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DELIVERABLE 3.5.1
Smart Energy Management Dashboard

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Executive Summary

This deliverable D3.5.1 "*The Smart Energy Management Dashboard"* presents the design and implementation of the prototype of the smart energy dashboard for prosumers and utilities corresponding to SIT4Energy TG1 and TG2.

The prosumer dashboard focuses on providing visualisations of energy production and consumption to inform decisions to improve energy management complemented by recommendations on how to optimise production and consumption.

The utility dashboard was developed to support utility analysts to analyse energy demand and supply to identify consumption and production patterns that could be used to aim the decision-making process regarding energy management in the company.

In addition, this deliverable illustrated both applications by presenting evidence of the design and implementation of the dashboards.

This deliverable is structured as follows:

Section 1 introduces a description of this deliverable as well as the related tasks.

Section 2 presents the prosumer dashboard regarding the objectives, the design and the implementation process. The main functionalities focus on supporting prosumers to improve energy management by analysing their energy consumption and production to promote self-sufficiency. The presentation includes screenshots of the prototype illustrating the main functionalities of the application. In addition, it includes a brief description of a feedback session with potential users obtained in the last user workshop as well as the results obtained so far.

Section 3 describes the utility dashboard regarding the objectives, the design and the implementation. The dashboard supports exaplainable interactive forecasting of day-ahead demand for small utilities by combining machine learning techniques (kNN) with visual analytics. The first prototype enables utility analysts to describe the expected day in terms of expected weather parameters and to obtain a selection of most similar days from the past and the visualisation of of their demand and supply curves (historical data), as well as the parameters that characterized the days in question. The analysts can then use visual analytics functionalies to inspect the visualized results for the different days and the underlying parameters in order to compare them between each other and determine the most likely expected demand for the expected day. Since the analysts can set the input parameters for the day to be forecasted at will, the prototype also allows them to perform "what-if" analysis for any given expected situation (e.g. deviations from expected weather forecasts for the day ahead, or looking ahead for more than one day). In this way, the utility analysts can analyse the relationship between the behaviour of different factors over the day and their influence on the energy demand and production.

Section 4 presents the conclusions and the guidelines for the development of a future version of the dashboards.

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List of Acronyms and Abbreviations

Term	Description
EE	Energy Efficiency
EMS	Energy Management Service
EU	European Union
HUA	Harokopio University of Athens

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1. Introduction

The goal of the SIT4Energy project is to demonstrate how integrated energy management for prosumers can be realised through smart IT solutions supporting the identification of efficiency potentials in local energy production and consumption. The project includes the development of applications under the user-centered design perspective to actively support users to improve energy management.

This deliverable presents the development and implementation of a Smart Energy Management Dashboard for prosumers and for utilities to support them to improve their energy management activities. To this end, a prosumer dashboard was developed to enable prosumers to analyse their energy consumption and production in order to optimise their energy management accordingly and thus to reduce their energy costs and carbon footprints. The development of the utility dashboard was focused on facilitating the analysis and interactive forecasting of energy demand and supply considering relevant factors such as weather conditions. Both applications take advantage of visualization and visual analytics techniques to facilitate the understanding and identification of patterns regarding consumption and production. Therefore, this deliverable describes the first prototypes of the two dashboards, their design and implementation. The prototypes will be evaluated and further refined in the project pilots that are organized in workpackage 4.

1.1 Scope and objectives of the deliverable

This deliverable presents the Smart Energy Management Dashboard for prosumers (Section 2) and for utility analysts (Section 3). For both applications, the relevant use cases and/or information needs that provided the basis for the development of the applications, as well as the user-centered design process are outlined. Then, an overall description of the main components in the implementation process is presented. Finally, the system design and the implemented applications are described. The latter includes the use of visualization and visual analytics techniques to support the interaction and analysis of relevant patterns of energy consumption and production.

The objective of this deliverable is to:

- Describe the design and implementation of the first prototype of the Smart Energy Dashboard for prosumers and of the Smart Energy Dashboard for utility analysts.
- Provide an overview of the main features implemented in each of the two functional prototypes,
- Give a brief outline of the user-centered design process.

1.2 Structure of the deliverable

This deliverable D3.5.1 "*The Smart Energy Management Dashboard*" is structured in 4 sections. Section 1 introduces the deliverable. Section 2 describes the smart energy management dashboard for prosumers providing a background on the user-centred design process as well a description of the prototype design and implementation. Section 3 addressed the development of the smart energy management dashboard for utilities including a description of the architecture and the system design. Finally, section 4 presents the conclusions of this deliverable.

1.3 Relation to other tasks and deliverables

This deliverable covers the design and development of the smart energy management dashboard for prosumers and for the utilities. The SIT4Energy applications are developed under the user-centred design methodology, therefore, it is important to understand the user as well as their energy-related activities in order to design these applications. Accordingly, this deliverable is related to the insights presented in the deliverable D1.3.1 User Information Model that contains the description of the user information needs. Subsequently, the prototypes described in this deliverable will be used, evaluated and refined in the project pilots (T4.3).

2. Smart Energy Management Dashboard for Prosumers

The smart energy dashboard prototype for prosumers is based on the use-cases *“Visualisation of energy production and consumption to inform the decisions of prosumers about achieving energy balance”* and *“Receiving recommendations for prosumers to optimize their consumption and production”* presented in MS1.1. The main objective is for prosumers to have a tool that provides them with information on their production and consumption as well as allows them to increase their self-sufficiency.

The smart energy dashboard combines interactive visualization, explorative analysis and provides recommendations to prosumers on how to better manage their energy demand. In this way, prosumers can plan their energy consumption accordingly, as well as better balance their energy production and consumption.

The first prototype of the sit4energy dashboard for prosumers is available at: http://h2823152.stratoserver.net:8080/

2.1 Background and user-centred design process

As defined in the D1.3.2 User Information Model prosumers can be motivated by various factors (e.g. monetary, environmental) [1], but overall they invest in PV plants or other energy-producing technology with the idea of being able to cover a part or their whole energy consumption without being reliant on external energy resources from the utility.

The main idea of the dashboard is thus o encourage prosumers to improve their self-sufficiency, meaning to be better at matching their consumption to their production. Improving self-sufficiency means consuming energy when there is a lot of solar energy available and consuming less when the production is low. The concept of self-sufficiency has been studied within the area of energy efficiency, prosumers and PV panels, it was mainly related to such concepts as storage [2, 3], or was researched as allowing to better manage energy resources from a community perspective [4,5]. However, we propose that self-sufficiency is an important indicator also for those prosumers who don’t have storage and are not necessarily a part of an energy cooperative (or community). By being able to constantly monitor their self-sufficiency levels as well as being conscious when the production peak is coming would allow them to balance out their consumption so that they can use more of the energy they produce themselves. In this way, the prosumers are paying less for their energy bill and are more sustainable by relying on their own production.

The dashboard is then designed with self-sufficiency concepts that span through most of the visualizations. In order to improve their self-sufficiency, the dashboard provides self-sufficiency indicators for various time periods: for a day, a month or a year; it shows the actual self-sufficiency that was achieved as well as potential self-sufficiency which could be achieved if the users could use up all of the energy that they produce. Additionally, users receive recommendations on how to increase their self-sufficiency as well as notifications about times

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when production is expected to be high (for example, a higher than the average number of sun hours) – described in D3.4.1 Context-aware triggering service. Taken together these mechanisms ensure that the prosumers are able to optimize their consumption to achieve higher self-sufficiency levels.

In order to design the dashboard, a workshop with a set of prosumers has been conducted where their needs as a prosumer were derived (reported in D1.3.2 User Information Model). Then a set of mock-ups has been developed to cover the main ideas and needs of the prosumers. Then several of these mock-ups have been implemented into a prototype (presented in Section 2.3). Then in December 2019, the prototype was demonstrated to a set of prosumers of Stadtwerk Hassfurt (see Figure 1) who would be the potential users of the dashboard to verify whether the developed prototype matches their needs. Overall, the users responded well to the prototype and said that they would be willing to use it once it becomes available. They also gave several feedback points which will be implemented in the next version of the dashboard.

Figure 1: Prosumer Workshop in Hassfurt

2.2 System design

The application was built using the React framework by Facebook. We created the dashboard as a collection of several, independent components. Each component displays a piece of information such as consumption and production data, weather, energy prices and other controls.

The components use basic HTML elements and several JavaScript functions. Those functions allow to fetch, process and render the data needed to display a short piece of meaningful information. The components also allow communication among them to create complex interfaces. For the graphs, we used the D3.js library to react which renders data into SVG and HTML elements. D3.js also supports mouse and keyboards events. The components are then grouped together to form each page of the dashboard. The user can navigate between the pages without needing to refresh the browser. The components are capable to update their own interfaces when they detect a data change.

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The application is compiled using webpack and mounted on an express server. The server makes the application available on http://h2823152.stratoserver.net:8080. This server redirects all the petitions from the browser client to the application. The application then handles the routes and serve the corresponding dashboard page. Finally, pm2 is used to make sure the server is re-launched on failure.

2.3 The prosumer dashboard application

The dashboard is designed to have several components: visualizations of self-sufficiency ratios, energy production and consumption over various time intervals (hourly, daily, weekly), as well as recommendations on how to improve self-sufficiency. The dashboard provides the summaries over the day (month, year) where self-sufficiency is at the core, as well as the detailed views on consumption/production for the finer-grained time intervals. The dashboard also connects to the weather data relevant for PV prosumers as well as the current EEX prices. In the current version of the prototype three components have been implemented: daily summary, daily details as well as recommendations page. The pages for other time points will look similar, only the level of aggregation will be different. The dashboard is available in two languages: English and German (as the prosumers are from the German utility partner).

In Figure 2 one can see the daily summary view (for the case of consumption). Apart from the absolute values on consumption and its distribution between the amount that was consumed from the grid and that was self-produced, the bar shows the relative amounts of these values (in %). At the same time, it displays the *self-sufficiency indicator* – which is the ratio of % of solar-generated energy that was consumed to the total amount of consumed energy. Along with the actual self-sufficiency the users can see their potential self-sufficiency which is the ratio of total solar-generated energy to the total amount of consumed energy – basically representing the best case scenario if they used all the energy they produced themselves. This indicator allows the users to set a goal to improve their self-sufficiency by spreading out their consumption to the time points where the energy is produced. The users will rarely achieve potential self-sufficiency, but they in this way know their way forward.

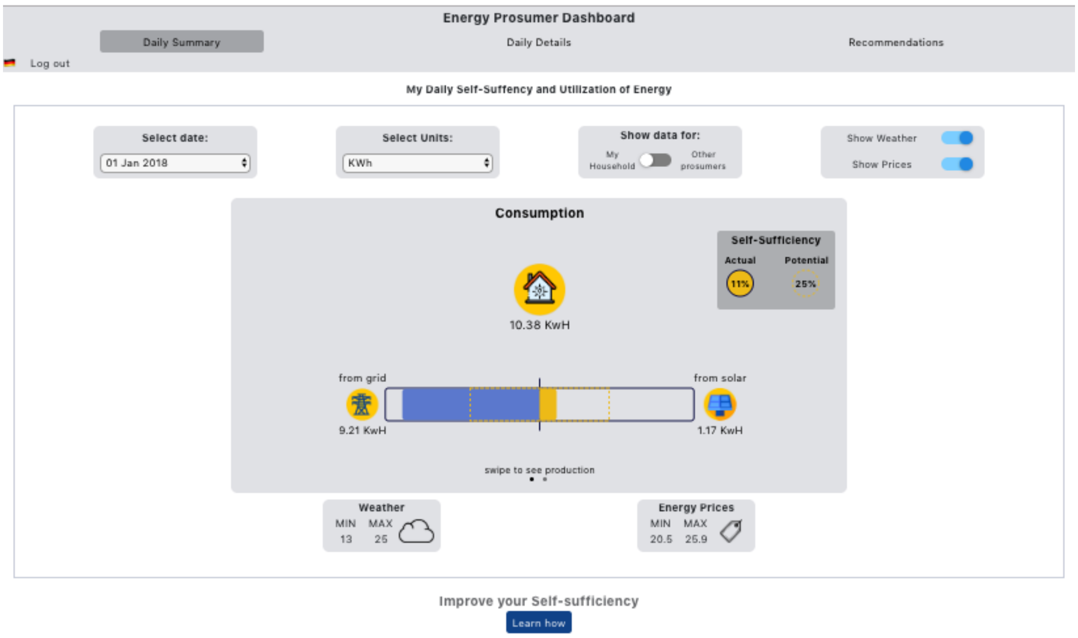

Figure 2: Screenshot of the energy prosumer dashboard displaying the daily summary visualization (consumption)

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By swiping below the widget, a similar visualization shows the same information from the perspective of production (Figure 3). The visualization shows the total amount of energy which was produced from solar, and how much of this energy was consumed and how much sold to the grid in absolute values as well as relatively with the help of the bar. In this view, the indicators are utilization which is the ratio of the solar energy that was consumed to the total amount of produced energy. This indicator mirrors the self-sufficiency indicator, but is not entirely the same, as it is viewed from the basis of total production, and not consumption as is the case with self-sufficiency. Similarly, potential Utilization is the ratio of the total need for energy that could be provided from own source to the total amount of produced energy. Overall, if the need is higher than the capacity of the solar panel this indicator is equal to 100%. Additionally, in this view, both for production and consumption, one can see the average weather conditions and energy prices of the day.

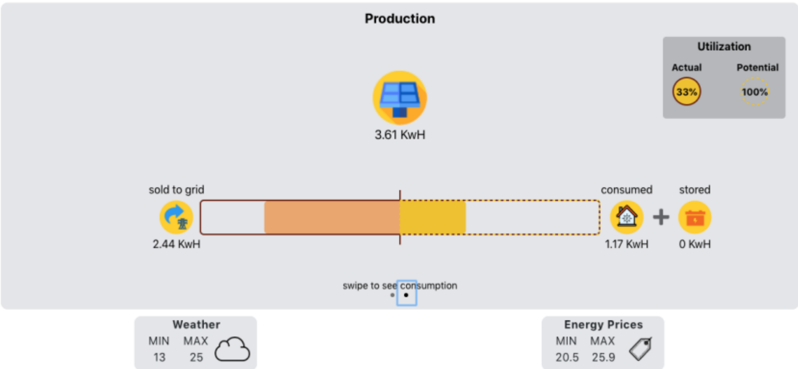

Figure 3: Screenshot of the energy prosumer dashboard displaying the daily summary visualization (production)

Another view present in the dashboard is the daily details view (Figure 4) which shows the consumption and production per hour, as well as their breakdown into consumption from solar and consumption from the grid, as well as energy produced sold to the grid. The area chart used allows displaying all these values at the same time (as opposed to the daily summary view which shows the consumption and production separately). By showing to the prosumer all the information in one graph, it can help him analyse his production and consumption patterns, detect possible peaks and identify the times where the consumption can be adjusted. In the example in the Figure below one can see that the peak of production was around 11 and 12h and then gradually subsided around 15h. Although the production was high, the consumption remained low, which then explains the low self-sufficiency that was achieved on that day. In order to improve self-sufficiency, a user could try to spread some the consumption from the peak around 17h to an earlier time when the production was high (for example, start a washing machine then).

Additionally in this visualization, on the side, the self-sufficiency and utilization values are shown which connects this visualization with the previous ones. Moreover, one can toggle the “weather” button to display the weather values for each hour of the day; and similarly, the “prices” button to show the EEX prices of the day. This information can help the user explain the peaks in production: when the weather was warm and sunny, the production was high (and vice versa).

Figure 4: Screenshot of the energy prosumer dashboard displaying the daily details visualization

The final view which is available in the prototype are recommendations to improve self-sufficiency - one can see a preview of recommendations in Figure 5. The recommendations display the text of the recommendation itself as well as the number of other users who have already implemented the recommendations. By displaying this information on the number of other users we believe that others might be motivated to execute these recommendations themselves. The list of recommendations will still be adapted to include a larger number and variety.

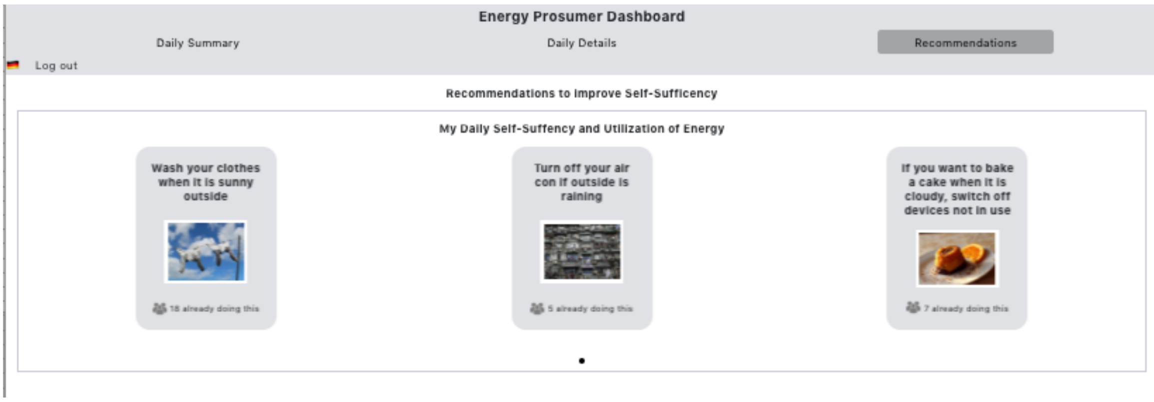

Figure 5: Screenshot of the energy prosumer dashboard displaying the recommendations

3. Smart Energy Management Dashboard for the Utility

The smart energy dashboard for the utilities is based on the use-case "*Using the smart energy management dashboard to perform dynamic analysis of energy supply and demand*."

The utility dashboard combines machine learning techniques (kNN) with interactive visualisations and explorative visual analysis to support utility analysts to identify consumption and production patterns. Based on the input parameters describing the expected day-ahead (or any desired "what-if" scenario) entered by the user, the kNN algorithm identifies the most similar days in the historical data and provides the resulting data to the dashboard (day characteristics in terms of weather data, hourly energy demand and supply data). This data is then visualised in the user dashboard in an interactive way that allows the user to inspect and analyse the results. By comparing the characteristcs of the most similar days delivered by the kNN algorithm to the expected day, the analyst can understand why the machine learning algorithm considered those days as most similar to the target day – and to which extent and by what parameters they indeed are similar. This is one way in which the system logic is made explainable to the user.

By visualizing the hourly demand and supply curves that occurred on those days and comparing them to the weather patterns characterizing them, the analyst can then interactively reach a decision as to what demand might be most likely to expect for the target day, given its expected characteristics. In this way, the analysts are not dependant on a static outcome of the machine learning algorithm as a given forecast for the target day, but can develop their own understanding of what the most likely outcome might be and why. This puts them in control of the forecasting process that is "only" assisted by the smart system and allows them to develop an understanding of how different factors may influence the demand and supply patterns. This can support both the trustworthiness of the system and thus its acceptance by the analyst, as well as enhance the effectiveness of the analysts' forecasts and the subsequent energy management practices of the utility.

3.1 Background and user-centred design process

As defined in the D1.3.2 User Information Model, the main motivation for utiity analysts relies on having a tool to analyse energy-related information in the company such as energy demand and supply to support the decision-making process. The analysis of this information combined with additional variables such as weather could help them to identify consumption patterns to forecast energy demand and supply [6]. According to some research, using explainable forecasting could help users from local utilities to understand the the behaviour of the energy-related factors to improve their operations in the company [7].

In order to design the utility dashboard, a literature review has been performed to identify and better understand the user information needs in the application context. As a result, a first mockup of the envisioned prototype has been developed and presented to potential utility analysts in a workshop. The insights were reported in D1.3.2 User Information Model. The results (feedback) were used to improve the utility dashboard design and implement a functional prototype in a form that is presented in section 3.4. In December 2019, this prototype was demonstrated to the utility representative as a first informal verification of the implemented design and to obtain feedback for further development. In next steps the prototype will be evaluated in a formative evaluation with additional participants. Finally, we intend to integrate the obtained results into future versions of the application.

Based on the insights presented in the User Information Model (D1.3), the development of the prototype smart energy management dashboard for the utilities is focused on the user's information needs presented below:

- Having a dynamic visualization of energy consumption and production by analysing information from historical records.
- Analysis of weather conditions related to energy production.
- Using different variables such as weather conditions, energy consumption/production to define what-if scenarios to facilitate the analysis of specific conditions to facilitate the decision-making process.

The implementation of visual analytics requires the use of historical data, therefore the utility dashboard was produced by using several datasets made available by the utility:
- Historical energy consumption
- Historical energy production
- Historical weather conditions

3.2 System design

The architecture of the system for the utility dashboard encompasses the components described below:

-**Database**: MyQSL was used to store the datasets to produce the visualisations (historical consumption, production and weather conditions).

-**Pre-processing**: A python script was developed to preprocess the data to be used in the similarity classifier algorithm (e.g. to convert data from15 minutes intervals into one-hour intervals).

-**Similarity classifier**: A similarity classifier implements a kNN-algorithm (in python) to calculate the most similar days in the historical data with respect to the input parameters entered by the user in the dashboard (avg weather conditions, k-value, etc.). Accordingly, the inputs for the similarity classifier are given by the pre-processed dataset of historical data and the user input parameters from the dashboard. As a result, the process currently provides several CSV files which are used as a data source in the visual analytics client (in the next version the results will also be stored in the MySQL database).

-**Visual analytics client**: End-user application (implemented in Qlik Sense) to produce the interactive visualisations based on the results of the similarity classifier algorithm. It allows the user to interactively visualise and explore the results and to analyse relationships between the parameters describing the expected day to be forecasted and the historical patterns of demand and supply on most similar days from the past.

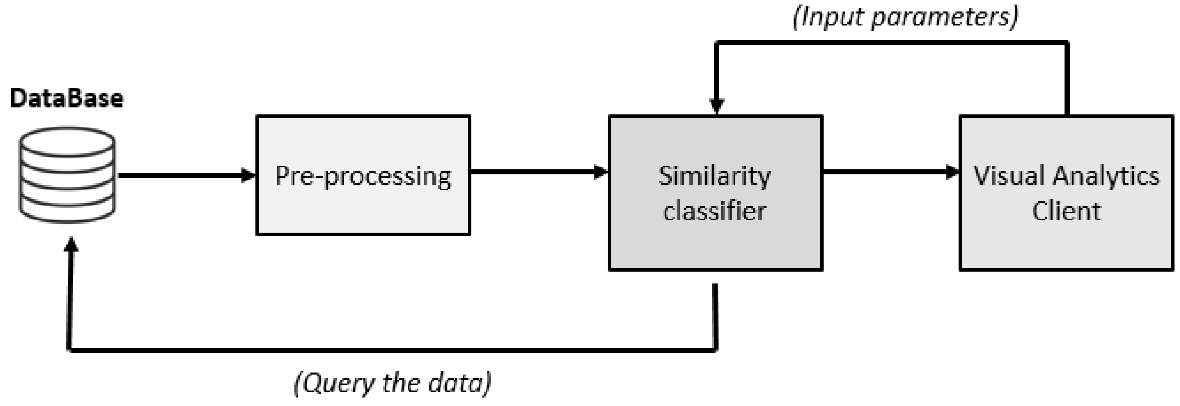

Figure 6: System architecture of the Smart Energy Management Dashboard for the utility

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3.3 The utility dashboard application

This prototype of the utility dashboard was implemented locally using the Qlik Sense visual analytics client, which includes the “single configurator tool” that can provide Qlik Sense visual objects from specific visualisations. As a result, these elements can be embedded in Html pages to create a customised dashboard. Accordingly, the utility dashboard has been designed in QlikSense and then implemented as a local web application.

In the beginning, the user inserts input parameters which are used in the kNN algorithm to calculate the most similar days in the historical data. By default, the application provides the k-value, however, the user can modify it, see Figure 7. When the user press the “submit” button, these parameters are sent to the kNN module (similarity classifier).

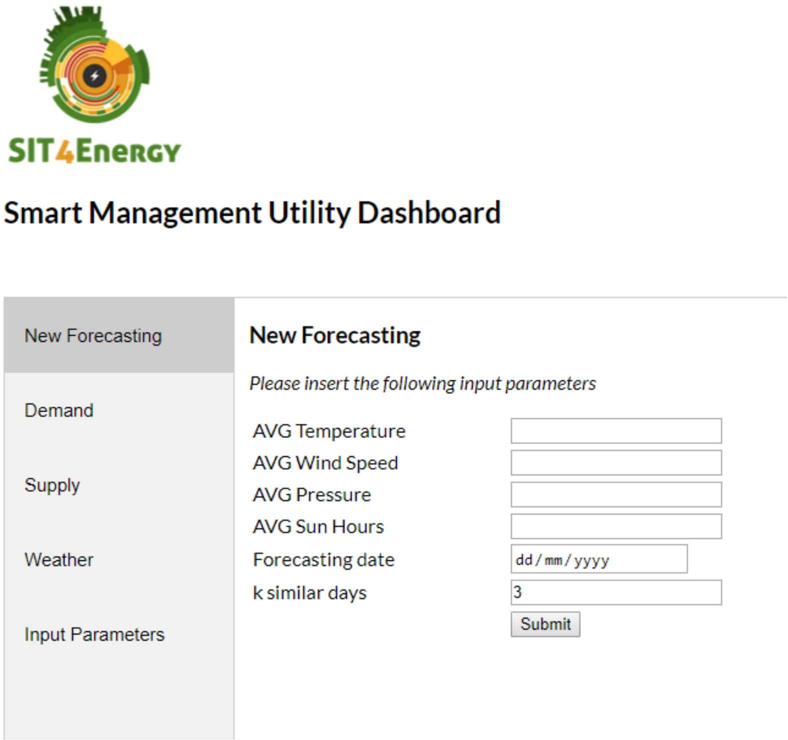

Figure 7: Insert input parameters

The demand tab presents the user with several charts visualising the energy demand of the most similar days (Figure 8): in the first chart, the bars are sorted by similarity to allow the user analyse the difference between the energy demanded on the provided dates, the second chart shows the hourly demand curve for the most similar days. After entering new input parameters, the user can refresh the dashboard by pressing the button “update dashboard” (Figure 8b). In addition, the radar chart provides an analysis of the closeness between weather conditions corresponding to the input parameters. In this way, the distances can be compared to facilitate understanding of the actual similarity between the days identified by the kNN algorithm. The user can also select one or several of the displayed days to focus the analysis (Figure 8c).

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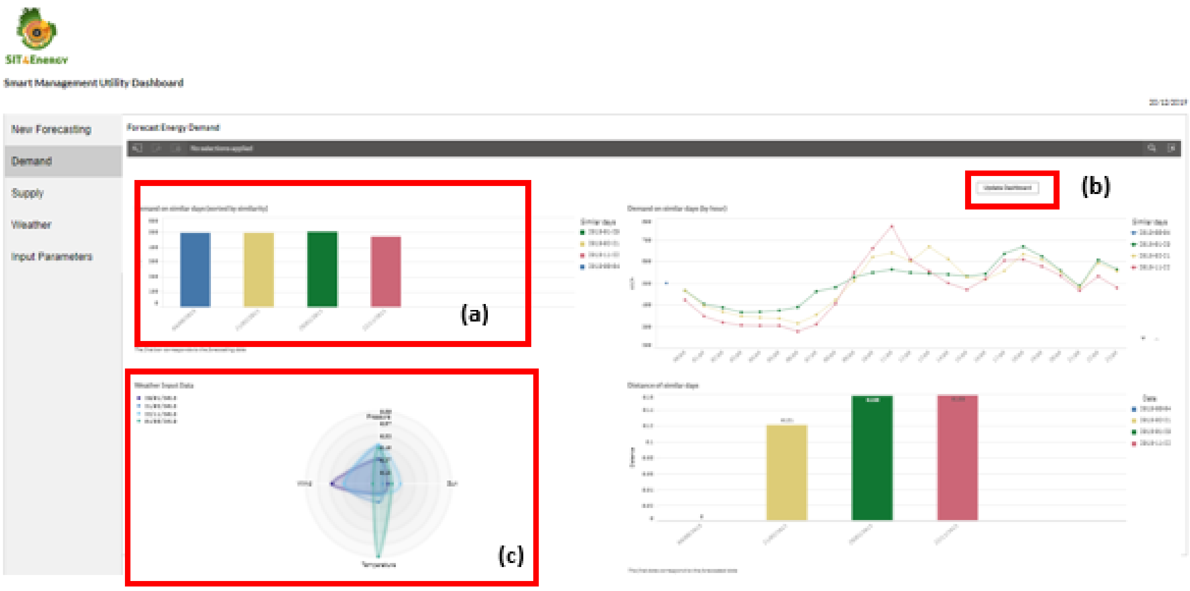

Figure 8: a) Energy demand on the k-most similar dates. b) update the dashboard button to refresh the application after inserting new input parameters c) Comparison between input

In order to provide the analysis of energy production, the dashboard includes hourly wind speed and sunshine which are related to hourly wind and sun production. In this way, the dashboard facilitates the user to identify relationships between weather conditions and energy production of the main power plants (photovoltaics, wind) run by the utility and then, compare data for the most similar days (Figure 9a). In addition, the weather tab presents the analysis of energy consumption and weather information such as temperature. In this way, the user can identify the relationship between temperature and demand behaviour over the day for the most similar days to the target day (Figure 9b).

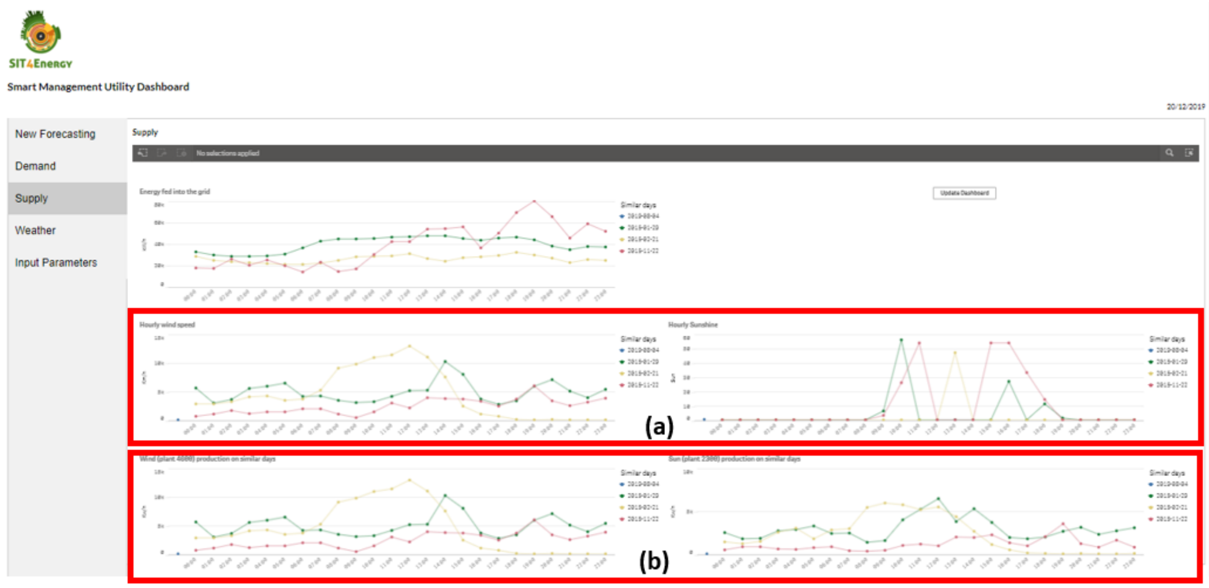

Figure 9: a) Hourly weather conditions (wind speed and sunshine) of similar days compared to b) hourly energy production of the wind and photovoltaics plants on the most similar days

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In addition, the weather tab presents the analysis of energy consumption and weather information such as temperature. In this way, the user can identify the relationship between temperature and demand behaviour over the day for the most similar days to the target day (Figure 10).

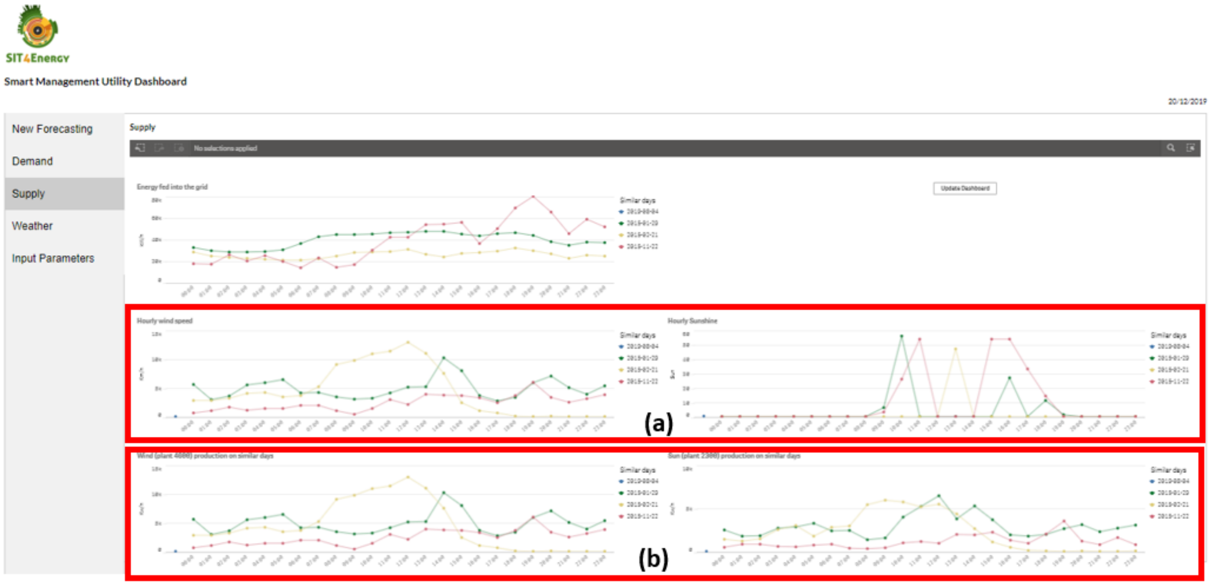

Figure 10: a) Hourly weather conditions (wind speed and sunshine) of similar days compared to b) hourly energy production of the wind and sun plan on the most similar days

The provided visual analytics functionalities allow the user to select and compare individual elements and keep the selection for the rest of the charts (linked views filtering). In this way, the analyst can perform a more detailed analysis and look for patterns and relationships in the data, as all the charts are automatically updated based on the selection (Figure 11).

Figure 11: Individual selection keeps the selected elements in all charts in the dashboard

Finally, the last tab presents the average input parameters to allow the analysis of the data in a table. This visualisation can also keep the personalised selection overall in the dashboard (Figure 12).

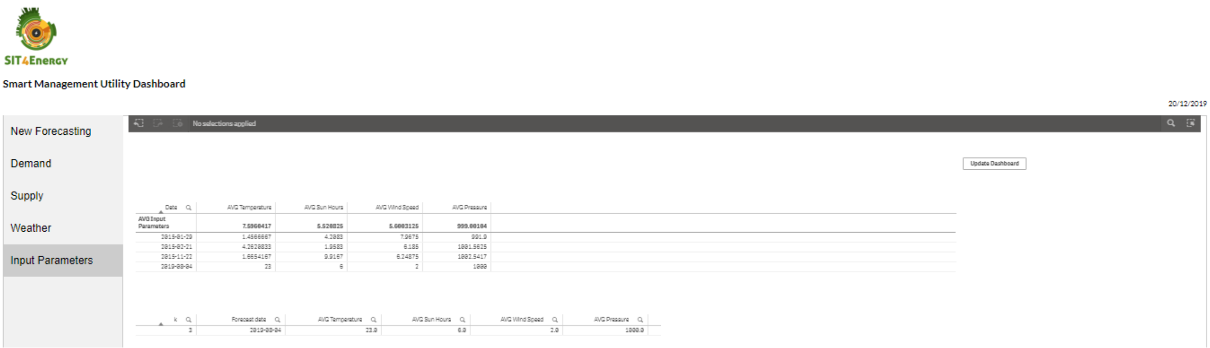

Figure 12: Avg weather parameters for the most similar dates

4. Conclusions

This deliverable presented the developed first prototypes the *The Smart Energy Management Dashboard* for prosumers and for utilities.

The prototype of the smart energy dashboard for prosumers has been designed to provide interactive visualizations of prosumer's energy consumption and production based on their smart meter data, as well as to provide recommendations on how to increase their self-sufficiency. Future versions of the dashboard will include more screens that show other data aggregation points (weekly, monthly, yearly), a forecasting for the next day as well as an expanded version of the recommendations. The prototype will also be refined based on on the evaluation and user feedback to be obtained in the project pilots.

The designed and implemented prototype of the energy dashboard for utilities combines machine learning techniques (kNN) with interactive visualisations and explorative visual analysis to support utility analysts to identify consumption and production patterns in defined scenarios. Based on the input parameters describing the expected day-ahead (or any desired "what-if" scenario) entered by the user, the kNN algorithm identifies the most similar days in the historical data. By using the interactive visualizations of this data in the dashboard (e.g. the hourly demand and supply curves that occurred on those days) the analyst can then interactively identify the most likely demand to expect for the target day. The developed approach puts the analysts in control of the forecasting process that is "only" assisted by the smart system and allows them to develop an understanding of how different factors may influence the demand and supply patterns. This can support the trustworthiness of the system and its acceptance by the analyst, as well as enhance the effectiveness of the analysts' forecasts and the subsequent energy management practices of the utility. The dashboard has been implemented with a one year test data set from a historical data collection provided by the utility. In next steps it will be tested with live data from the utility database after the integration process in work package 4. Furter refinement of the dashboard will be based on the evaluation and user feedback to be obtained in the project pilots.

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