuable at the stage of involving the Open Call SMEs. The new partners were able to quickly adopt the GE Publish/Subscribe Context Broker - Orion instances set up by the original partners to be used as an effective web service interface, being able to choose from passively receiving of the data or actively polling the instance. Normally, the publish/subscribe message buses do not enable accessing the last data in a topic to be at rest and available for newly arrived message consumers. Instead, they have to first subscribe to a topic, and only receive the values with the next update. Further, by properly organising the topology of the Publish/Subscribe Context Broker - Orion instances it is possible to create web services which at different access points provide different entity attribute availability. Also, having a common well-defined standard enabled fast integration. If we had decided for any of the alternate technologies, we could have expected steeper learning curves and longer integration times.

2.2.2 Alternatives to the GE Complex Event Processing (CEP) and GE Gateway Data Handling

Complex Event Processing software, or engines as they are usually called, is a domain widely researched and a quite well addressed market. There are several advances from research side led by universities such as

- Stanford University[7]
- Cornell University[8]
- UC Berkeley[9]
- Karlsruhe Institute of Technology[10]

They all offer prototypes or ready to use software packages for the described tasks of analyzing incoming events in real time.

On the commercial market, also different vendors offer their solutions, e.g.:

- Microsoft StreamInsight[11]
- JBoss Drools[12]
- SAP Event Stream Processor[13]
- IBM Active Middleware Technology[14]
- Software AG Apama Analytics & Decisions Platform[15]
- Esper[16]

The last software also builds the foundation for the GE Gateway Data Handling which shows alternative software to the GE Complex Event Processing (CEP), the GE Gateway Data Handling itself. Both offer comparable functionality in terms of analysis of data streams with pre-defined patterns. The GE CEP however targets larger data streams and facilitates cloud based architecture, whereas the Gateway Data Handling is meant for on-premise deployment and a pre-filtering of data. However, the FIWARE documentation gives not a clear point when to switch from one solution to another, though this might not be necessary.

Both event processing GEs, the CEP and Gateway Data Handling, offer very good functionality, configurability, and scalability. There is no loss against existing commercial and open source solutions, interoperability of the software allows for an easy exchange of the software.

In general, CEP engines are rather easy to substitute and do not offer any specific advantages in terms of functionality. But, the distinct advantage of both GEs is their embeddedness into FIWARE and the surrounding software tools such as the Publish/ Subscribe Context Broker. This allows for a much easier and more seamless integration of the CEP engine into existing environments. This creates a convincing value proposition for FIWARE.

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[7] Stanford Stream Data Manager: http://infolab.stanford.edu/stream/
[8] Cayuga: http://www.cs.cornell.edu/bigreddata/cayuga/
[9] TelegraphCQ: http://telegraph.cs.berkeley.edu/
[10] SpoVNet: http://www.spovnet.de/
[11] Microsoft StreamInsight: http://technet.microsoft.com/de-de/library/ee362541(v=sql.111).aspx
[12] JBoss Drools: http://www.drools.org/
[13] SAP Event Stream Processor: http://scn.sap.com/community/developer-center/esp
[14] IBM AMT: http://www.research.ibm.com/haifa/dept/services/papers/amt_fact_sheet.pdf
[15] Software AG Apama: http://www.softwareag.com/corporate/products/bigdata/apama_analytics/overview/
[16] Esper: http://esper.codehaus.org/

2.3 Lessons Learned using GEs and FIWARE

The B2B energy eco-system in the WP3 trial consists of a number of solutions developed by different partners, which are integrated to form the overall solution. Gathering and processing data from various sources and in turn providing data for other components are a common task. The FIWARE GEs and the FIWARE platform proved to be a suitable platform for the development of the specialised components. They also provided an elegant way for the integration of all individual components into a larger B2B energy ecosystem. Especially the Publish/Subscribe Context Broker GE greatly supported the integration of the components. The GE is the interface commonly used by all parts of the trial to provide processed data for the next component to include it in the application ranging from the gathered data to the visualisation of the results.

The FIWARE GEs provided the functional performance necessary in the trial components for the special tasks like e.g. the complex event processing. It enabled the developers to focus on solving the problem at hand rather than spending the time and effort to implement event-processing algorithms. Being able to focus on the solution of the actual task, by using the GEs as ready-made implementations for special technologies needed, considerably improved the time from concept to production-level solutions.

One major advantage is also the openness and the availability of the source code of the GEs, this way there is no vendor lock-in to be considered when planning and developing the system. Developers were able to choose the GEs appropriate for the solution and could adapt them to their needs or use the GEs to develop the domain specific enabler, which in turn represents a specific technical solution usable in similar contexts as ready-made implementation without presenting restrictions of use according of licences.

Using the FIWARE platform and the GEs turned out to lead to a fast development as it provided the functionality and the hosting in the same step. This platform can also be combined with the private instances of those GEs where the possibility for a private instance is available wherever the use of public instances was not appropriate.

The documentation of the GEs was mostly good and supported the developers in setting up the application. Questions and problems occurring during the development were answered by the developers of the GEs and by the helpdesk of FIWARE very competently. This allowed the developers to rely on the FIWARE infrastructure and the support of the FIWARE team and the GE developers.

The trial demonstrated how a B2B eco-system architecture can be developed and implemented based on Future Internet technologies. FIWARE GEs and the FIWARE platform formed a technological layer, which allowed the developers to rely on support and without the costs of infrastructure. The open standard and the interoperable platform reduced the effort needed to set up the applications and allowed a rapid system prototyping and testing.

Running the trial and testing the system showed that the FIWARE instances sometimes crash and need manual intervention to restart. Here the possibility of setting up private instances of the GEs was the solution to build a reliable system.

During the trial the continuous use of the chosen GEs for the implementation of the B2B energy eco-system in its different components showed that they were suitable for the application and fulfilled the requirements on the functionality and performance.

A test for the GE Publish / Subscribe Context Broker Orion showed that within about 10 seconds we could get the readings from up to 1100 DERs all sending their data. That is, each DER would send a reading once every minute, but all of them started at the top of each minute. The application subscribed to the stream of updates would get all 1100 of them within 10 seconds. This means that theoretically we could scale this up for about 3-4-times before having to add parallel Orion instances.

2.4 Recommendations for adopting FIWARE

The transformation of the energy supply in Europe is under way. The goals are to avoid the dependence on fossil energy sources and expensive energy imports by reducing energy consumption and by integrating the increasing number of renewable energy resources into the energy supply. To reach these goals presents great challenges for utilities in Europe. They need to contribute to these climate goals by finding new business models and customer-relationship models to conform to the new technologies developing with the changing situation including the private distributed energy resources and the future needs and requirements of their customers. The FIWARE platform and the GEs provide a setup, which enables developers to implement, test and validate new applications to meet the needs of the utilities to deal with the greater diffusion of renewable energy sources, high load applications like electric vehicles and increased prosumer activity. This Future Internet approach of reusable software components like the GEs, and cloud based services, promote the standardisation of interfaces and reduce the product development costs and the development times.

The B2B energy eco-system trial provides a solution for the balancing of energy generated by renewable energy sources and the consumption by industrial partners implemented based on Future Internet technology.

It represents one of the best practice examples in the FINESCE Project showing that using FIWARE and the FIWARE GEs the challenges of the energy transition can be met and that FIWARE provides Future Internet technology for the energy area. During the trial implementation the GEs made technology solutions available for the areas of Applications/Services and Data Delivery, Data/Context Management, Internet of Things, Services Enablement and Security. They enabled the development team to focus on implementing the energy applications and reduced the effort and time of development. This leads to an early start of implemented applications which could then be tested and refined.

For the integration of two new partners in the Trial as a result of the Open Call the commonly used and available interfaces of the GEs showed to be advantageous as a link to connect the parts of the architecture and to integrate private cloud and public cloud applications to an overall system.

3. Trial Results on B2B Energy Balancing

3.1 Visualization of B2B Energy Ecosystem

Software solutions supporting any complex business process often involve a set of specialised components in charge of exchanging data between machines and services. The purpose of these systems is to reduce the time and effort needed for repetitive tasks, provide monitoring of the processes that would be invisible without the use of Smart Energy technologies. The humans who use the system need to interact with and monitor the system’s runtime, and therefore need a user interface to form a bridge between technological aspects of the application. This interface needs to be designed in such a way that it helps the users as much as possible, provide emphasis where needed, guide the user towards their goal, while at the same time contain few distractions and obstacles for the user’s day-to-day operation.

In the FINESCE project, we designed and implemented the FINESCE Presentation Layer (FPL) to work on top of the services created for individual FINESCE trials. The FPL provides a rich set of functionalities needed in both design of the applications and an efficient visualisation during the application runtime. This was a WP3 effort, but the support for trials extends beyond the WP3 trials.

The major components of the FPL include:

- Data Broker: a core component which receives the data from various sources, buffers and stores the data history, and processes it for efficiency and additional insight into data,
- Visualisation Framework: a generic base for creating web-based graphical user interface,
- Visualisation Widgets: graphical elements to populate the Visualisation Framework and, when coupled with specific data, to visualise for the user the Smart Energy data.

We developed each of the components to be an abstraction of the component below. In this way it was possible to assign the meaning of the visualisation when developing the applications, gaining a high level of flexibility and reusability. The whole FPL stack evolved gradually by increasing the support of the trials’ API at the lower levels of the architecture, while at the same time we added support to new visualisation widgets. In this way it was possible to visualise more data, while also enriching the applications with additional interesting and useful ways of displaying the data.

3.1.1 FINESCE Presentation Layer Components

Data Broker is a back-end service, which collects data from many data sources, harmonises and enriches the data internally, then offers it to the visualization layer or other clients.

The support for the data sources grows, and it currently supports all the sources, which expose the B2B Energy Balancing related data. This includes web services at QSC and at FIR, and the context brokers at the RWTH and SOPTIM's premises. The Data Broker actively polls the data from the passive sources, and it supports the NGSI entities being pushed to the service. It is also capable of subscribing itself to any configured NGSI-compliant Context Brokers such as the GE Context Broker Orion.

The Data Broker stores the received data in a NoSQL database or an object store (e.g., the HDFS of the GE BigData Analytics Cosmos). It then periodically runs Map/Reduce jobs to process the data into representations which are much more suitable than the raw data normally is. This includes bringing the data into a common equidistant time scale, which is at 1 minute. This means that Data Broker interpolates the values that come at an irregular interval, and extrapolates the ones metered at 15 minutes. The processing also performs a number of data aggregations, including:

- aggregations by the aggregating (parent) meter, as described in the Section 3.1.4, computing a sum of the power or the energy consumed by the machines on a production floor level or the whole factory,
- aggregations by energy source type,
- temporal aggregations to provide a coarser granularity of the data than originally presented, usually by hour, 4 hours, day, week and month. Here, the Data Broker sums all the energy metered within the interval of aggregation, and averages the power metered within the interval of aggregation. The result is useful for showing longer time ranges of the history data without slowing the application down and without majorly affecting the meaning of the chart.

The Data Broker offers a RESTful API to make the data in the various aggregated forms available to the clients. The API is themed according to the meaning of the data, providing a uniform view over the VPP data regardless if it comes from the QSC API or the RWTH's simulator. The design of the API is targeting a fast retrieval of the data for showing it in the graphical user interface of the end-user application, thus it provides a lot of flexibility in terms of the retrieved data range and scope, and the level of detail in terms of the temporal aggregations. We have documented the interfaces in the FINESCE API and Handbook report[17].

3.1.2 Visualisation Framework

The Visualisation Framework in the FPL hosts the Visualisation Widgets and additional elements to be composed into an end-user application. The framework is flexible and enables building and changing the applications with a small amount of the needed effort. It relies on proven building blocks such as the HTML5, CSS and the JavaScript technologies, coupled with the solutions such as the Ember.js[18] and Bootstrap[19] framework.

Our design of the visual framework, thanks to the chosen technologies, enables creation of applications, which follow the responsive interfaces principles. As a result, the applications may be used at almost any size and type of the display, from the mobile devices, across the desktop flat panels to the large projected displays. This helps reduce the price and time of the application development, because it requires little or no specialised work to bring the application onto a specific device. Instead, a standard up-to-date web browser is all that is required.

In the Visualisation Framework, we enable the separation of functionalities and visualisations into a set of tabs or views, where each tab contains only the elements which follow the same goal or theme.

[17] FINESCE Consortium, *D3.6 FINESCE API and Handbook*, 2015

[18] Ember: http://emberjs.com/

[19] Bootstrap: http://getbootstrap.com/

3.1.3 Visualisation Widgets

The views are further separated into logical components – **Visualization Widgets** – which provide generic functionality to present data and are reusable across views and even other applications. For example, we have packaged our graphing widget for the Wirecloud Application Mashup GE and published it on the public FIWARE Lab Store as the **MultiChart** package[20].

MultiChart is based on the popular graphing library NVD3.js[21]. It enables the user to display graph data with eight different visualization modes (bar, line and pie charts, scatter plot etc.), switching between them at the time of the wiring in a single widget. In visualizations for WP3, we have used stacked area charts to sum up the power consumption of machines in the smart factory and line charts for individual machines, with similar usage for generation in the VPP. The Wirecloud widget installation contains documentation on how to specify input with examples for each of the graph types. The Figure 2 shows an example wiring with multiple visible instances of the widget, each set to a different chart type.

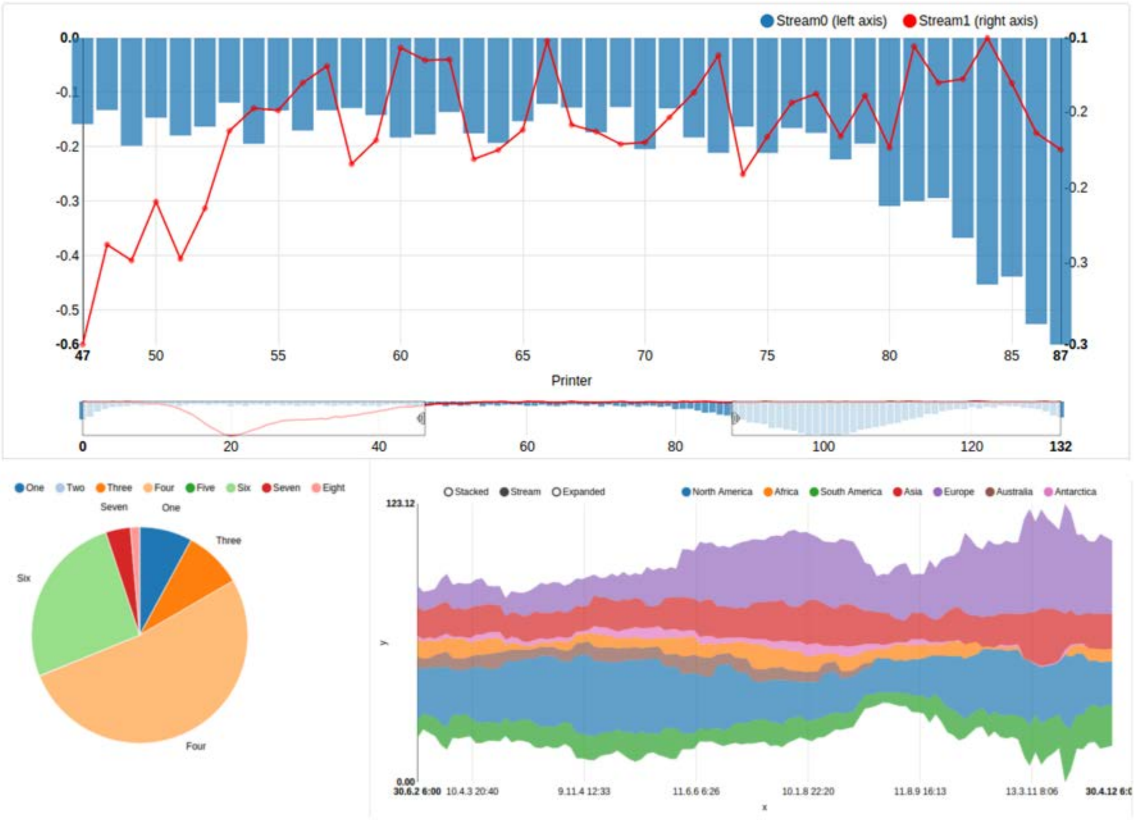

Figure 2: Example visualization modes of the MultiChart widget

Among the more specific components of the Visualization Framework there is the Factory Process Editor. It represents a graphical interface where material flows between factory machines can be specified. With an additional service providing the supply status of materials at factory stations, the stored information of the hierarchical schema could then be used for live visualization of the factory floor, with material supply and flows shown as animations. Figure 3 shows an example workflow represented in the editor.

3.1.4 Smart Factory application

We designed two Web applications to support the B2B Energy Balancing stakeholders. Each of them is aimed at an operator in the two major parties involved in the Energy Balancing, and each one addresses the party's specific needs. On the outside it may appear that the two solutions have very little in common. However, they exhibit elements, which are only possible

[20] MultiChart Wirecloud Widget: https://store.lab.fiware.org/search/tag/finesce

[21] NVD3.js: http://nvd3.org/

thanks to the integrations done in the background to connect the information systems of the generation party with that of the production party.

The purpose of the Smart Factory application is to support the operators and production planners in a Smart Factory to monitor the energy consumption during the production, and to assess the impact that past production had on the energy consumption.

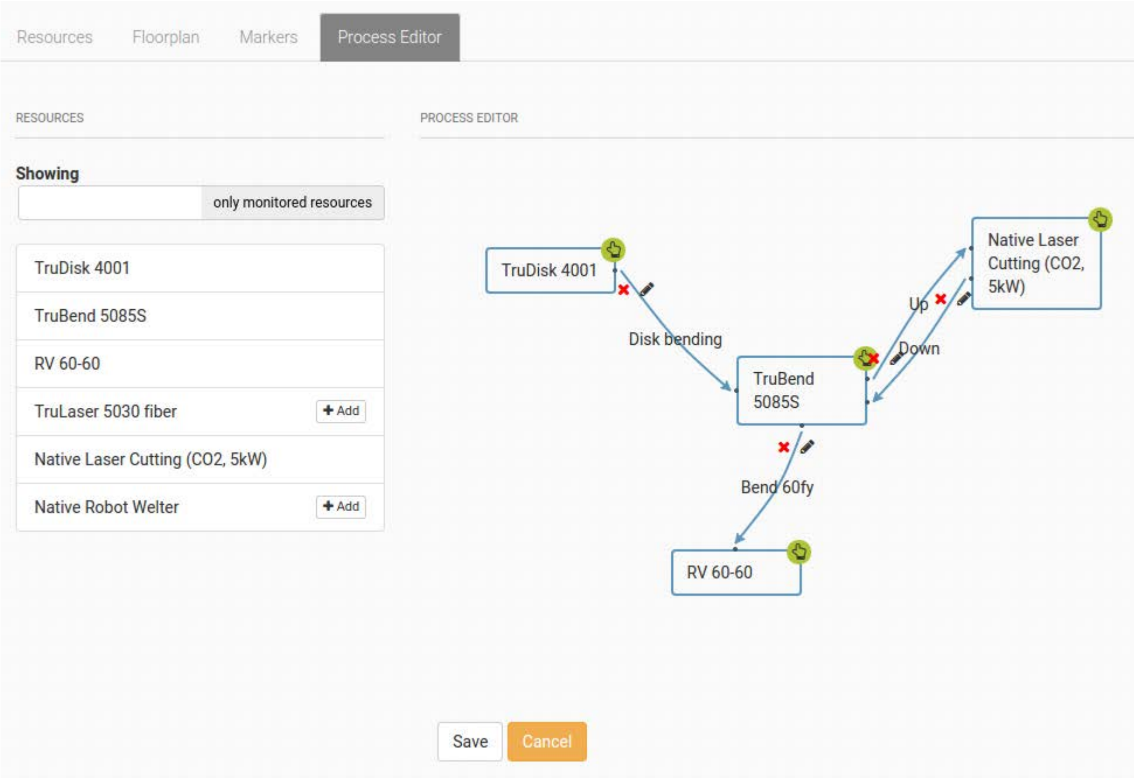

Figure 3: Factory Process Editor

The application is organised in three major views (or tabs):

- Overview – the view representing ongoing processes in the factory
- Machines – the view offering detailed and per-machine data visualisation, showing charts and statistics of the history data
- Factory – offers the details of the available energy consumption schedules for the next day and the history of the past schedules.

When the user logs into the application, she receives the **Overview** of the Smart Factory's live data from the factory floor, such as the one shown by the Figure 4. The main purpose of this view is to serve as a live insight into all the ongoing processes of the factory, with the features including:

- plant's power consumption, updated on a minute basis,
- plant's scheduled power consumption at the time of display,
- the accumulated energy consumed since the beginning of the day,
- if the actual power consumption deviates too much from the schedule, the page alerts the user by showing the plant's power consumption in red,
- history of the power consumption of the factory from the beginning of the day, compared to the scheduled consumption of the power,
- the history of energy consumed in deviation of the schedule, indicating the amount of kW either in excess of or below the acceptable deviation from the schedule,
- statistics for the machines providing the time spent and energy consumed in one of their reported states (operating, idle, off),
- the history of the average hourly consumption grouped by day, shown as a heat map.

This view is therefore suitable for always being displayed on the operator's screen, or on the large display of the factory's operations centre, because it packs all the crucial information needed for continuous monitoring of the factory's energy consumption.

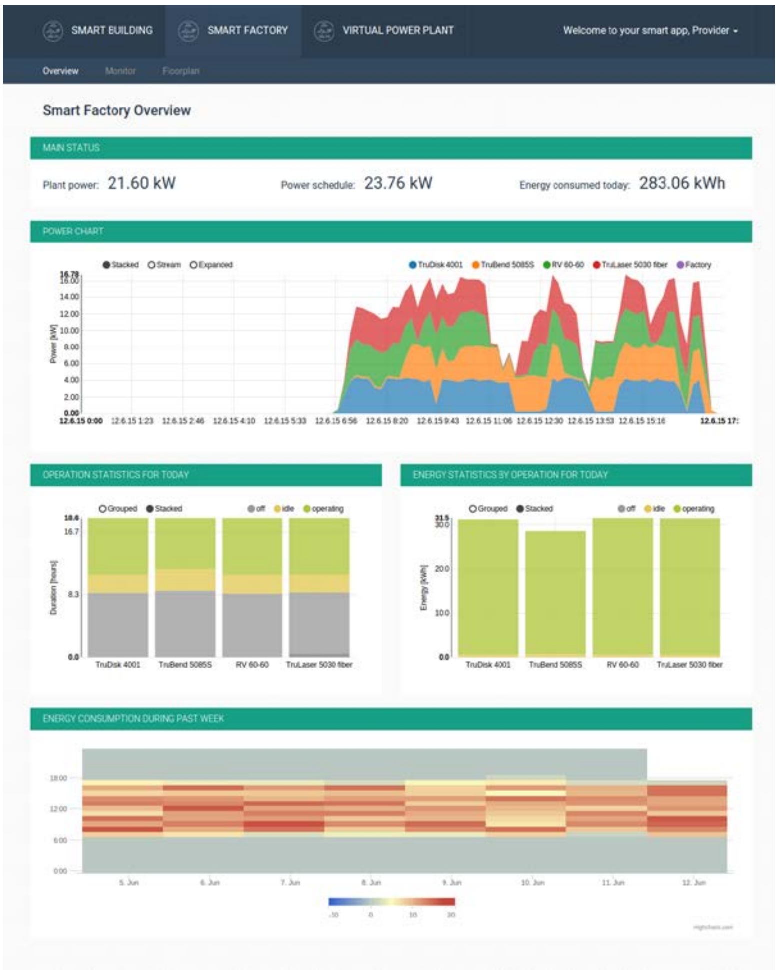

Figure 4: The Smart Factory application's Overview tab visualises the data relevant for continuous monitoring of the Smart Factory 's energy consumption

The Overview shows the data on the fixed set of time ranges because it is optimised for the most efficient presentation of the data at any time. However, the operators often need to analyse parts of the day's consumption at a more detailed level, or they want to get a larger picture on the consumption history of a specific machine. The Smart Factory application accommodates these needs by providing a much more flexible **Machines** view. The Figure 5 shows the appearance of this view, which includes:

- the date and time range selection, where the user can select the range of the history data to be used for the rest of the view,
- a list of the machines on the production floor, and where available, the last known status of the machine. The user can select a machine from the list to have the visualisation show the data for the selected machine,
- the details of the selected machine as registered in the application,
- the latest metered power of the machine,
- the energy consumed in the selected time range,
- a chart showing the history of the power consumption of the selected device in the selected date and time range,
- the statistics of the device's time spent and energy consumed in one of the reported states (operating, idle, off), shown on the daily basis.

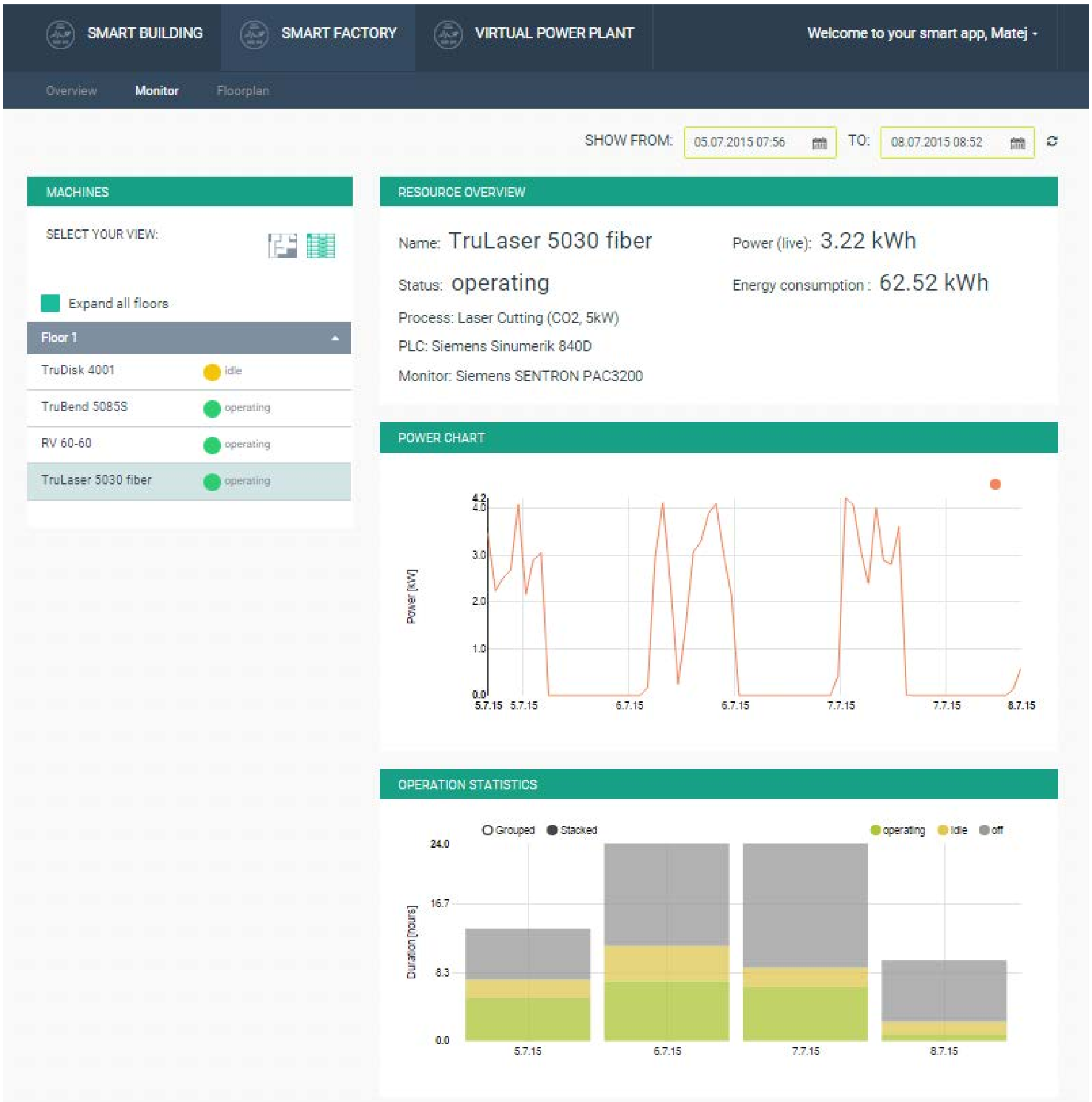

Figure 5: The Smart Factory application's Machines view shows live and history data of the selected machines.

The Machines view offers two ways of showing and selecting the machines in the factory floor. One is the list of the machines, grouped by the floor or a production unit. An alternative view is the widget showing the machines on the plan of the factory floor or production unit. The Figure 6 shows an example of the two views.

A clear benefit of the floor plan view is that it shows the information spatially and in a context of the production floor. The user can therefore locate at a glance much more easily any machine of interest, and the live updated statuses provide a sense of the production's state. The users can edit the floorplans in a separate floor plan editor, as described later in the section.

The **Factory** view supports the operators in the phase of the planning of the next day's production. It offers the data shown at the Overview page, but with the option of selecting custom date and time ranges for displaying data consumption history. The first part of the view, shown in the Figure 9, focuses on showing the consumption history using the following widgets:

- the date and time range selection, where the user can select the range of the history data to be used for the rest of the view,
- the chart showing history of all the production plant's machines, stacked in the same chart to show the accumulated consumption; it is possible to exclude individual machine's contributions to the chart,
- a heatmap chart showing the average hourly power consumption for each of the selected days.

The second part, shown in the Figure 8, focuses on showing the consumption schedules:

- the date selector provides a way to select a schedule, because all schedules are for the whole day ahead,
- a chart showing all the schedule alternatives provided by the factory operators on the day before the selected day; the user can highlight the optimal schedule as decided by the Energy Balancing service. For the days that the actual consumption is available, the chart also displays the metered consumption profile,
- a bar chart showing the scheduled energy to be consumed on the selected day, comparing to the actual energy consumption,
- and a bar chart showing the amount of energy consumed above and below the permissible threshold for the consumption deviation from the balanced schedule.

The Figure 9 shows another example view of the consumption schedules as seen at the current day, showing all the schedules produced on the previous day, with the thick line showing the alternative, which the Balancing service selected as optimal. Overlapped, the profile of the measured consumption is shown up to the time of the viewing.

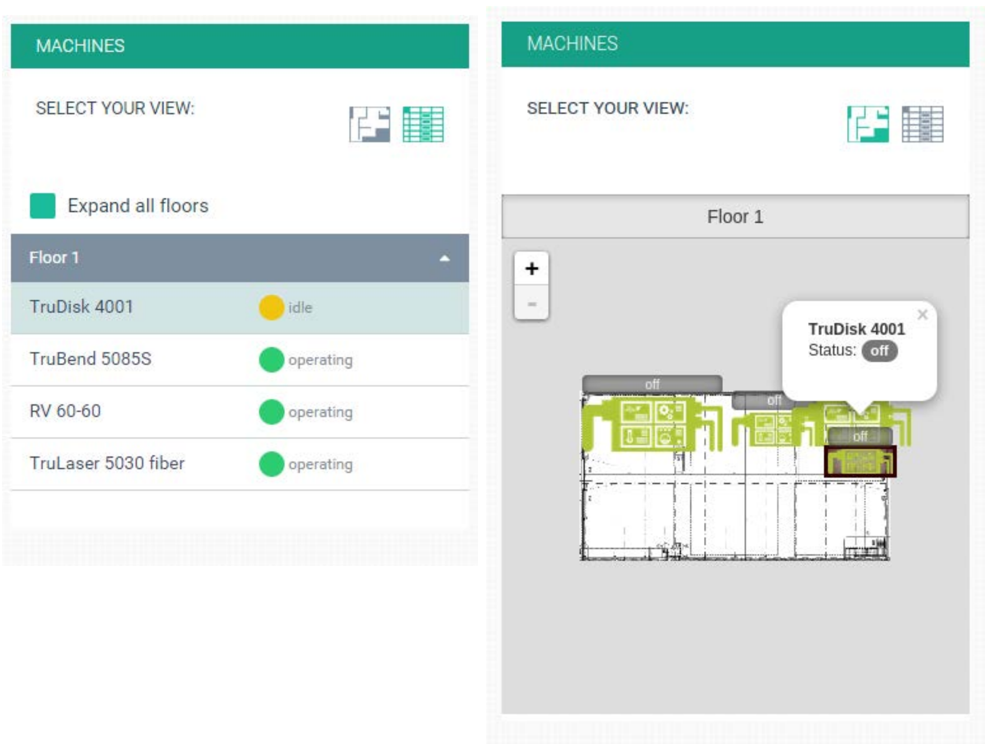

Figure 6: Two types of the machine selection: a list (left) and a floor plan (right).

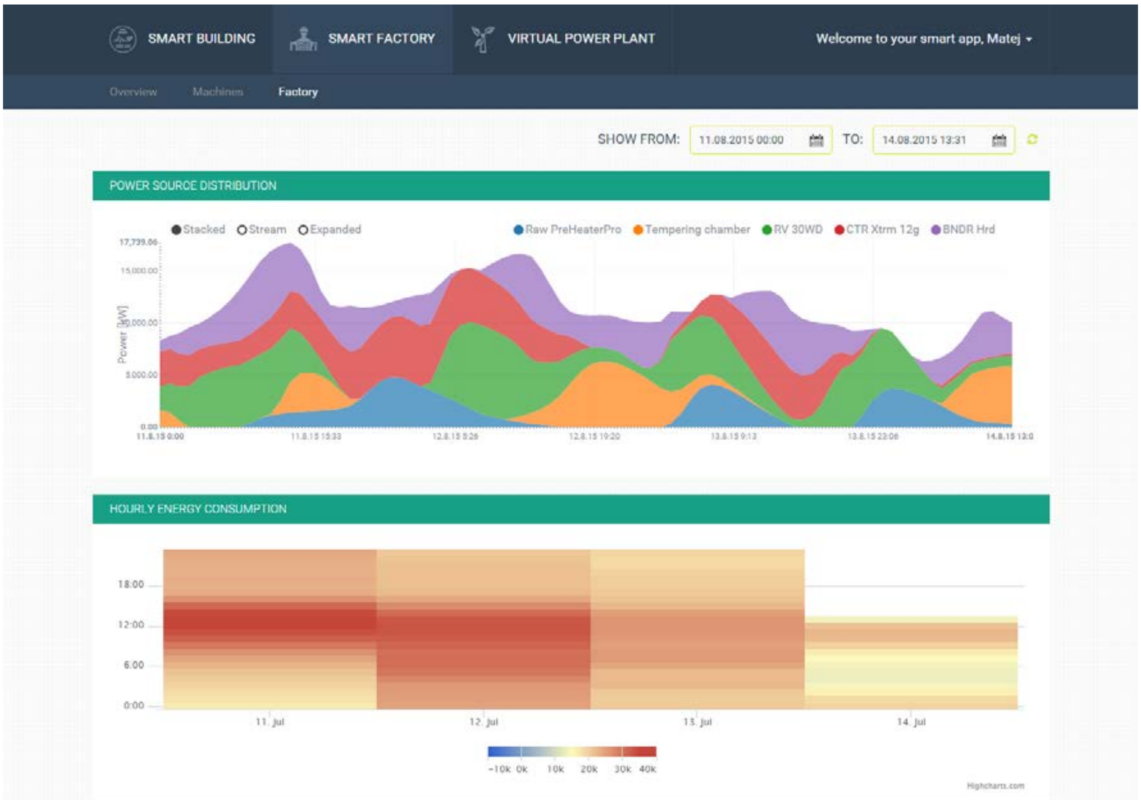

Figure 7: Custom time range for displaying aggregated power consumption history in the Smart Factory application

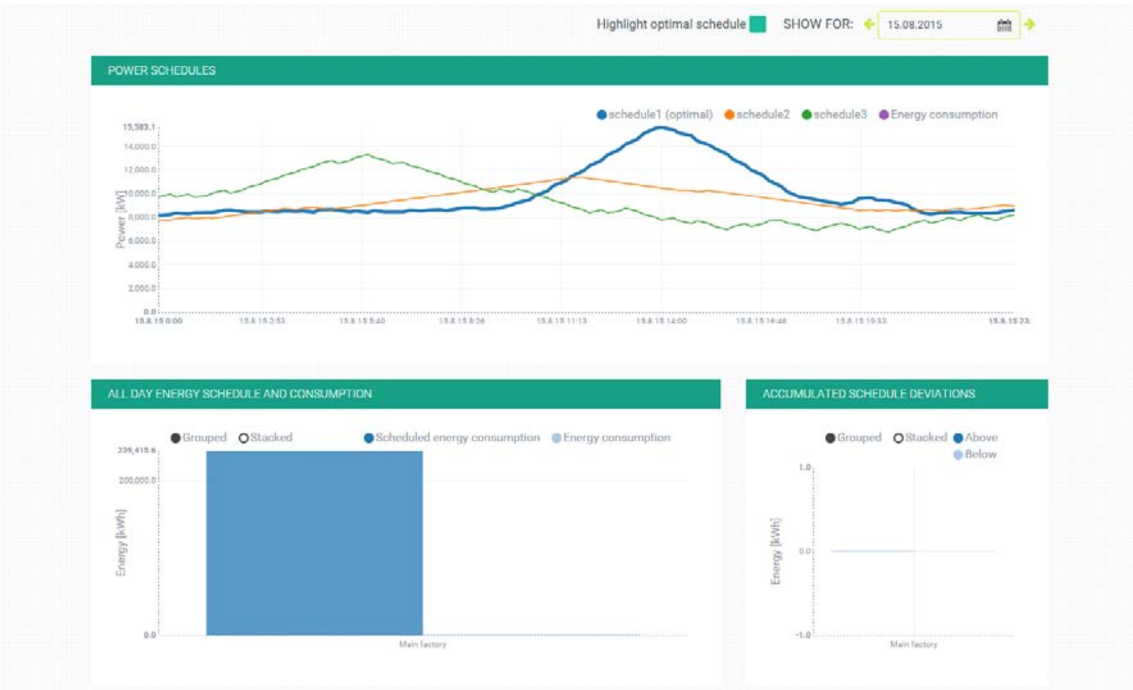

Figure 8: Smart Factory's power consumption schedules

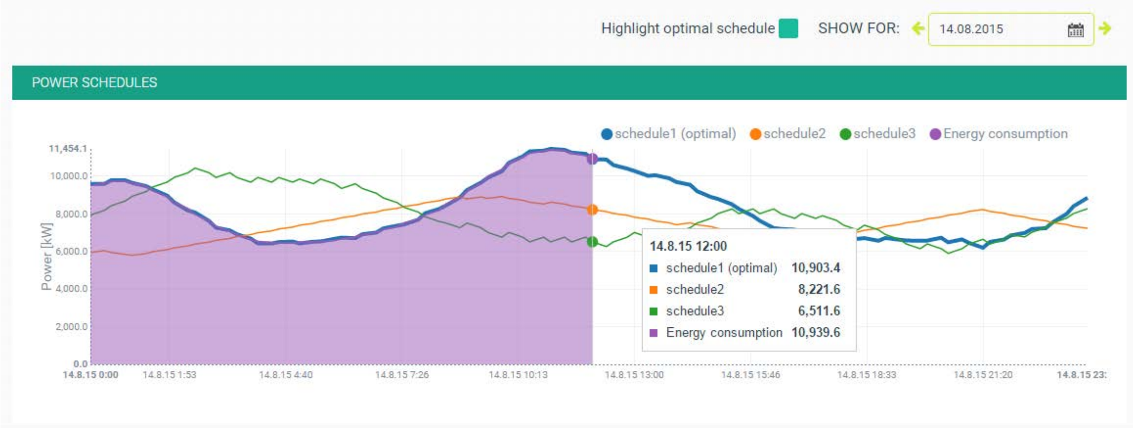

Figure 9: Load schedule alternatives in the Factory view, as visible on 14 July at 12:00. The balanced schedule is in blue.

To complement the three views, the Smart Factory application also includes the **Floorplan editor** (Figure 10). This sub-application has the following capabilities:

- management of the list of machines to be displayed in the main part of the application and included in the computation statistics,
- graphical editor of the floor plans,
- management of the images and shapes used by the floor plan view and editor for representing individual machines.

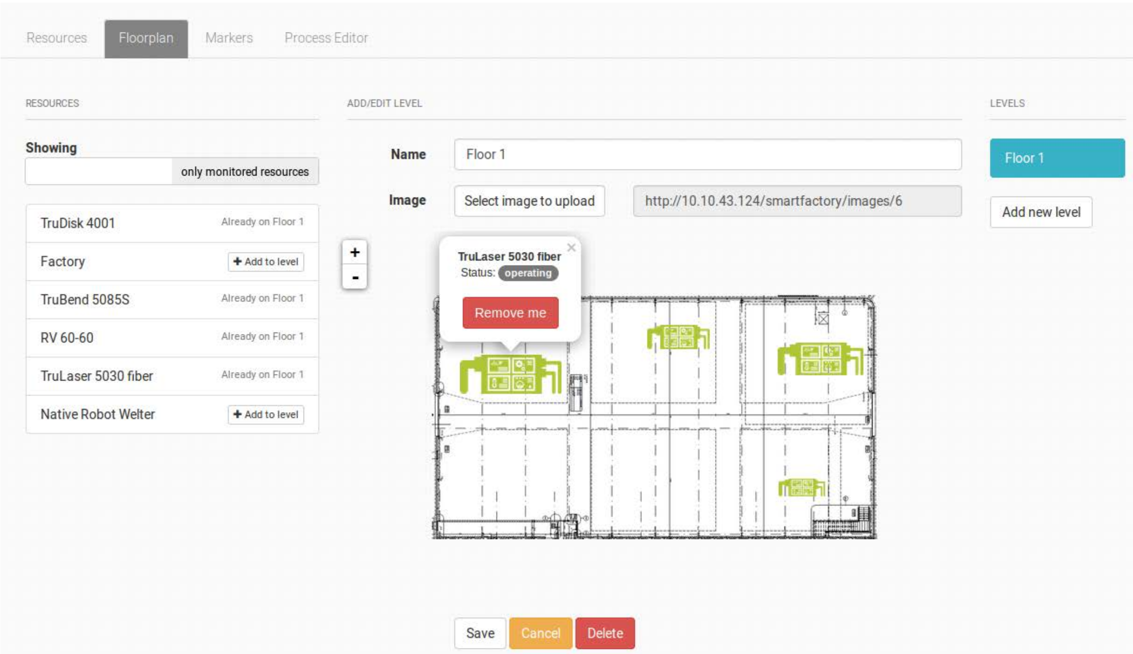

Figure 10: The Smart Factory Floorplan Editor

The machine list initially contains the entries that the IoT system automatically collects. In our case, these are the machines and their respective data obtained from the FIR's service. These native machines are always in the system, but the administrator can add new machine entries. The machine properties form provides the fields where the administrator provides custom information about the new machines.

The machines can form a hierarchy, such that some of the machines can be parents to other machines. In this way it is possible to mark the meters which monitor the consumption upstream from the ancestor machines. For instance, a meter may be placed at a floor's main plug, or at the leads of the whole factory.

In the Smart Application, only the native machines receive the measurements. However, each machine marked to be the parent of at least one other machine has a calculated aggregation of the metered values of all the ancestor machines. For the native machines this means that it is possible to obtain both their metered reading and the sum of the metered readings of the downstream machines. For the non-native machines, only the calculated values are possible. This makes them useful as a virtually placed aggregation meters.

Individually, it is possible to enable or disable the display of a machine on the list in the application. In this way, malfunctioning meters can be disabled so that they do not contribute to the aggregated values.

The floor plans can be organised by floors or levels. The administrator can assign a background image of each floor, giving the floor plan a backdrop or a drawn plan. The machines can then be dragged from the list and dropped into the selected floor or level. This makes the machine appear as a marker on the floor plan. It is also possible to change the location of the already placed machines by dragging their markers around. Short clicking the marker displays a pop-up with options, including the button for removing the machine marker from the plan.

The administrator can select a marker from the library of markers to represent a machine. The marker is a geometric shape or a bitmap, and each machine can have its own custom scale of the marker. The library of the markers is dynamic, so the administrator may upload new bitmaps or disable or delete any of the existing markers.

Adding or changing the floor plans has an immediate effect on the side of the operator's application, with the floor plan widget being updated automatically.

3.1.5 Virtual Power Plant application

The VPP application is aimed at the operators of the generation side of the B2B Energy Ecosystem, and the operators of the energy distribution. Neither of these profiles is concerned with the internal planning processes of productions or the consumption by individual machines. Instead they view the smart factory as a single prominent energy producer. The more important aspect is the monitoring of the generation data as reported by each distributed resource, and aggregated across the whole VPP. Also, the application shows the impact of including a VPP in the power system, where the business players use IT to balance the demand with the planned generation.

The VPP application is organised into the following major views (or tabs):

- Overview – the view representing the ongoing generation and major loads' consumption
- VPP – detailed data visualisation for the whole VPP
- Resources – detailed and per-resource (DER) data visualisation
- Grid – the data related to the power system where the VPP operates

The VPP application's **Overview** tab is designed to be always open on the VPP operator's screen or on the big network operator centre's screen. The Figure 11 shows an example of this view, which includes:

- the momentary power generated, displayed as aggregation per energy source and for the whole VPP, and the capacity of the DER sources, against the aggregated capacity of the DERs,
- the amount of energy generated today by the DERs,
- power generation history from the start of the day, on a chart with stacked values showing aggregations by energy type, and also showing the loads' power consumption,
- the bar charts highlighting the relative amount of energy generated per energy source, and a bar chart showing the ratio between the momentarily generated power.

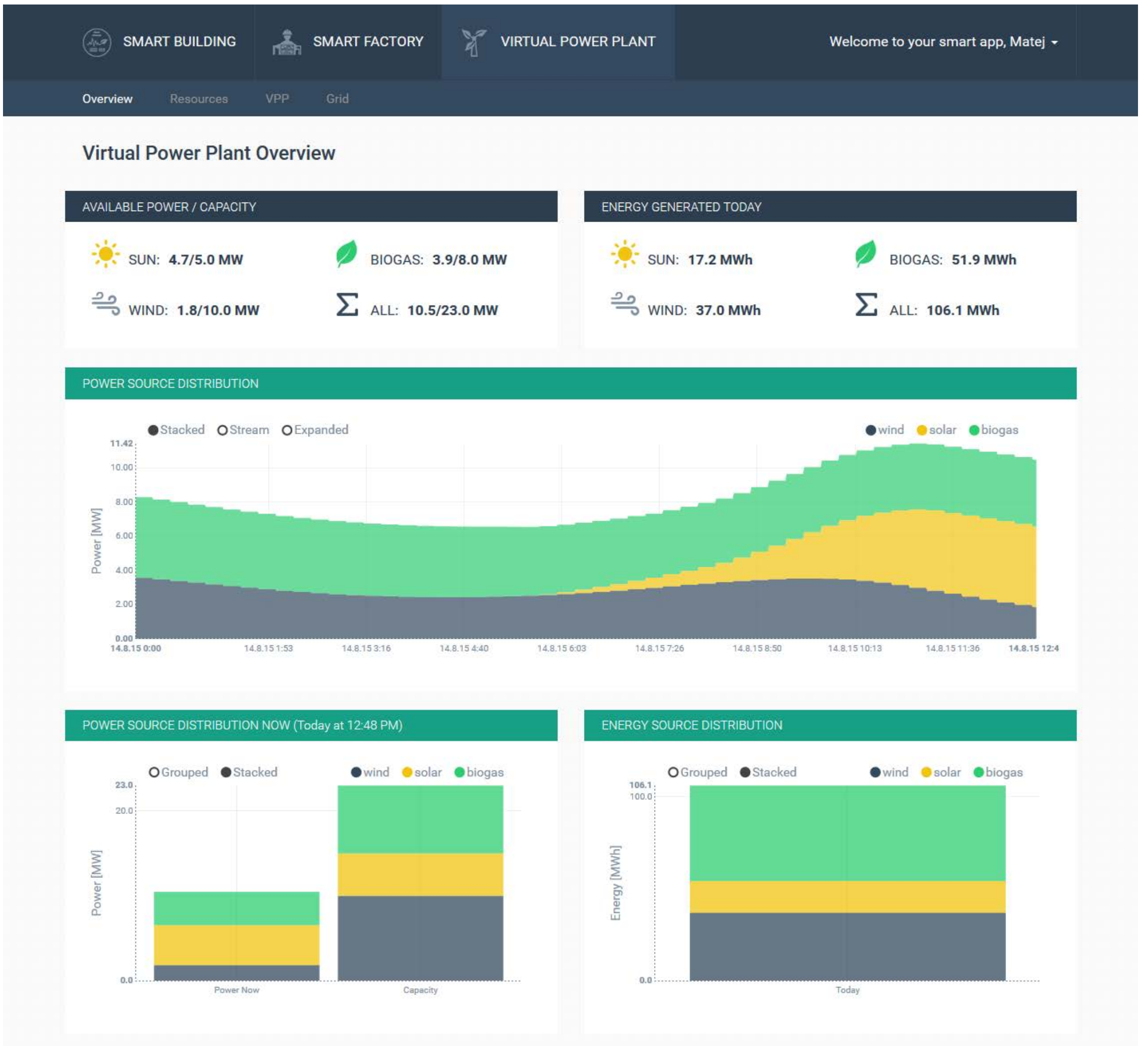

Figure 11: The VPP application's Overview tab shows the data relevant for continuous monitoring of the distributed energy generation

The **VPP** view offers an extended set of the data that is available in the Overview, but at custom time ranges to enable monitoring the data at a higher detail or at larger ranges. The Figure 12 shows an example of this view, which also includes:

- the date and time range selection, where the user can select the range of the history data to be used for the rest of the view,
- power generation history in the selected range, on a chart with stacked values showing aggregations by energy type,
- the bar charts highlighting the daily energy generation from each renewable energy source.

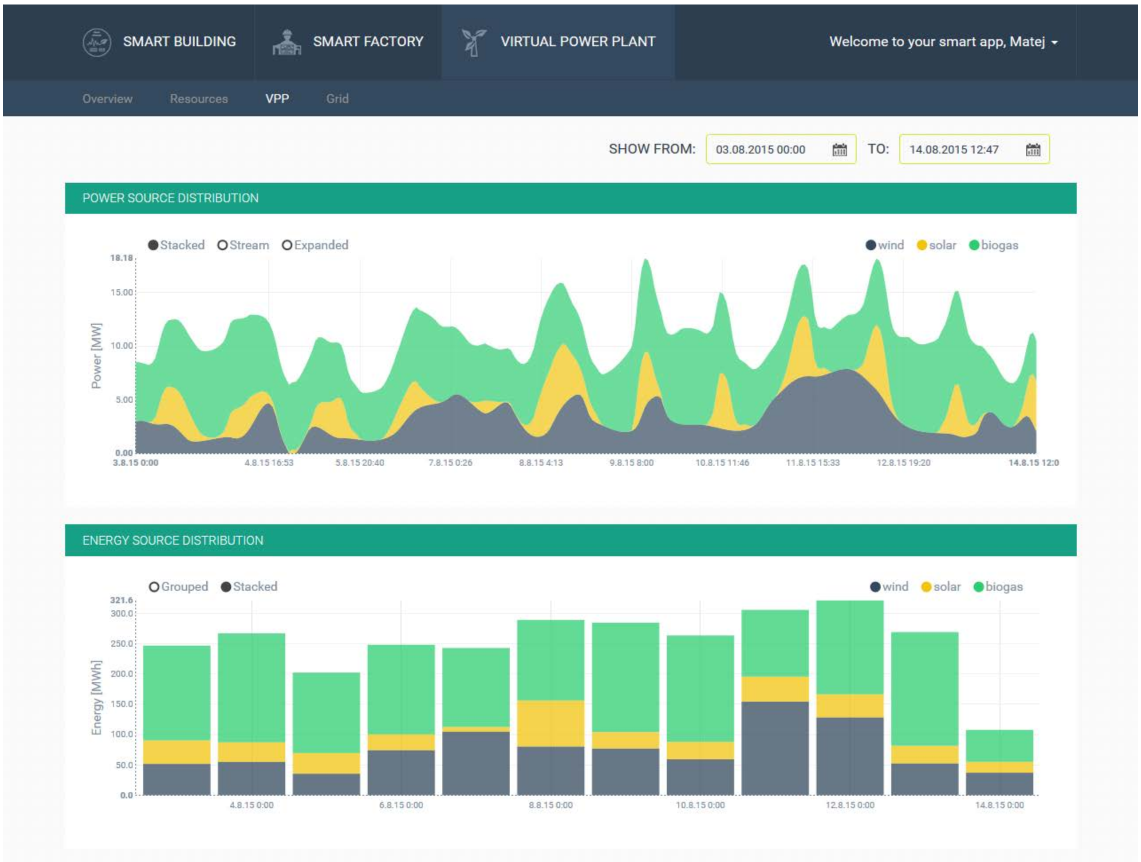

Figure 12: The Virtual Power Plant's detailed view of the VPP's operation.

The **Resources** view enables analysis of the generation history by offering display of the data at arbitrary time ranges. The Figure 13 shows an example of this view, which includes:

- the date and time range selection, where the user can select the range of the history data to be used for the rest of the view,
- a list of the DERs that the user can select to obtain the details and the history data for in the whole view,
- the details of the selected resource as registered in the application,
- a chart showing the history of the power generation of the selected DER in the selected date and time range.

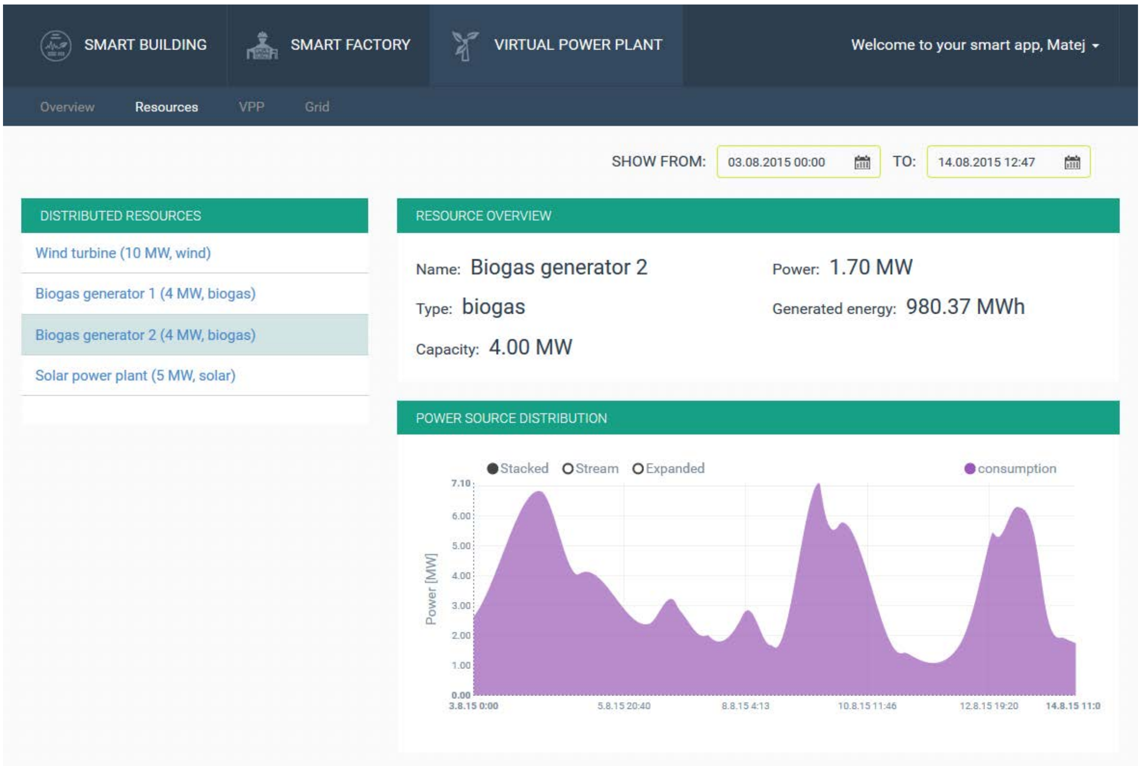

Figure 13: The VPP application's Monitor view shows live and history data of the selected DERs

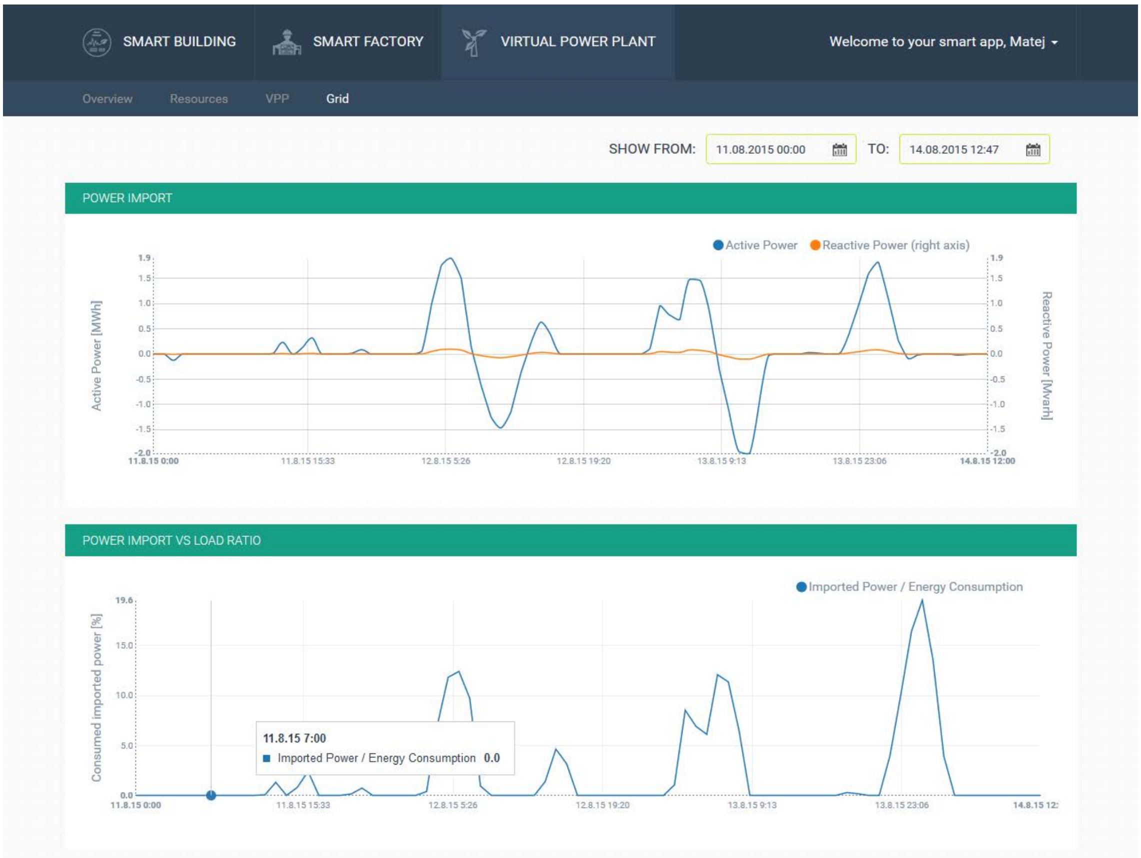

Figure 14: The top part of the Grid view in the Virtual Power Plant's application

The **Grid** view is aimed at the DSOs. It provides the data obtained at the power lines from the power system where the VPP and the consumer are located. The system is presented in Section 3.3. The Figure 14 and the Figure 15 show an example view, which also includes:

- the date and time range selection, where the user can select the range of the history data to be used for the rest of the view,
- a chart showing the power import from the external grid, including both the active and reactive power import history,
- a chart showing the percentage of the import with respect to the consumer's load,
- a chart showing the history of the active and reactive power total loss,
- a list of power lines in the power system, where the user can select a line to inspect the data from,
- a chart showing the history of the active power flow for the selected power line,
- a list of voltage nodes, which the user can click to select an individual voltage node to inspect the data of,
- a chart showing the node's voltage history.

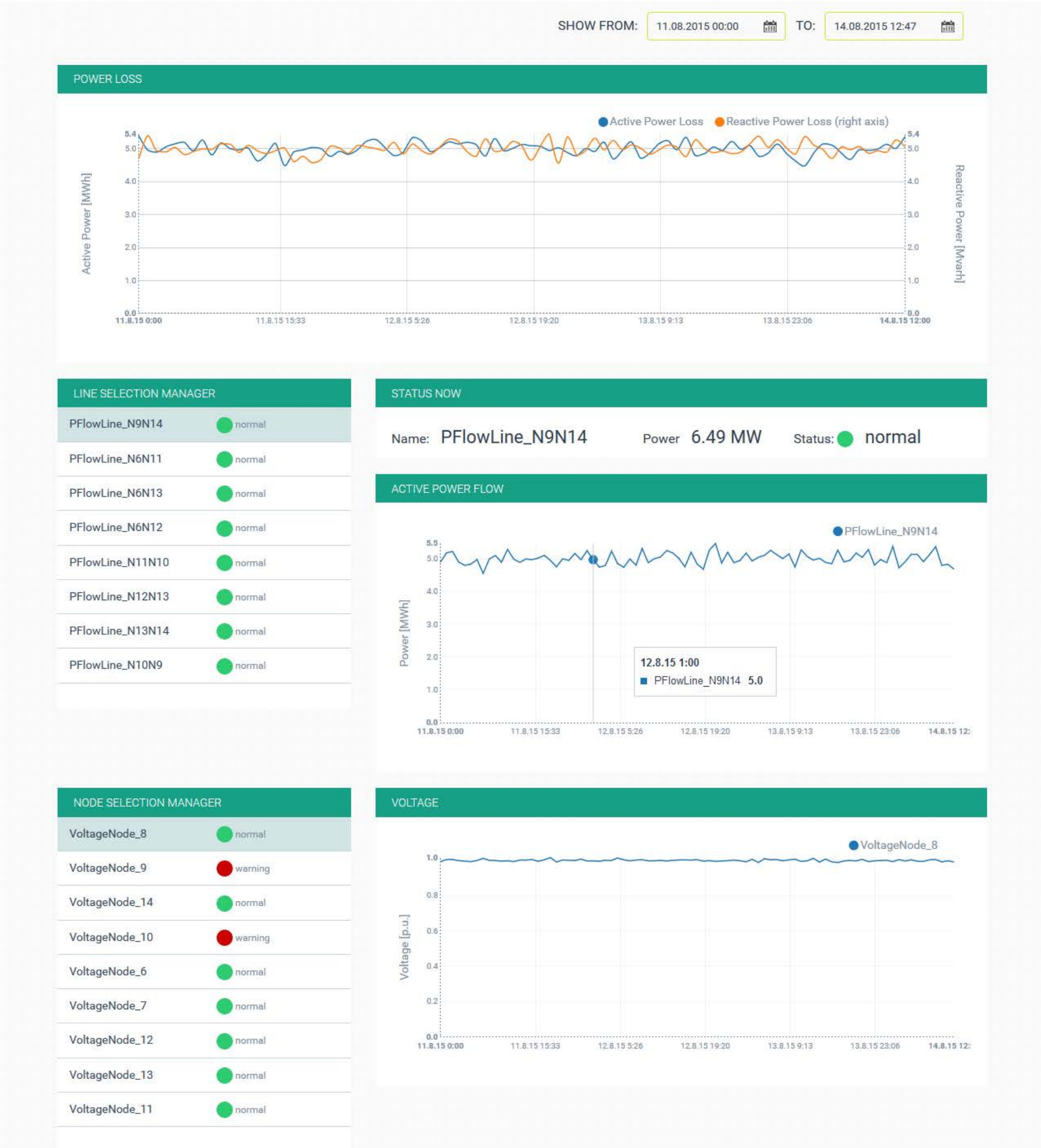

Figure 15: The bottom part of the Grid view in the Virtual Power Plant application

To demonstrate the application's functionality, we integrated the simulation, explained in more detail in Section 3.3.

3.2 Mechanisms of balancing

Today we are seeing an increasing amount of electricity produced by renewable energy. This has many advantages such as less CO_2 emissions, decrease of the dependence on coal and other fossil fuels, etc. For this reason there is a trend to use green power to run the production in factories. Typically, this is being used as marketing instrument to demonstrate the protection of the environment. On the other hand the volatile character of renewable energy makes necessary to find mechanisms to deal with the uncertain availability of renewable energy. In this work package the virtual power plant represents the volatile energy generation by renewables while the Smart Factory consumes this energy to carry out the production.

The energy balancer makes sure to identify the production plan fitting best the energy generation forecast of the power plant. This is done in advance as planning phase. The system is built in a way that the relevant information for the energy balancing is communicated via Generic Enablers. This information is the energy generation forecasts, the production plans as well as the deviation of both. Using Generic Enablers for this communication allows for easy implementation and configuration of this system. In the Figure 16 you can see the architecture with respect to the energy balancer.

Prerequisite for the energy balancing are the energy generation forecasts of the power plant as well as the factory production schedules describing the forecast of the energy consumption. The balancer takes both into account and determines the best fit. There might be deviations on the energy generation and energy consumption which come in as kind of real time event. Such events may be reported by the VPP or the Smart Factory. In case such event rushes in, the balancer determines the necessary adoptions to the production plan and reports the changes in both directions, to the power plant as well as to the factory.

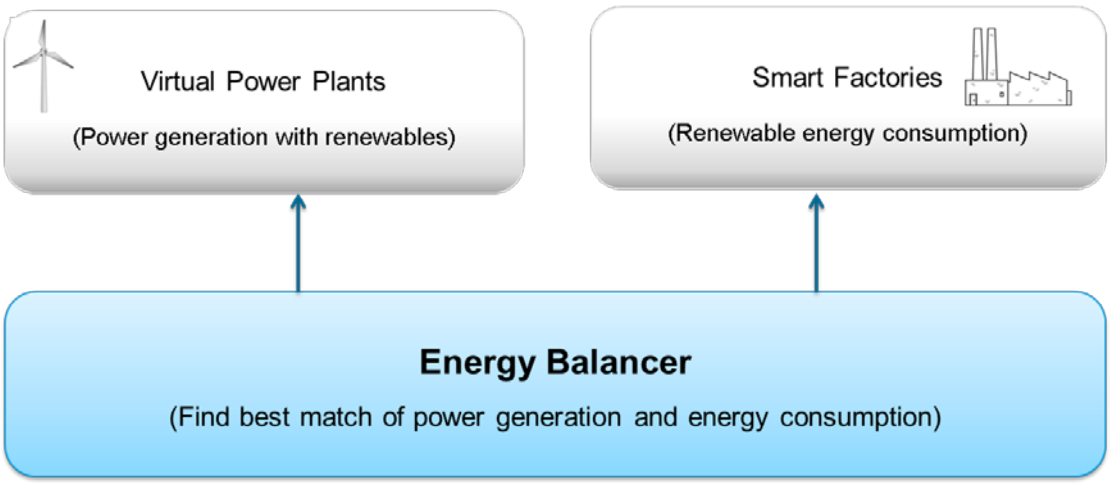

Figure 16: Energy Balancer

WP3's system allowed the evaluation of the principles of energy balancing and clearly showed how easily such systems can be created using Generic Enablers. These components providing a standard way to transport information between the different parts of the system allow easy plugging together the different parts of the architecture.

Currently energy balancing focuses on a single region where the energy is both generated and consumed. An outlook would therefore be to refine the balancing in a way that this is taken into account. Doing so, this would be a great step toward smart grids where the energy is preferably consumed in the same region as it is generated. Thus, the transmission grid power flows would be balanced as well.

For this refinement some adjustments would be necessary. The information on the power generation must be collected per region as the consumed energy must be collected per region. This regional information must be provided for the forecasts as well as for the deviations which come as real-time events.

3.3 Simulation based analysis of impact of VPP operation on electrical grid

Impact of B2B balancing approach on electrical grid operation is evaluated based on simulation of a benchmark power system that includes distributed energy resources operated by a VPP in order to represent the trial site. Standard IEEE 14-bus system, illustrated in Figure 17, is selected as a benchmark power system which is modelled and simulated in Real-Time Digital Simulator. Benchmark power system is updated in order to more realistically represent the trial site, i.e. frequency and voltage levels are adjusted according to European power grid. Simplified models of DERs are added into the benchmark power system model in RTDS. A distributed solar/wind generation (DG) unit is represented as a grid-feeding distributed generation unit modelled as a voltage controlled source. Active and reactive power profiles of DGs can be fully controlled in simulation model which allows for representation of realistic generation profiles of real DGs of the trial site. It is important to emphasize that real-time simulation of power system and DERs provided by RTDS enables realistic validation and demonstration of a cloud-based VPP platform since balancing, monitoring and visualisation functionalities of VPP platform can interact with simulated DERs in the same way as with real DERs from trial site.

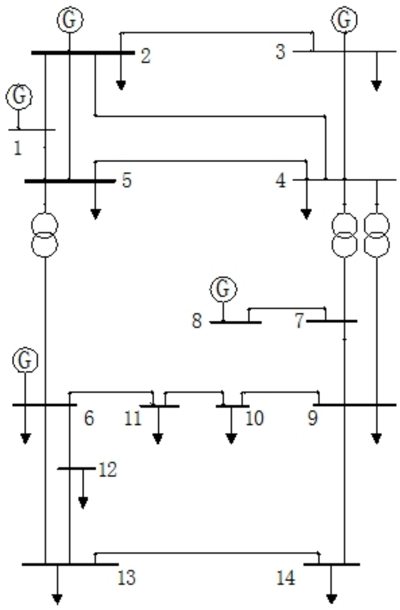

Figure 17: Benchmark power system

Described simulation of trial site is carried out to investigate impact of B2B energy balancing approach on technical aspects of electrical grid operation. In this respect, the following aspects are considered:

- voltage profiles,
- power import from external grid,
- line utilization (line power flows)

As already mentioned and illustrated in this document, Smart Factory offers three alternatives of consumption schedules to energy balancing mechanism: Schedule 1, Schedule 2 and Schedule 3. Based on total generation of VPP, energy balancing mechanism selects the optimal schedule. For simulation purposes, consumption schedules of the Smart Factory as well as generation profile of VPP are generated based on real data from the trial site. Simulation analysis presented in this document considers operation of one day. In all simulation scenarios Smart Factory as a dynamic load is scaled up with the goal to evaluate extreme scenarios from energy balancing and electrical grid perspective.

In order to gradually demonstrate impact of VPP operation together with energy balancing mechanism on electrical grid, the following simulation scenarios were analysed:

Scenario 1 – Reference scenario without local generation: This scenario is considered as a reference scenario and entire demand of Smart Factory is covered by external network. There is no local generation provided by DG and therefore, balancing mechanism is not applied. Simulation of this scenario is performed for three different use cases, namely, for consumption profiles of Smart Factory based on three alternatives: Schedule 1, Schedule 2 and Schedule 3.

Scenario 2 – Local generation without balancing mechanism: In this scenario DG units that are comparable to Smart Factory load are integrated in the same area, i.e. bus 10 in benchmark power system. Generation provided by DG units covers in average Smart Factory demand but balancing mechanism is not applied. This refers to the scenario when consumption profile of Smart Factory is defined according to the schedule ranked with lowest priority by energy balancing mechanism, which in worst case might be the schedule with highest priority from Smart Factory perspective. This scenario is referred to as unbalanced scenario.

Scenario 3 – Local energy balancing: This scenario reflects B2B energy balancing approach implemented in the trial site of WP3 within FINESCE. Namely, in addition to scenario 2, a balancing mechanism is applied to local generation and Smart Factory demand. Therefore, Smart Factory follows schedule suggestion from energy balancing mechanism. More precisely, this refers to the scenario when consumption profile of Smart Factory is defined according to the schedule that is marked as optimal by energy balancing mechanism. This scenario is referred to as balanced scenario.

3.3.1 Simulation results of scenario without balancing mechanism

Simulation results of Scenario 2 and Scenario 1 with Smart Factory load following consumption profile according to unbalanced scenario are compared in this section.

Voltage profiles are expected to be regulated within standard limits of ±10% with respect to nominal (1 per unit) value. Based on results illustrated in Figure 18, it can be concluded that integration of local generation improves voltage level with respect to buses that are far from connection to higher voltage level, such as voltage at bus 14. However, voltage at buses that are located near to connection to higher voltage level and to local generation, could be increased outside limits in case of higher penetration of distributed generation. Even within acceptable limits in this simulation case, this effect is indicated with simulation results of voltage profile at bus 11.

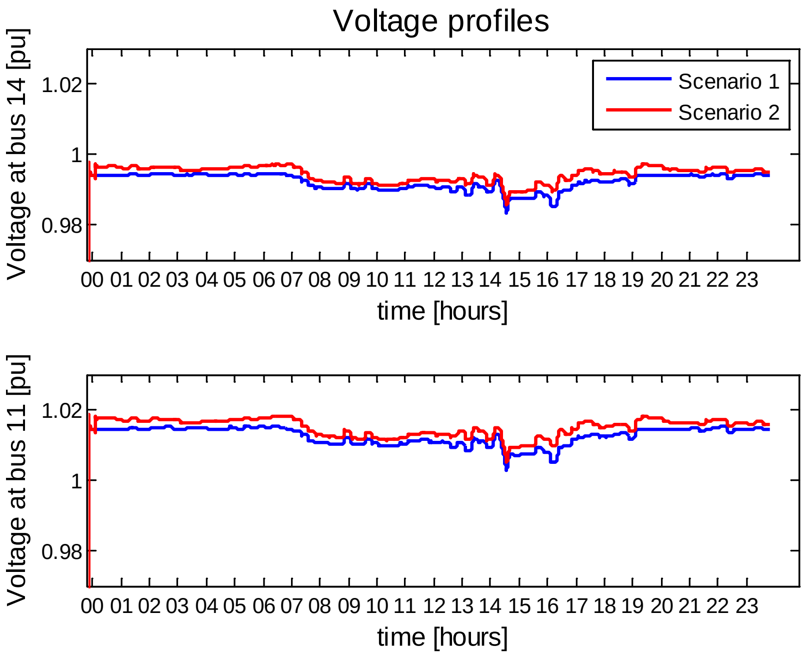

Figure 18: Comparison of voltage profiles of scenarios without (Scenario 1) and with local generation (Scenario 2)

Scenario 1 refers to the reference scenario without local generation as described above, with total demand covered by external network. Therefore, in scenario 2 power import from external network should be decreased. As illustrated in Figure 19, obtained simulation results indicate that integration of DGs allows in general for decrease of the import from external electrical grid However, since balancing mechanism is not applied, peak of demand from external network is not significantly reduced. This means that a significant support from external network is still needed.

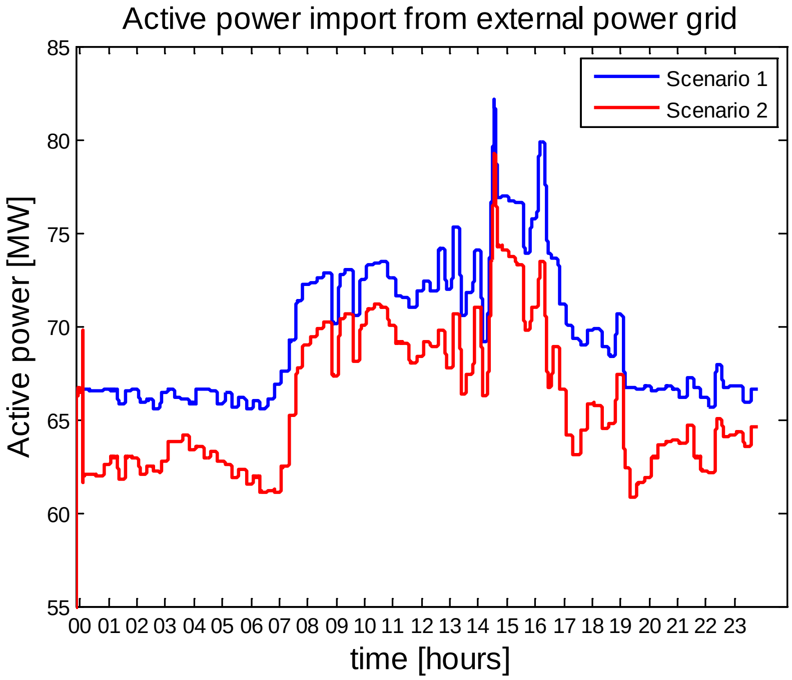

Figure 19: Comparison of active power import from external (high voltage) grid of scenarios without (Scenario 1) and with local generation (Scenario 2)

With respect to line power flows, it is preferred to to achieve lower utilization of lines with introducing local generation. However, this is not the case for all lines. The Figure 20 illustrates active power line flows influenced by local generation where both effects are indicated. Namely, power flow through a line can be decreased due to local energy consumption, but generation that is not utilized locally increases power flow of some lines.

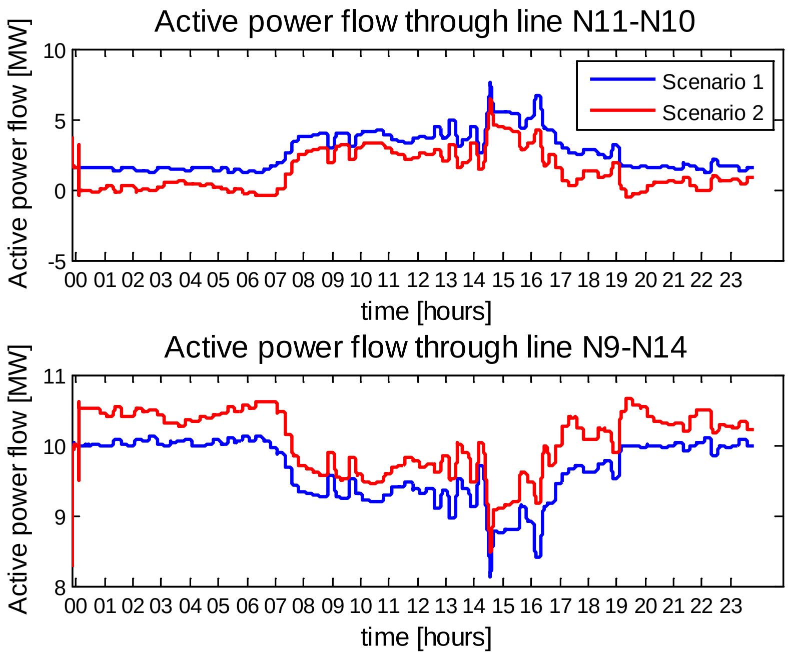

Figure 20: Comparison of active power flow through lines in scenarios without (Scenario 1) and with local generation (Scenario 2)

3.3.2 Simulation results of scenario with local energy balancing

Simulation results of Scenario 3 and Scenario 1 with Smart Factory load following consumption profile according to balanced scenario are compared in this section.

Figure 21 illustrates that similar conclusion can be derived for voltage profiles regarding bus location with respect to high voltage connection and DG connection. However, in addition, balancing significantly improves voltage profile in terms of variations. This effect was not achieved in Scenario 2, although voltage levels were increased in general.

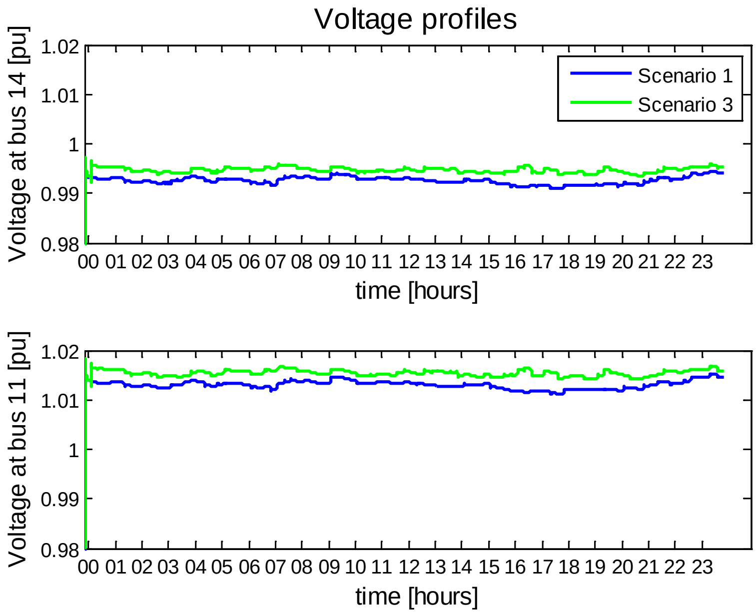

Figure 21: Comparison of voltage profiles of scenarios without local generation (Scenario 1) and with local energy balancing (Scenario 3)

Figure 22 shows import from external grid in case of balanced scenario 3. As expected, demand is decreased due to local generation, and furthermore, peaks are flattened due to better balancing of local generation and local consumption compared to scenario 2 that is illustrated in Figure 19.

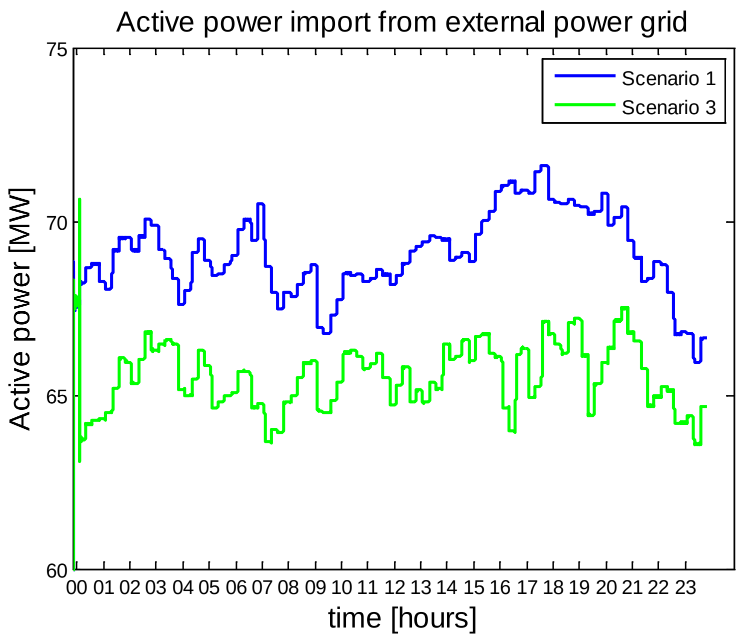

Figure 22: Comparison of active power import from external (high voltage) grid of scenarios without local generation (Scenario 1) and with local energy balancing (Scenario 3)

Figure 23 illustrates simulation results with respect to line power flows.

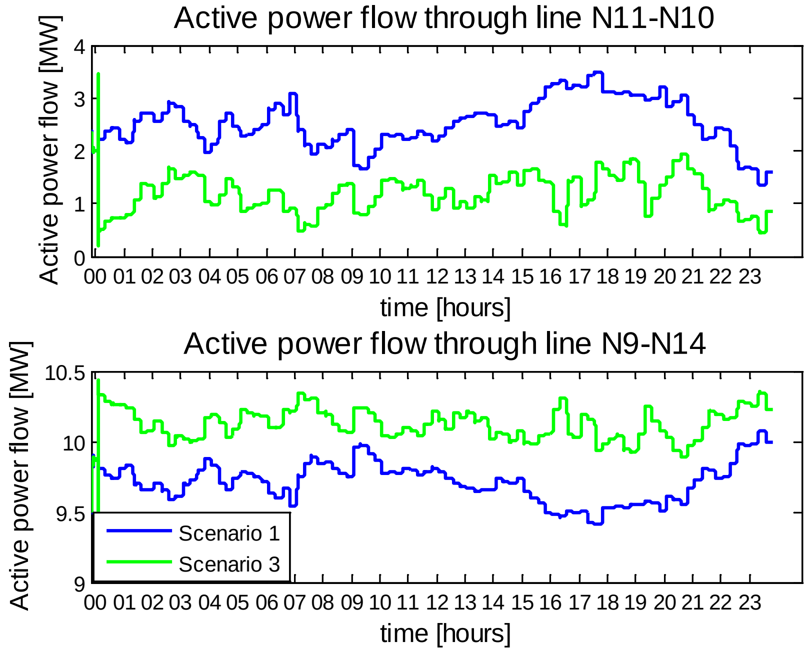

Figure 23: Comparison of active power flow through lines in scenarios without local generation (Scenario 1) and with local energy balancing (Scenario 3)

3.3.3 Conclusion

Benefits of balancing approach developed within FINESCE with respect to addressing challenges of increasing penetration of renewables are demonstrated here. It can be concluded that proposed balancing approach has a positive impact on electrical grid operation compared to "fit&forget" principle of integrating DERs.

3.4 Demand Side Management

Integration of factories is a crucial aspect of this set-up, as traditionally they do not actively engage with the energy grid. As discussion with factory operators showed, the complexity of such integration should be hidden from the factory as much as possible. From the three possible communication strategies, we chose the least invasive one from the factory's perspective: The factory's production planning and control system (e.g. ERP or MES) creates three alternative production schedules of equal conformity with production goals. Those are being fed to the VPP, which then chooses the one with the highest overlap with their desired load profile. Figure 24 shows the three strategies, with the chosen one the Flexible Loads approach.

To gather the necessary data for such integration, energy monitoring infrastructure needs to be rolled out. Discussion with the industry show that such investments are only carried out if combined with an additional value proposition – e.g. predictive maintenance for the machines based on their energy consumption data.

Integrating such energy balancer in the VPP infrastructure allows to know about the energy consumption in advance and to be able to optimize energy generation accordingly. On the one hand this means to optimize the efficiency of the power plant and on the other side to distribute the energy locally and thus, to relieve the transmission grid.

To combine distributed energy sources to one VPP a monitoring infrastructure is needed to gather the necessary data. The monitoring and management of the VPP does not interfere with the normal operation of the energy sources. The ICT system to process the data and communicate with partners is separate from the energy sources.

The factory manager in such a system has a significant role, and hence a well-structured and useful user interaction with them is important in order to allow for a successful system. They need to gain insights into their factory to involve them in the system, and they also need to understand their role and the results of their actions without detailed knowledge about the energy grid.

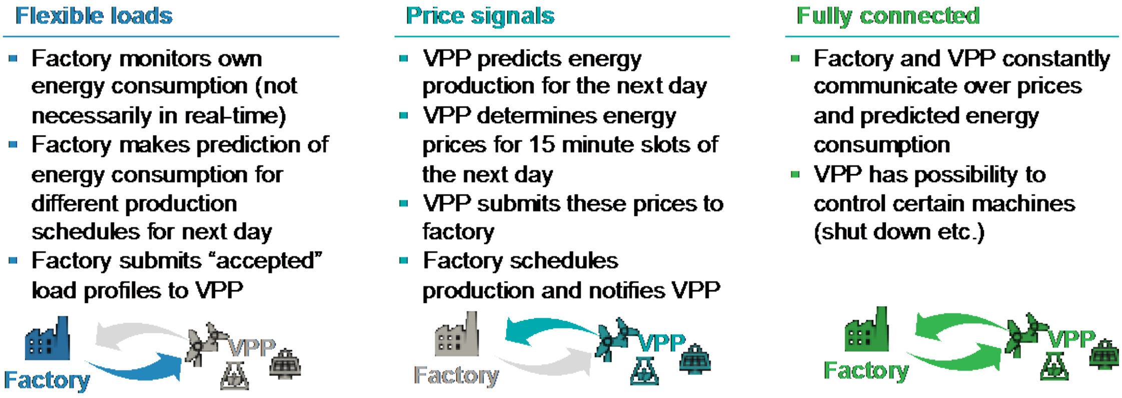

Figure 24: Three possible strategies to integrate a factory into a VPP

A cloud-based infrastructure, i.e. using FIWARE, as deployed in the trial offers a large potential benefit for the wide-scale adoption of demand side management: by moving the business intelligence and rules out of the local IT and into the cloud, it becomes more abstract and therefore applicable to different environment. This means, that the same analysis and intelligence solutions can be used in several factories, while only being developed and validated once. The software developed within the trial can be transferred to another factory with ease; only the underlying infrastructure (energy monitoring devices and their connection) needs to be carried out in a similar/ compatible manner. Further improvements on the algorithms then in turn are made available to the first factory as well. This creates a network effect where all users of the same cloud infrastructure benefit from each other.

4. Trial Results on Simulation of scaled up trial scenarios

Impact of VPP operation, in particular of balancing concept, on electrical grid was studied in Section 3.3 based on developed simulation framework. Focus of simulations that were carried out was on basic scenarios available by trial infrastructure. Benefits and impacts of balancing approach were illustrated. Further investigation based on scenarios that might bring challenges in preserving technical standards of electrical grid operation in case of presence of distributed generation and VPP operation are performed. Namely, this chapter further extends results on trial findings based on scaled up trial scenarios.

The following scaled up trial scenarios are considered and investigated:

- Scaled up scenario I: VPP operates DERs located in two different areas from electrical grid perspective.
- Scaled up scenario II: Higher penetration of renewables and presence of intensive industrial loads in electrical grid.

4.1 Simulation results of scenario with 2-area VPP

As mentioned, in this scaled up simulation scenario VPP operates DERs located in two different areas from electrical grid perspective. Namely, VPP units are connected to bus 10 and 13 with respect to benchmark power system. This simulation scenario is designed in a way that identical VPP that was studied in Scenario 3 in Section 3.3 located at bus 10, is additionally added to the bus 13. It is assumed that Smart Factory follows consumption schedule suggested as the optimal from energy balancing mechanism. The goal is to get insights into scalability of energy balancing mechanism.

Two simulation scenarios are illustrated here. Scenario I.1 refers to reference scenario where VPP is only added to the bus 10. Scenario I.2 refers to scaled up scenario where VPP is added to buses 10 and 13 as described above.

Simulation results of voltage profiles for both scenarios are illustrated on Figure 25 indicating that scaled up scenario follows the same trend. Voltage levels are increased additionally if VPP is added to the bus 13 in addition to the bus 10. Balancing mechanism helps to keep relatively small variations of voltage levels in scaled up scenario.

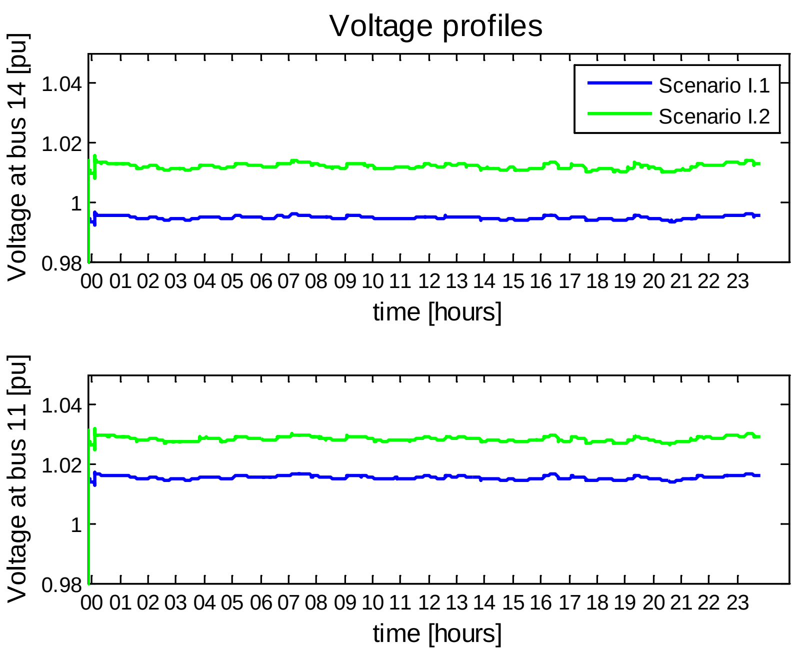

Figure 25: Comparison of voltage profiles of scenarios with 1-area VPP (Scenario I.1) and 2-area VPP (Scenario I.2)

Active power import from high voltage grid in case of reference and scaled up scenario are shown in Figure 26. Results demonstrate that balancing mechanism helps local utilization of energy and decreases demand from external grid. It should be emphasized that total load is increased, but with properly balanced local generation the total demand from external grid is decreased.

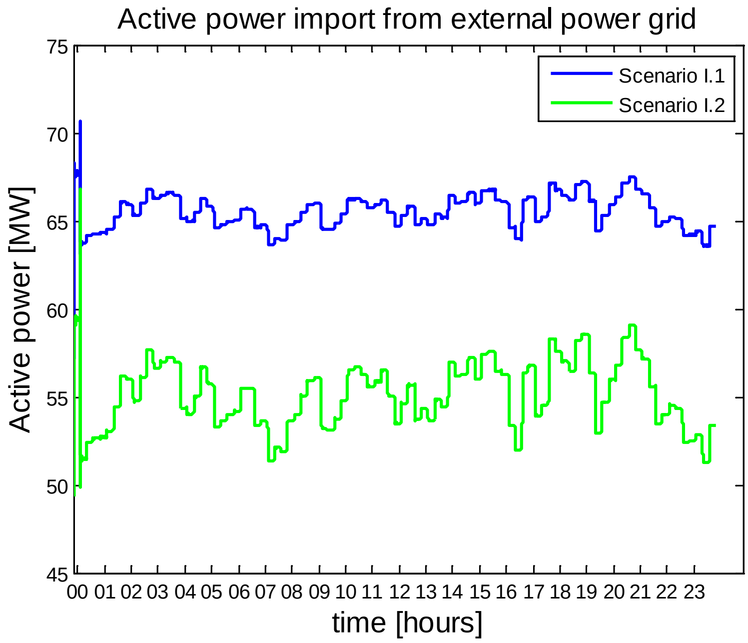

Figure 26: Comparison of active power import from external (high voltage) grid of scenarios with 1-area VPP (Scenario I.1) and 2-area VPP (Scenario I.2)

Figure 27 illustrates simulation results with respect to active power flow through lines. As expected, local balancing applied in 2 areas results in flows with relatively smaller variations.

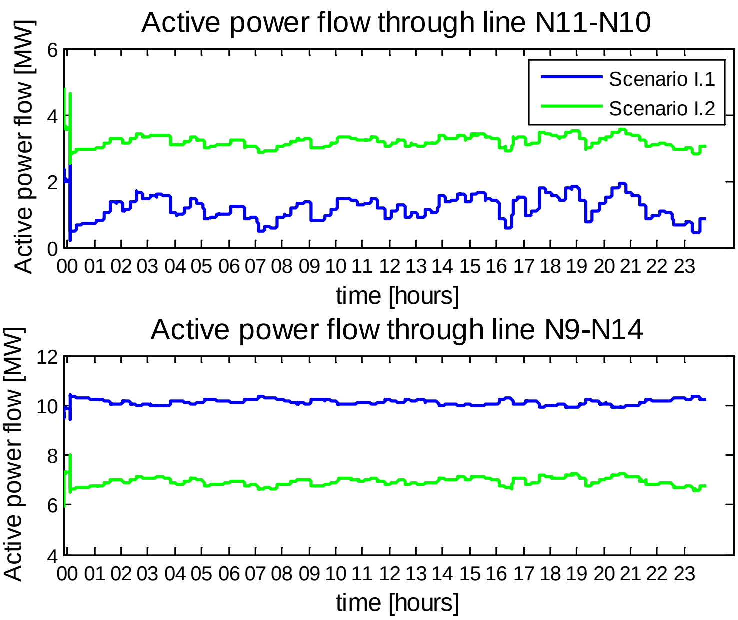

Figure 27: Comparison of active power flow through lines in scenarios with 1-area VPP (Scenario I.1) and 2-area VPP (Scenario I.2)

4.2 Simulation results of scenario with high penetration of distributed generation and presence of intensive industrial loads

This section analyses scaled up scenario with respect to level of penetration of distributed generation and higher presence of industrial load profiles. Scenario in previous section 4.1 is considered as reference scenario (Scenario II.1) and further scaled up. Namely, apart from additional area of VPP operation, generation profiles are scaled up by factor 5, while consumption schedule of Smart Factories is scaled up by factor 2. This scenario is referred to as Scenario II.2 and represents situation where only part of the generation is balanced with demand, while the other part is not. The aim is to demonstrate the need to include more loads into balancing mechanism in case of higher penetration of distributed generation. In this case, all benefits of balancing mechanism could be fully exploited in particular in case of future power systems with dominant distributed generation over conventional power plants.

Voltage profiles are illustrated on Figure 28. It can be concluded that in scaled up scenario voltage levels are closer to recommended limits (5-10%). Integrating more loads into balancing mechanism could help to maintain voltage variations.

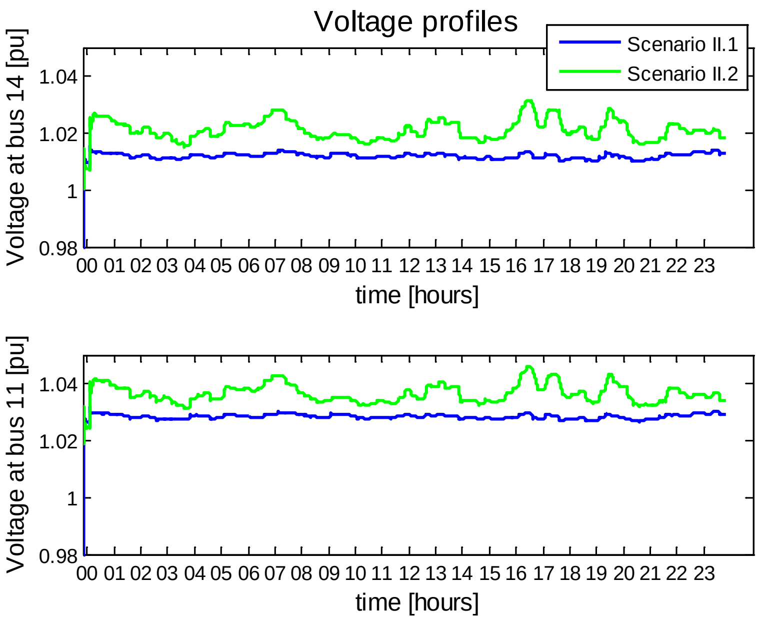

Figure 28: Comparison of voltage profiles of Scenario II.1 and Scenario II.2

Figure 29 illustrates that although there are time frames with very low demand from external power grid, to eliminate entirely the need of external import for a specific range, it is needed to include additional load profiles into balancing mechanism.

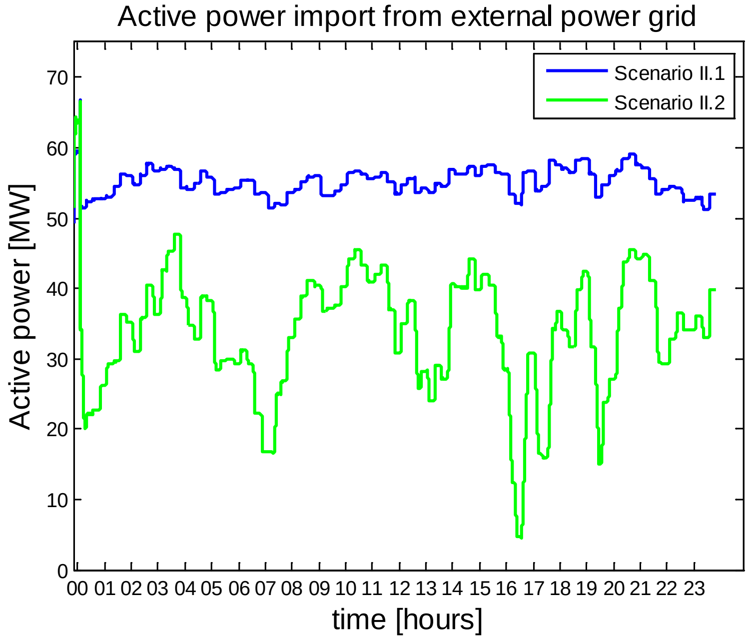

Figure 29: Comparison of active power import from external (high voltage) grid for Scenario II.1 and Scenario II.2

Finally, active power flows in both simulation scenarios II.1 and II.2 are shown on Figure 30. Significant change in power flow is expected due to integration of high level of distributed generation. Furthermore, reverse power flow is obtained for the line between nodes 10 and 11. In this particular topology, this is not an issue, but it might be for other topologies.

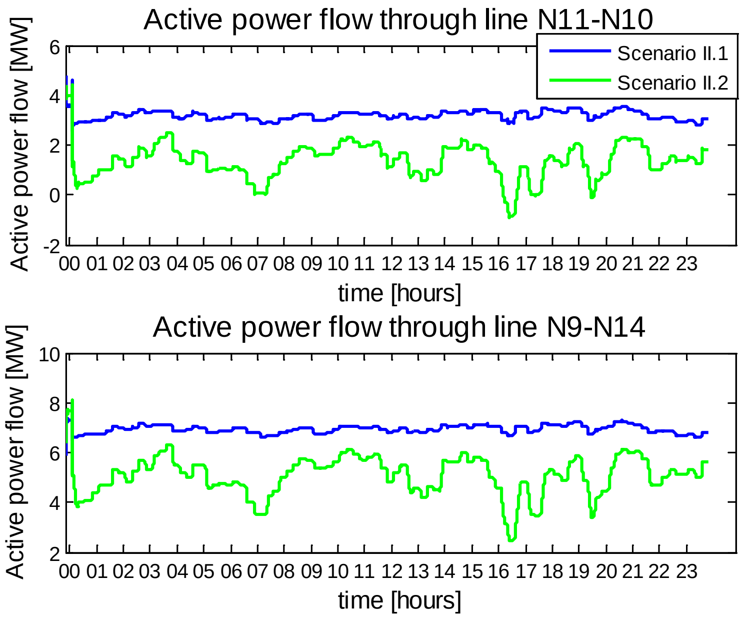

Figure 30: Comparison of active power flow through lines for Scenario II.1 and Scenario II.2

As already mentioned, this simulation scenario is designed to illustrate effects of situation with high level of distributed generation that is only partly balanced with local demand. This approach allowed for explicit demonstration of the importance of balancing approach developed within FINESCE as well as the benefits to integrate more loads into balancing mechanism.

4.3 Conclusion

Further investigations based on scaled up trial scenarios that might bring challenges in preserving technical standards of electrical grid operation in case of presence of distributed generation and VPP operation were performed. Aiming at the best utilization of the local generation by local consumption, energy balancer enables the reduction of global balancing problem based on solving local balancing problems. Simulation results indicate that this is beneficial in particular in scenarios with high penetration of renewables and presence of intensive industrial loads in electrical grid.

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5. Conclusions

FIWARE and its GEs have been proven to be of substantial help in setting up the trial site infrastructure. The trial went live after sixth months, which was only possible due to the deployment of mature and useful technologies. Compared to alternative solutions, all deployed GEs readily offer the functionalities required by the trials, and they also perform well. The FIWARE GEs provided the functional performance necessary in the trial components for the special tasks like e.g. the complex event processing. They therefore enabled the developers to focus on solving the problem at hand rather than spending the time and effort to implement event-processing algorithms. The new partners who joined the project as a result of the Open Call were also able to quickly and smoothly integrate into the existing work.

One major advantage is also the openness and the availability of the source code of the GEs, this way there is no vendor lock-in to be considered when planning and developing the system. During the trial the continuous use of the chosen GEs for the implementation of the B2B energy eco-system in its different components showed that they were suitable for the application and fulfilled the requirements on the functionality and performance.

The trial combines renewable energy resources in different countries to one VPP, managing the VPP in a cross-border scenario. Additionally, the trial features an energy driven factory. Having such an infrastructure at disposal for testing new methods and software systems is a strong value proposition for big industry players from a variety of fields. Our trial showed the potential of integrating discrete manufacturing factories into the smart grid for the sake of energy balancing. The potentials for utilities are especially large for urban areas like the Cologne/ Aachen region with a lot of factories and DERs as well. A cross-border integration greatly improves balancing potentials. For telecommunications operators this development also holds market potential, as a variety of DERs and manufacturing machines need to be equipped with more sophisticated communications technology.

The technologies built into the trial include the complete stack, which starts at the lowest level with the tools for reading the power consumption in the factory and ends with the graphical user interface at the very top. This makes for a complete product offering demonstrated on the real generators and factory. The implementation is composed of a good balance between FIWARE GEs, custom proprietary components and open-source DSEs. On the other hand, a number of components in this stack may be used independently of the other components, granting a high level of reusability and possible customization for creating new or similar products. One example of such reusability is the visualisation framework, which we already used in the WP1's Smart Building trial.

Benefits of balancing approach developed within FINESCE with respect to addressing challenges of increasing penetration of renewables are demonstrated based on a realistic simulation framework. It was concluded that proposed balancing approach has a positive impact on electrical grid operation. Aiming at optimal utilization of the local generation by local consumption, balancing approach is beneficial in particular in scaled up scenarios, i.e. scenarios with high penetration of renewables and presence of intensive industrial loads in electrical grid.

Based on the trial results, a real-world setup of such a B2B energy eco-system can be realized in an efficient manner. The technical feasibility could be shown, as well as potential for balancing loads within such an environment. A scaling up of the eco-system in a simulation further showed its applicability to larger areas involving larger number of flexible loads and renewable generation units in balancing mechanism.

6. List of Abbreviations

B2B	Business to Business
BMS	Building management system
CAPEX	CAPital EXpenditure
CENELEC	European Committee for Electro technical Standardization
CEP	Complex Event Processing
COTS	Commercial off-the-shelf
CPMS	Charge Point Management System
CSA	Cloud Security Alliance
EMS	Decentralised energy management system
DER	Distributed Energy Resources
DMS	Distribution Management System
DMTF	Distributed Management Taskforce
DSE	Domain Specific Enabler
EAC	Exploitation Activities Coordinator
ERP	Enterprise Resource Planning
ESB	Electricity Supply Board
ESCO	Energy Service Companies
ESO	European Standardisation Organisations
ETP	European Technology Platform
ETSI	European Telecommunications Standards Institute
FISFEPS	Future Internet Smart Factory Energy Planning System
FPL	FINESCE Presentation Layer
GE	Generic Enabler
HEMS	Home Energy Management System
HV	High Voltage
I2ND	Interfaces to the Network and Devices
ICT	Information and Communication Technology
IEC	International Electro-technical Commission
IoT	Internet of Things
KPI	Key Performance Indicator
LV	Low Voltage
M2M	Machine to Machine
MPLS	Multiprotocol Label Switching
MV	Medium Voltage
NIST	National Institute of Standards and Technology
O&M	Operations and maintenance
OPEX	OPerational EXpenditure
PM	Project Manager
PMT	Project Management Team

PPP	Public Private Partnership
QEG	Quality Evaluation Group
S3C	Service Capacity; Capability; Connectivity
SCADA	Supervisory Control and Data Acquisition
SDH	Synchronous Digital Hierarchy
SDN	Software defined Networks
SDOs	Standards Development Organisations
SET	Strategic Energy Technology
SET	Strategic Energy Technology
SG-CG	Smart Grid Coordination Group
SGSG	Smart Grid Stakeholders Group
SME	Small & Medium Enterprise
SoA	State of the Art
SON	Self Organizing Network
SS	Secondary Substation
TL	Task Leader
TM	Technical Manager
VPP	Virtual Power Plant
WP	Work Package
WPL	Work Package Leader