

EnerMan

Energy Efficient Manufacturing System Management

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Short Description

This report presents the Industrial Management Visualisation System, which is the main user interface to the EnerMan system and aims at providing all necessary means for the intuitive visualisation of information on energy consumption, energy cost and environmental impact, as well as to alert users when anomalies are detected (or foreseen) and to support them during the efficient management of the target processes by interfacing with other EnerMan modules.

After performing a state-of-the-art review of visualisation features currently available to selected EnerMan end-user pilots, as well as a state-of-the-art overview of existing commercial solutions, we analyse the user requirements and the associated system requirements. Furthermore, we provide the features of Industrial Management Visualisation system already implemented and demonstrate a subset of these for one indicative pilot use-case.

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1. EXECUTIVE SUMMARY

Organisations, and especially factories, increasingly want to establish a company-wide policy for energy sustainability so that they can identify and reconfigure energy-wasteful processes and react on increasing volatility of electricity prices or power outages leading to reduced operating costs, less downtime and enhanced reputation as a socially responsible organisation.

This report presents the Industrial Management Visualisation system, which is the main user interface to the EnerMan system and aims at providing all necessary means for the intuitive visualisation of information on energy consumption, energy cost and environmental impact, as well as to alert users when anomalies are detected (or foreseen) and to support them during the efficient management of the target processes by interfacing with other EnerMan modules.

First, we provide a short overview of visualisation features currently available to selected EnerMan end-user pilots, where we noticed that in most cases the industrial manufacturing management typically relies on the user interface provided the Supervisory Control and Data Acquisition (SCADA) system employed. Furthermore, we provide a brief state-of-the-art overview of existing solutions, which offer a variety of visualisation charts (e.g., pie charts for breaking down an aggregate value into its subcomponents, trend charts of a Key Performance Indicator - KPI etc.) and reports for getting useful insights on energy performance, nevertheless these only rely on historical and real-time data for energy consumption.

Then, we analyse the functional and non-functional user requirements that were elicited based on the responses of pilot users. Functional requirements were grouped in 3 categories: Energy Analysis that is comprised of 12 needs, Energy Management that includes 5 distinct requirements and Dashboard Management that results in 3 additional expectations. On the other hand, non-functional requirements were related to User Management and Security, which totalled 6 and 2 requirements respectively.

The transformation of the user expectations and requirements to technical specifications for the EnerMan visualisation platform, led to the identification of 19 system requirements related to User Management, 25 system requirements associated with Energy Analysis, 4 system requirements fulfilling the Energy Management needs, and 5 system requirements related to Dashboard Management.

The aforementioned system requirements were consequently mapped into 10 distinct features of the Industrial Management Visualisation System, which include the following: 1) Services Dashboard, 2) Timeline Analysis, 3) Statistical Analysis, 4) Floorplan status, 5) Details, 6) Weather Details, 7) Energy Details, 8) Synced filters, 9) User Inputs and 10) Custom Workspace.

Finally, we present the internal architecture of the Industrial Management Visualisation System and demonstrate it using the historical analysis service for one indicative pilot use-case.

GLOSSARY OF ACRONYMS

Acronym	Definition
AHUs	Air Handling Units
APIs	Application Programming Interfaces
AVT	Advanced Visualisation Toolkit
BMS	Building Management system
CCM	Continuous Casting Machine
CO2	Carbon Dioxide
EAF	Electric Arc Furnace
EMS	Energy Management System
ES	ElasticSearch
FEMS	Factory Energy Management System
HMI	Human Machine Interface
iDSS	intelligent Decision Support System
IEMS	Industrial Energy Management Systems
IIoT	Industrial Internet-of-Things
IPMVP	International Performance Measurement and Verification Protocol
IVM	Industrial Management Visualisation
KPI	Key Performance Indicator
LF	Ladle Furnace
PLC	Programmable Logic Controller
REST	Representational State Transfer
SCADA	Supervisory Control and Data Acquisition
SRP	Solution Ready Package
UI	User Interface
VD	Vacuum Degassing

2. INTRODUCTION

2.1. Purpose and Scope

Organisations, and especially industrial factories are considered to be the most energy hungry sector, increasingly seeking to establish a company-wide policy for energy sustainability so that they can achieve one, or more, of the following benefits:

- realise untapped energy efficiency potential by identifying energy-wasteful processes;
- reduce operating costs and the impact of increasing volatility of electricity prices, as well as legislative carbon targets;
- reduce impact of power outages by tapping into flexible production schemes, optimised maintenance schedules, local energy consumption and energy storage systems;
- enhance the entity's reputation as a socially responsible organisation, e.g., by reducing greenhouse gas emissions.

The current typical approach of industrial manufacturing management on measuring and accessing energy consumption is static and relies on aggregate data (e.g., building level) or measurement values from a few points in the manufacturing production line rather than managing energy consumption holistically. While a wide set of Key Performance Indicators (KPIs) can be defined for monitoring and adjusting energy sustainability, some of those may not fit the domain of the target organisation. Furthermore, different users inside the same organisation have different needs. For example, executive managers want to ensure that energy performance is aligned with company long-term planning and thus one would expect them to focus on the KPIs related to cost, while operations managers for a certain production line should be interested in KPIs relevant to those activities only.

In EnerMan we introduce energy sustainability as a three-dimensional process, combining energy consumption, energy cost due to the power grid electricity price and environmental impact (e.g., Carbon Dioxide/CO₂ emissions) due to the consumed energy for realising the production process.

Organisations will be able to use the EnerMan Management System for having access to a variety of visualisation charts and reports for getting useful insights on energy performance. These include, among others, pie charts for breaking down an aggregate value into its subcomponents, trend charts of a KPI compared to time or another variable, scatter plots for associating values of a KPI with different values of another independent variable, etc.

Furthermore, users will be able to see alerts when anomalies in energy consumption or machines' status is observed. The amount of "hidden" information inside the huge amount of seemingly unrelated data can be considerable when it comes to energy consumption. The only way to extract hidden information from data, is to apply a holistic data processing approach based on big data analytics and/or artificial intelligence that excel at this role. Thus, apart from actual measurements obtained from EnerMan deployed Industrial Internet-of-Things (IIoT) nodes, legacy systems, as well as historical data, the EnerMan solution will be using a digital twin for each industrial processes to simulate various scenarios suggested by the EnerMan intelligent Decision Support System (iDSS) and predict the energy related performance indicators like consumption or cost. Based on these outputs, the operators will be able to choose the appropriate configuration that could be automatically deployed.

This report focuses on the Industrial Management Visualisation (IVM) system, which aims at providing all necessary means for the direct and intuitive visualization of functional and environmental parameters provided by the EnerMan system, as well as to support the efficient management of the

target processes in order to meet the users' objectives. The aim is to identify the best methods, to provide knowledge to users in an optimal way, e.g., information (warnings, alerts), processes, and experiences.

2.2. Structure of the document

The document is organized as follows. Chapter 3 provides a short overview of visualisation features currently available to selected EnerMan end-user pilots, as well as a state-of-the-art overview of existing commercial solutions with an emphasis on visualisations employed. Chapter 4 provides a list of functional and non-functional requirements that were elicited based on the responses of pilot users. Chapter 5 presents the transformation of the user expectations and requirements to technical specifications for the EnerMan Industrial Management Visualisation system, describes the repository of visualisation features implemented along with the internal architecture and demonstrates a subset of these for one indicative pilot use-case. Chapter 6 concludes this report and presents the next steps.

3. STATE OF THE ART

This chapter provides a short overview of visualisation features currently available to selected EnerMan end-user pilots, as well as a state-of-the-art overview of existing solutions. Note that the focus here is on visualising energy-related information and associated performance indicators for cost and environmental footprint, as well as managing infrastructure and industrial processes for better energy sustainability.

3.1. Current visualisations used by EnerMan pilot partners

3.1.1. ASAS

The current existing visualisation system of ASAS Trigeration plant is based on a Supervisory Control and Data Acquisition Human Machine Interface SCADA/HMI. With the SCADA HMI system in place, it is possible to monitor inlet and outlet temperatures, engines status (on/off), produced electricity, general temperatures of the equipments and pressure values. Figure 1 shows the real-time monitoring screen for the electricity generation



Figure 1 Current visualisation of electricity generation monitoring for ASAS (sensitive information is hidden)

Figure 2 shows the temperature and pressure monitoring screen (left) and the combustion chamber status (right), based on temperature and pressure data that are collected by pressure sensors and thermocouples. Monitoring data can be exported manually to an Excel file.

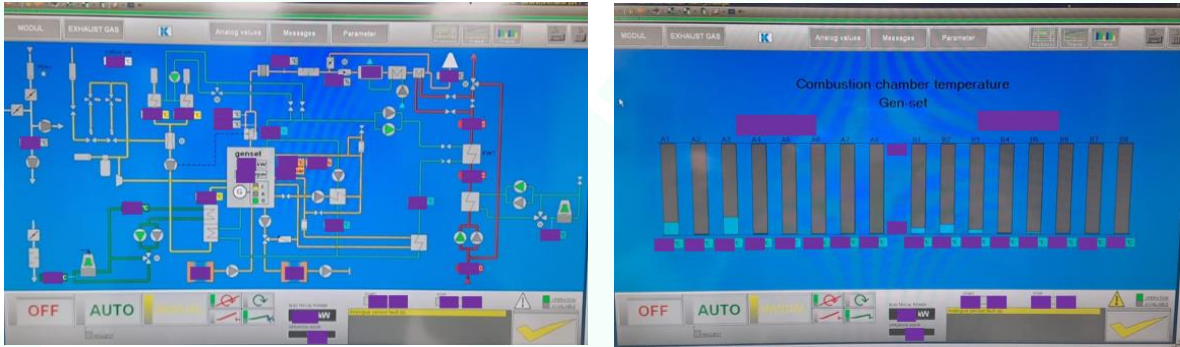


Figure 2 Current visualisation of pressure and temperature monitoring (left) and combustion chamber monitoring system (right) of ASAS, where sensitive information is hidden

ASAS has already identified the need for getting decision support regarding the production of the local trigeneration plant, in the sense that e.g., EnerMan could suggest and ideally control the number of engines to be used based on current and forecasted energy market conditions, production schedule and trigeneration facilities status itself.

3.1.2. AVL

AVL also uses a SCADA HMI system for the visualisation of the total process control system. Plants and testbeds are controlled via Programmable Logic Controller (PLC) systems. Within the visualisation, the status of several components is available, as well as different setups and settings can be configured (see Figure 3).

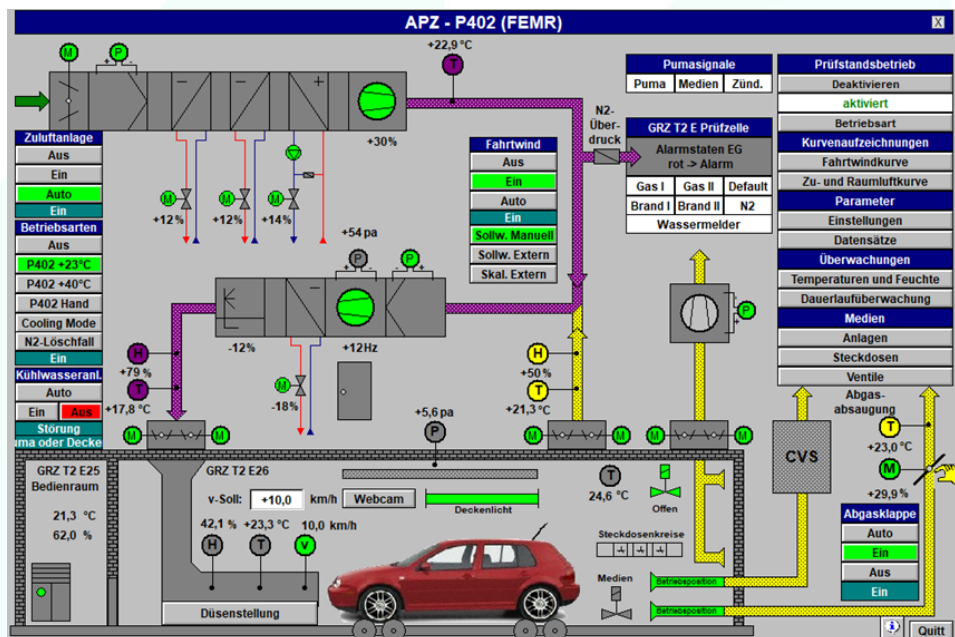


Figure 3 Current visualisation of the SCADA HMI currently used by AVL

Up to now regarding the use cases of AVL, sensors only provide temperature and humidity information. Data regarding energy consumption of each testbed is available only on an aggregated level. In the context of the EnerMan project, detailed energy consumption data will be collected, energy-related performance indicators and recommendations will be produced and eventually be presented to the managers for making informed decisions.

3.1.3. CRF

Bodyshop Use-Case

The current existing visualisation system for environmental heating of the Bodyshop building working area consists of a basic SCADA HMI in which the indoor air temperatures are reported. The temperature values shown on the display are associated to the Air Handling Units (AHUs) temperature probes that measure and control the working area temperature condition in the winter seasons (see Figure 4). In this way, the operators can monitor and check the real-time indoor air condition and the satisfaction of the desired temperature set-point maintenance. The values are reported with their position on a layout of the plant using pillars reference (e.g., 96-18 refers to column 96 and row 18).

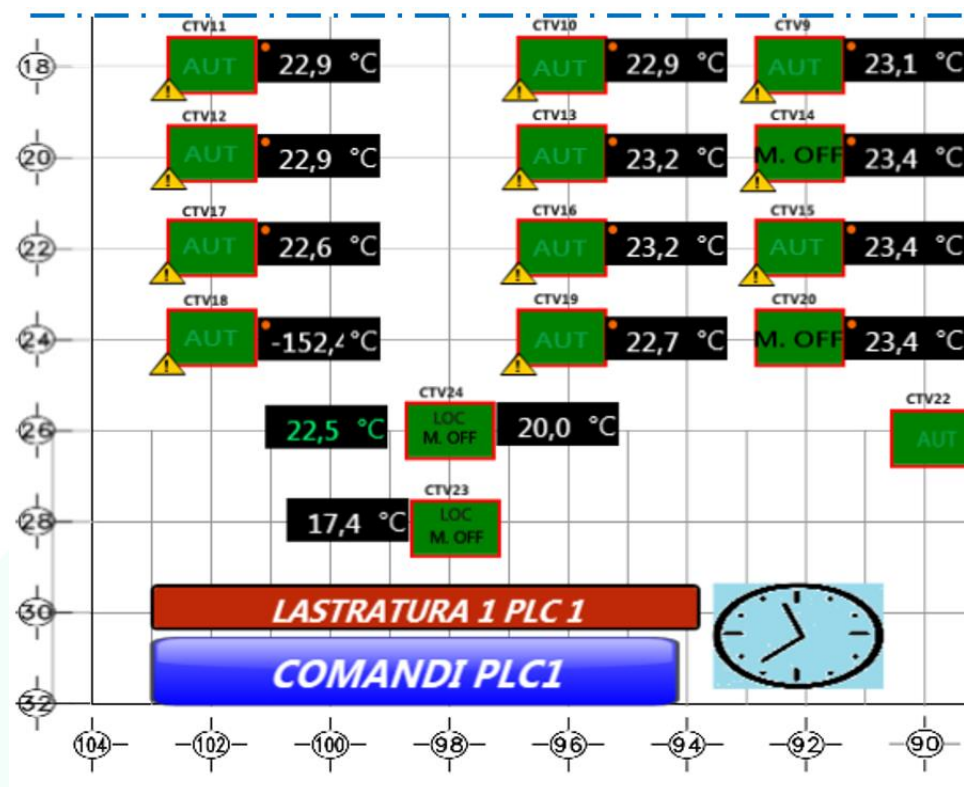


Figure 4 Extract of the current visualisation system used by CRF for bodyshop area heating

In the context of the EnerMan project, indoor environmental data will be collected for the complete bodyshop area (i.e., temperature values related to the area where no AHUs temperature probes are currently deployed) and presented to the user. In particular, CRF expects that the future visualisation platform will be user-friendly, providing the operators with the indications on the plant map about the several different types of zones (e.g. different colours for different thermal zone regulation) and detailed information about the devices that manage the indoor environmental heating (e.g. type of AHU, air flow rate treated, nominal thermal power of the machine, status “on” – “off” – “fault” and predicted reference consumption calculated with machine learning model). Finally, the EnerMan user interface should be able also to communicate energy optimization suggestions to operators through alarms and notifications.

Paintshop usecase

In a similar way to the Bodyshop, also for the two paintshop processes the plant has a similar visualisation system. The current regulation of the process utilities is displayed on a basic SCADA HMI in which the parameters are reported for each process using the devices layouts for the identification of measurements position (e.g., tank temperature, water tank set-point maintenance, relative humidity of topcoat AHU and so on).

The pilots of the tank and Top-coat AHU have in parallel to the official visualisation system of the plant, also a basic prototype system developed by CRF in collaboration with SIEMENS on Monet/DEOP platform, that in addition to showing the layout of the users, it also allows the operators to see the comparison between real and theoretical energy calculated with mathematical models. Furthermore, this prototype system allows to receive and display notifications/alerts when the real consumption differs from the calculated theoretical consumption and allows also to display the energy trend of the process consumption.

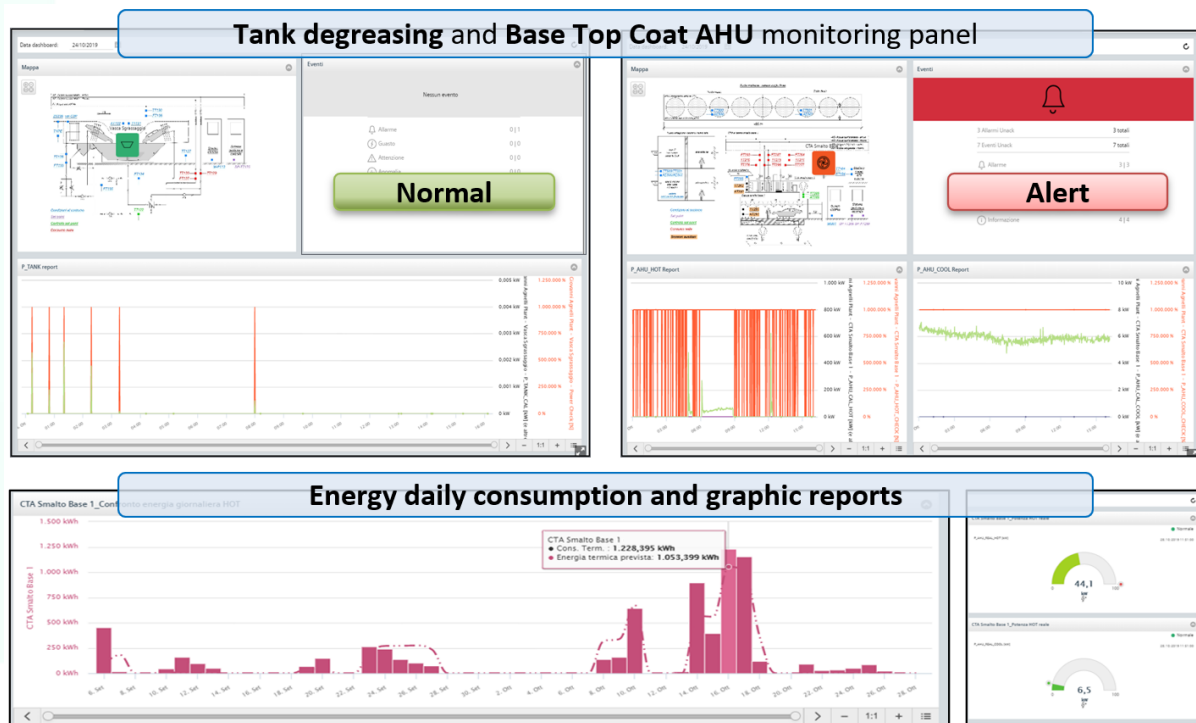


Figure 5 Extract of the CRF prototype visualisation system for the Degreasing Tank and Top Coat Air Handling Unit of the paintshop

CRF expects that EnerMan will offer a smart Energy Sustainability and Management System that can better predict energy consumption and give recommendations in order to avoid energy drifts (i.e., gradual losses of efficiency that occur after a solution has been commissioned) and losses. At the same time, the EnerMan visualisation platform will be offering real-time and historical analysis of energy consumption and associated costs, as well as clear alerts and recommendations.

3.1.4. DPS (Depuy Synthes)

Depuy Synthes in Cork currently uses a platform from CIM called PEAK [1] to visualise the energy and Building Management system (BMS) data that is being fed from the various monitoring points around the two sites that make up the plant.

PEAK offers basic visualisation tools such as historical graphing of data and incorporates some trends and alerting. Reports from the system can also be generated to monitor assets and determine when something is out of range or scope. Fault monitoring of equipment can also be shown within the PEAK platform.

Dashboards can be custom-made to show various KPIs for the site for the example below energy and cost savings are shown in Figure 6, along with days without issues.



Figure 6 Screenshot of the visualisation dashboard currently used by DPS

Historical data is shown in Figure 7 for the Deputy use case around the dust extract, where historical information about the exhaust fan status and exhaust air fan damper commands appears, while sample alerts and potential faults detected are shown in Figure 8.

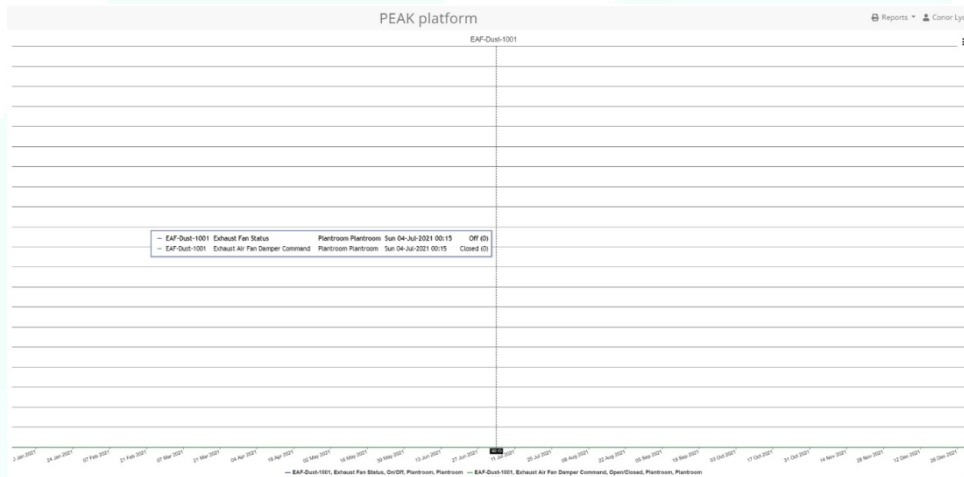


Figure 7 Snapshot of historical timeline chart currently available to DPS

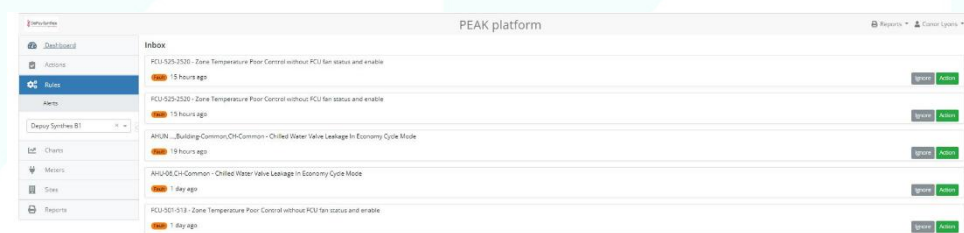


Figure 8 Snapshot of list of faults as currently presented to DPS users

DPS expects that EnerMan visualisation system will be able to present information (both current and historic) for certain energy-hungry equipment types, such as compressed air units and dust extraction system and eventually to provide recommendations for minimising operating costs related to energy, e.g., by optimally controlling the compressed air flow rate. These recommendations could be based on market prices, which are very volatile, and production schedule. Furthermore, alerting the user when equipment status is abnormal should be more actionable.

3.1.5. STN (STOMANA)

STOMANA aims at optimising the meltshop process in terms of electrical energy consumption. During this process, the scrap is melted by an Electric Arc Furnace (EAF), processed with other materials by a Ladle Furnace (LF) and after the optional Vacuum Degassing (VD), blooms or slabs are cast by a Continuous Casting Machine (CCM).

The existing visualisation system in the STOMANA steel plant is SCADA / HMI. It is possible to monitor temperatures with measurements made by a robotic system and requires a delay on the production process. Electricity consumption is also recorded in each production phase.

Figure 9 and Figure 10 show how the user can monitor the electrical and chemical energy consumption in EAF and in Ladle furnace respectively, as the energy consumption is the basis on which they decide when to measure the temperature of the metal, in order to proceed to the next phase.

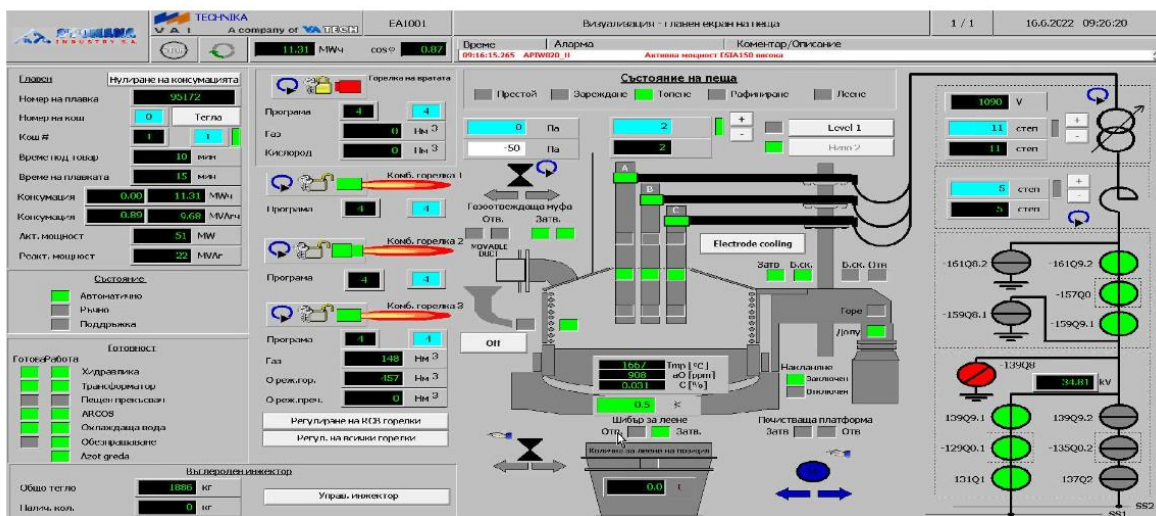


Figure 9 Monitoring the electrical and chemical energy consumption in Electric Arc Furnace (EAF)

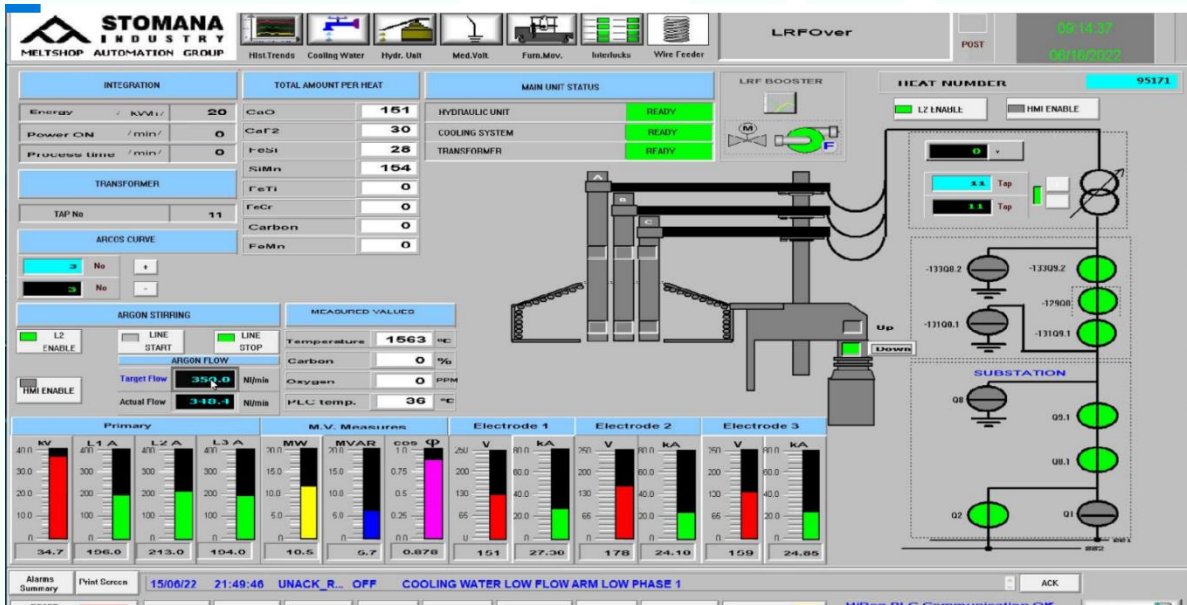


Figure 10 Monitoring the electrical and chemical energy consumption in Ladle Furnace (LF)

The final target is the casting temperature, which appears in Figure 11. In every transition from one phase to another there is a loss of temperature, and the target temperature limits are large upwards. This means consuming more energy than is needed. Optimizing energy consumption requires more accurate prediction of heat loss and targeting of lower temperatures per process phase.



Figure 11 Monitoring the casting temperature

STOMANA expects that EnerMan visualisation system will offer real-time analysis of energy consumption for each part of the process, allow engineers to run scenarios for production modes through the EnerMan digital twin and provide effective recommendations to the operators through the decision support system in order to reduce the energy consumption, especially by better controlling the tapping temperature in the EAF and LF.

3.1.6. Conclusions

Based on the high-level overview of existing approaches for visualising energy-related performance indicators we noticed that energy managers typically rely on the user interface provided the Supervisory Control and Data Acquisition (SCADA) system employed.

3.2. Visualisation approaches of existing Industrial Energy Management solutions

This subsection gives a state-of-the-art overview of existing solutions with an emphasis on visualisations employed.

3.2.1. Siemens SIMATIC Energy Manager

The SIMATIC Energy Suite is part of the SIMATIC product suite that provides an integrated solution for energy management. According to Figure 12, it supports energy measurement from field devices, data acquisition and storage (via the Energy Suite), processing and monitoring of energy efficiency, as well as energy analysis (via the Energy Manager). In this subsection, we will focus on the Energy Manager that is logically positioned on the top of the pyramid and focuses on providing plant and company-wide energy analysis capabilities.

It helps industrial production plants to visualise energy flows and consumption values in their processes by allowing user-defined performance indicators and flexible display widgets, dashboards, as well as reports. It provides the user with energy efficiency data for detecting energy waste (leaks and standby consumption) and energy cost accounting on a cost-by-cause basis so that she/he can understand the drivers for the changes occurred and eventually reduce operating costs. Furthermore, Energy Suite allows the user to evaluate implemented efficiency measures and compare energy efficiency across plants and locations. The user can also optimise energy procurement processes by supporting the selection of the optimal energy supplier and supplier contract (e.g., by consumption forecast and contract simulation) [1].

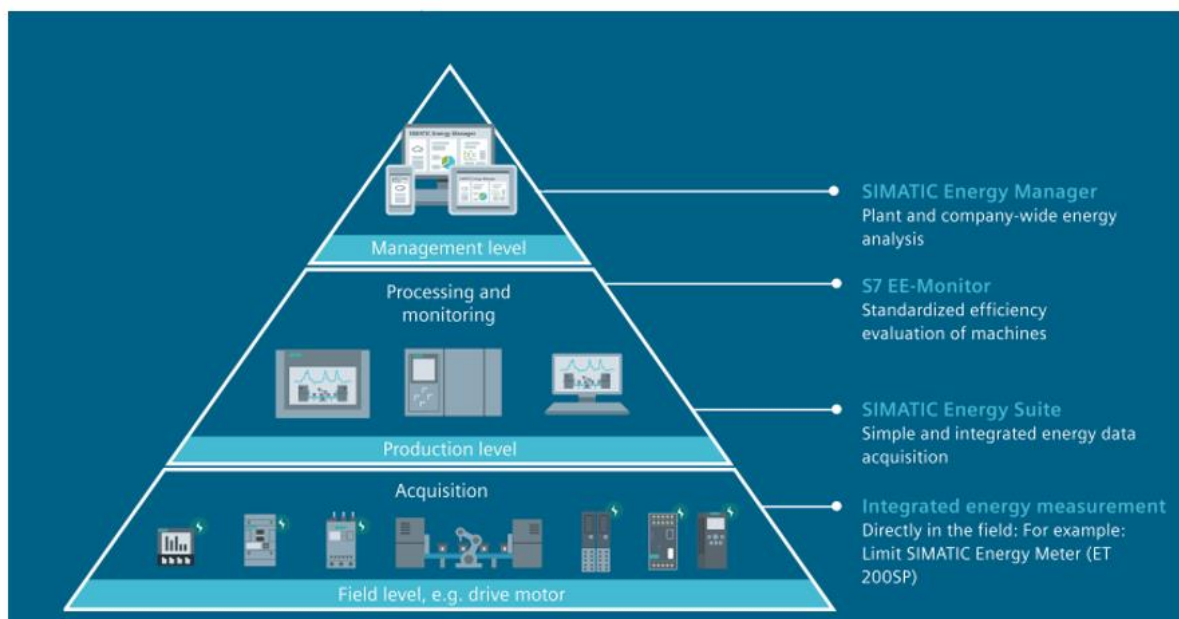


Figure 12 The SIEMENS SIMATIC Energy Manager as part of the overall SIMATIC product suite (from [3])

3.2.2. Siemens SENTRON Powermanager

The SENTRON Powermanager software provides an energy management solution that allows enterprises to store, process and analyse energy usage (including gas, steam, air and water) and status information. Furthermore, it can track energy related costs by building, feeder, or individual machines and identify hidden potentials for energy optimisation that can reduce energy related costs. The user

can manually define custom, real-time alarms for anticipated issues or rely upon predictive alarming of imminent conditions (see *Figure 14*).

The SENTRON Powermanager comes in several packages with an increasing set of features. For example, the “Expert” feature package provides the user with the ability to design custom interactive graphic screens like floor plans [4].



Figure 13 SIEMENS SENTRON Powermanager User Interface

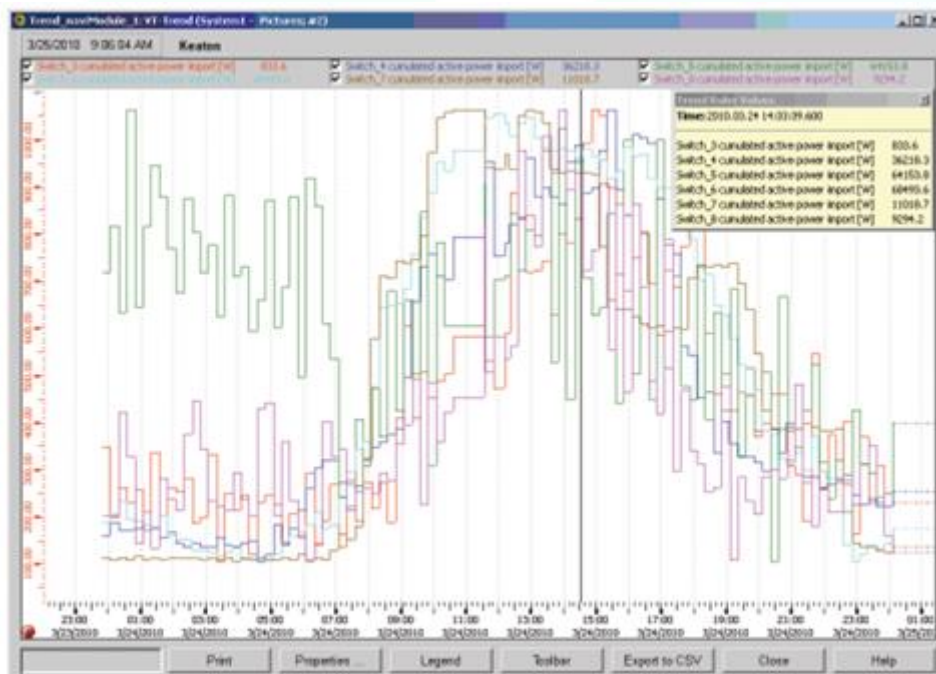


Figure 14 SIEMENS SENTRON Powermanager discovering unusual energy patterns

According to [5], the SENTRON product suite is better suited to smaller enterprises, which are connected to the low voltage distribution grid. On the other hand, the SIMATIC product suite targets industrial production plants.

3.2.3. Smappee Infinity System

The Smappee Infinity system offers a modular solution to energy monitoring and load control, with each system boasting the ability to monitor up to 28 circuits, plus gas and water monitoring. The Infinity system can also combine multiple systems for large sites. With a cloud-based reporting platform allowing for seamless reporting across all monitored sites, the Smappee Infinity system offers a versatile and cost-effective metering solution, enhanced with control and condition-based automations and the Smappee Infinity system becomes a complete energy management system in both homes and businesses.

Smappee Infinity [5] provides a modular energy monitoring and control system that can be utilised as a full energy management system for both homes and businesses. Smappee users can gain actionable insights into their energy usage, allowing them to implement strategies to reduce costs and environmental impact either by changing how and when they use appliances directly or by adding automatic control which is possible with the system. In commercial applications multiple Smappee Infinity systems can be used across a site with all real-time and historical data being made available via the online dashboard or smartphone app (Figure 15).



Figure 15 Smappee Infinity System Interface

3.2.4. Enel X EMS (Energy Management System) – ITA solution

Enel X [6] proposes the Energy Management System (EMS) that is a highly customizable platform capable of monitoring a company's energy consumption in real time. EMS monitors consumption, analyses and recommends data, makes energy expenditure values visible by providing reports and taking ad hoc actions to optimise energy performance. It also provides advanced features capable of highlighting any energy anomalies through algorithms deriving from Artificial Intelligence, energy

efficiency projects and monitoring production from any distributed generation assets. Figure 16, Figure 17, Figure 18 and Figure 19 show the main functionalities (i.e., Analysis, Monitoring, Reporting, Alerting, Advanced Functions) and the visualisation approaches of the EMS platform.

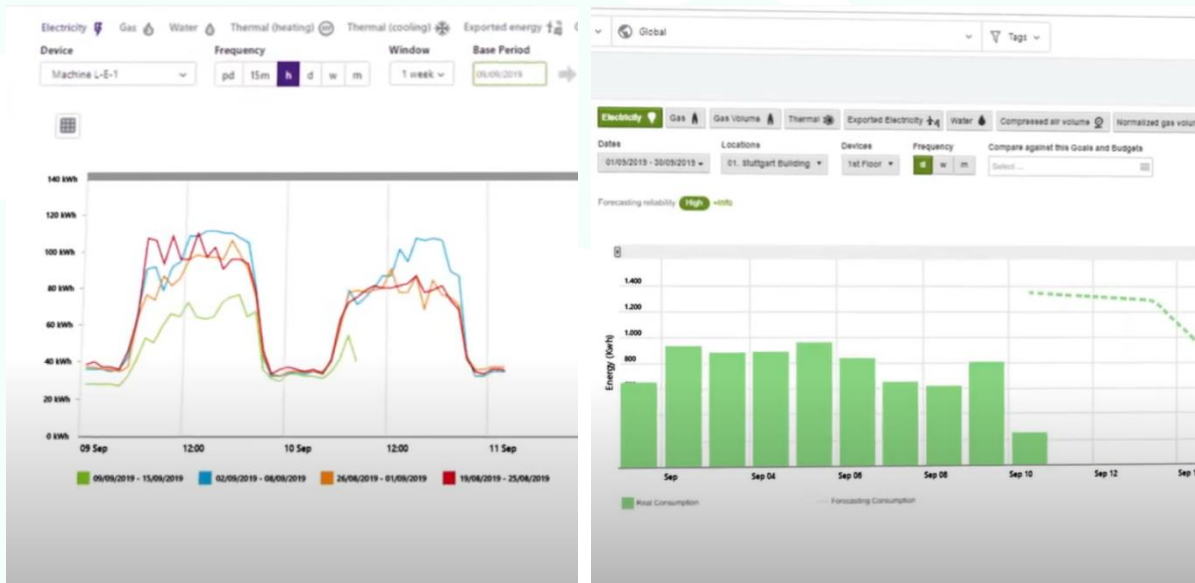


Figure 16 EMS Analysis functionality: a) Descriptive analysis visualisation (on the left); b) Forecasting analysis visualisation (on the right).



Figure 17 EMS Monitoring Functionality: a) Real-time monitoring (on the left); b) Production monitoring with graphical representation of input, withdrawal and self-consumption profiles (on the right).

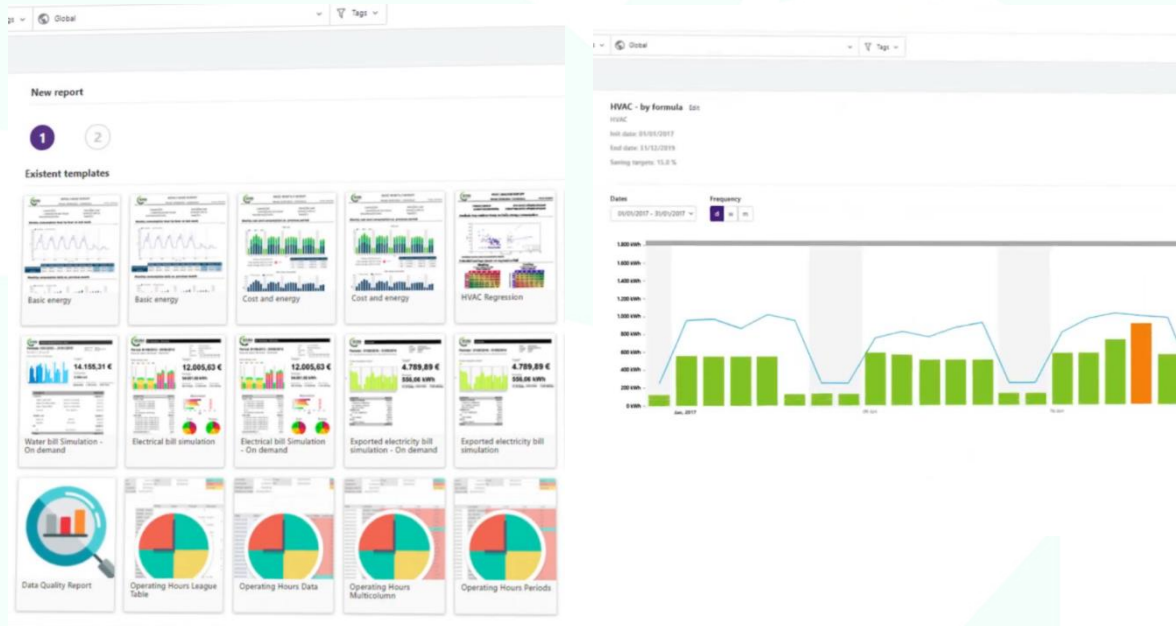


Figure 18 EMS Reporting Functionality: a) Several available templates for reporting (on the left); b) International Performance Measurement and Verification Protocol (IPMVP) (on the right).



Figure 19 EMS functionalities: a) Alerting (anomaly detection)

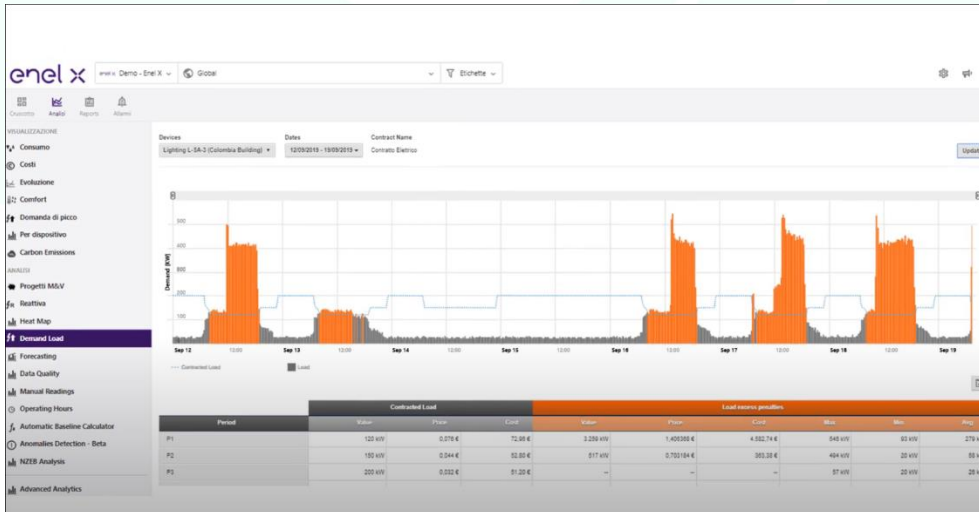


Figure 20 Advanced analytics.

3.2.5. Advantech Factory Energy Management System (FEMS)

Advantech offers a Solution Ready Package (SRP) that integrates hardware and software within Industrial applications aiming to reach 10% energy saving. The FEMS SRP allows collecting real-time data, monitoring energy consumption, evaluating energy cost, and optimizing energy efficiency, aiding in the energy management decision-making. In the following figures (Figure 21, Figure 22, Figure 23, Figure 24 and Figure 25) selected FEMS dashboard visualisations are provided. Performances, data, and reports can be visualised by means of the dashboard tools. The user can customize the navigation menu and dashboard displays to visualise trends, graphs, diagrams, and tables. It also provides KPI and alarm management functions.



Figure 21 Real-time Production Management



Figure 22 Machine Availability Management



Figure 23 Production Management: Day Shift & Night Shift



Figure 24 Energy Consumption Overview

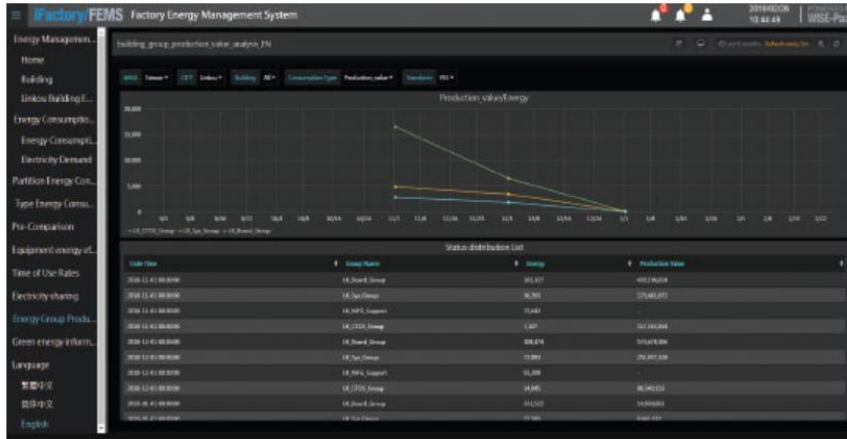


Figure 25 Energy Consumption and Cost Analysis

3.2.6. ABB Ability™ Energy and Asset Manager

ABB Ability Energy and Asset Manager [7] is a cloud-based solution that integrates energy and asset management in a single dashboard. Providing full remote visibility of asset and electrical-system behaviour, ABB Ability Energy and Asset Manager provides full remote visibility of assets and electrical system behaviour supporting the minimization of cost and risk and the maximization of performance and safety. The User Interface is depicted in Figure 26. The tool presents five main sections, i.e., Explore, Analysis, Events, Maintenance and Settings. The Dashboard is highly customizable thanks to several available widgets (Figure 27).

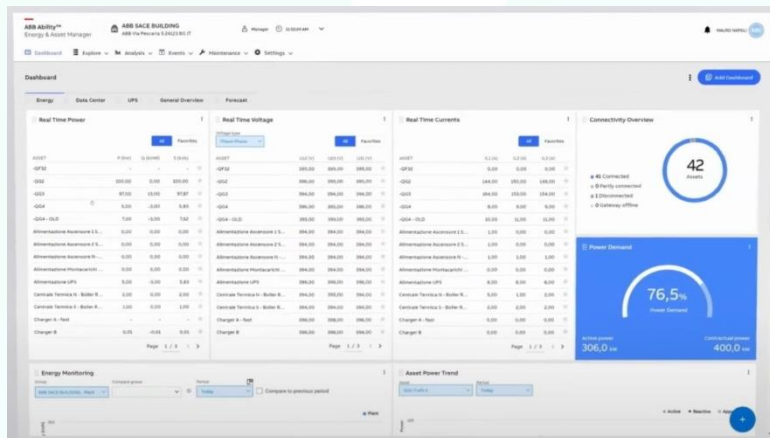


Figure 26 User Interface of ABB Ability™ Energy and Asset Manager.

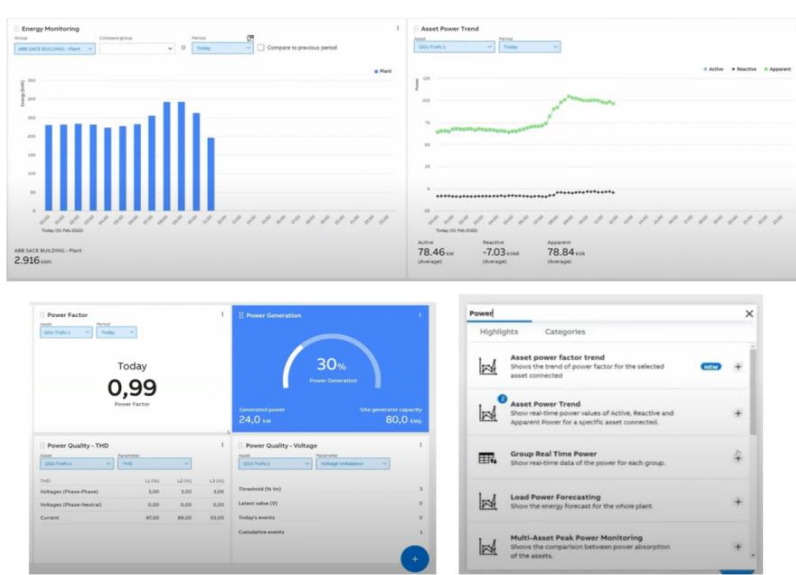


Figure 27 Some of the ABB Ability Energy and Asset Manager available widgets.

3.2.7. Industrial Energy Management Systems (IEMS) by General Electric (GE)

IEMS [8] is an end-to-end energy management solution aiming to monitor, control, report and automatize. IEMS by General Electric provides accurate monitoring of energy consumption, analysis of operational data, automated alerts and alarming, system events meeting application and operational requirements for several applications. The tool is based on a holistic system approach which is used to plan, schedule and control to achieve customer needs quickly and in a cost-effective way. By combining GE IEMS and third-party devices, it is possible to visualise real-time representation of equipment status and energy trends, and to remotely control devices and automatically respond to system conditions. Figure 28 depicts the visualisation interface of the GE solution.

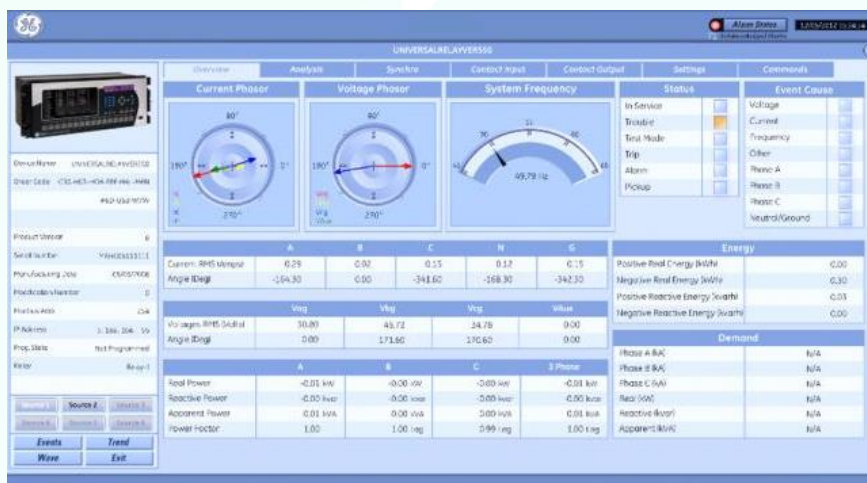


Figure 28 GE IEMS visualisation interface.

3.2.8. Energy Manager by Brightly

Energy Manager [9], developed by Brightly is not an Industrial Energy Management Solution. The software is developed for building operators. However, it is useful to report its functions and its approach to data visualisation. Energy Manager is a cloud-based software solution that allows

identifying waste, improving sustainability, and supporting data driven decisions from one platform (see Figure 29).



Figure 29 visualisation of Utility cost by Brightly's Energy Manager

3.2.9. Siemens Tecnomatix Plant Simulation

Plant Simulation from Siemens PLM Software [10] is a tool for discrete-event simulation and simulation-based analysis of production and logistic processes. Originally created to analyse logistic KPIs it also offers (limited) functionality to analyse energy consumption. The software/simulation model can be highly customized to meet certain customer requirements. A model is usually created following a given production layout, which can be visualised using 2D or 3D animations (for an example of a 3D visualisation see Figure 30).

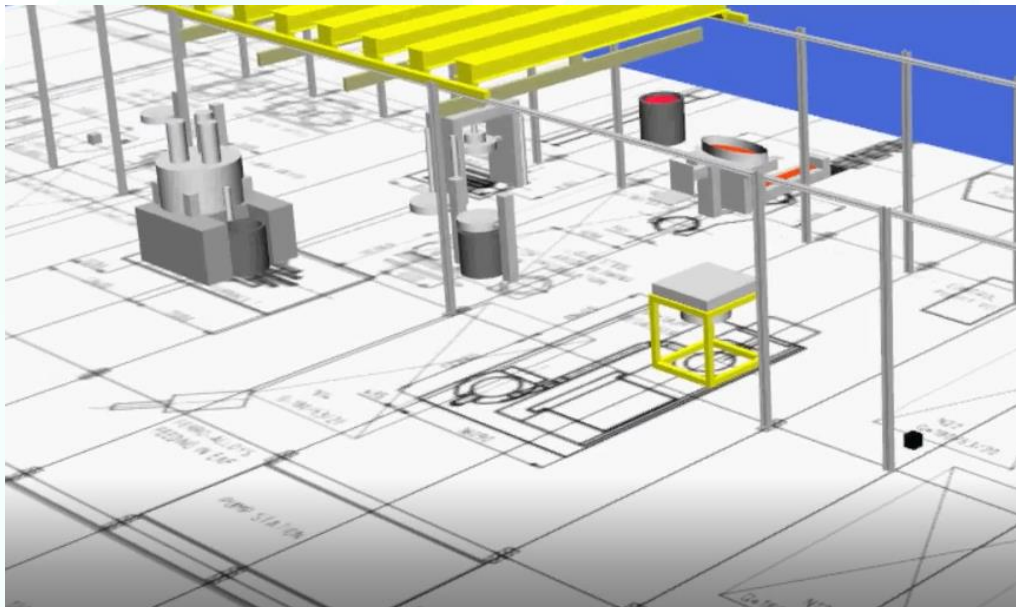


Figure 30 Part of 3D Visualisation of the Stomana Model (see also D4.2)

Visualisations can also include analytic elements like bar/column charts in a dashboard-like fashion. An example of this containing 2D/3D column charts is shown in Figure 31. Furthermore, Plant Simulation can also show a Sankey Diagram/Flow Chart alongside a production layout. This can also

be used to visualise simulated energy flows. A simple example of a flow/Sankey diagram in Plant Simulation is shown in Figure 32.

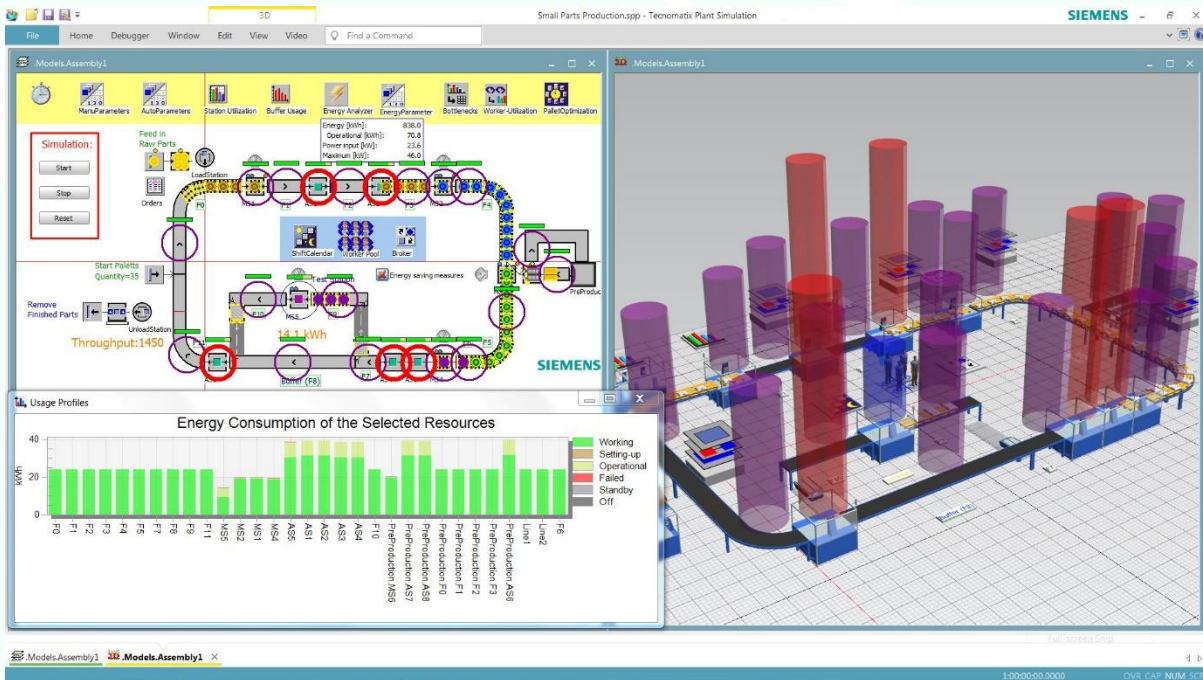


Figure 31 Analytic elements shown alongside elements.

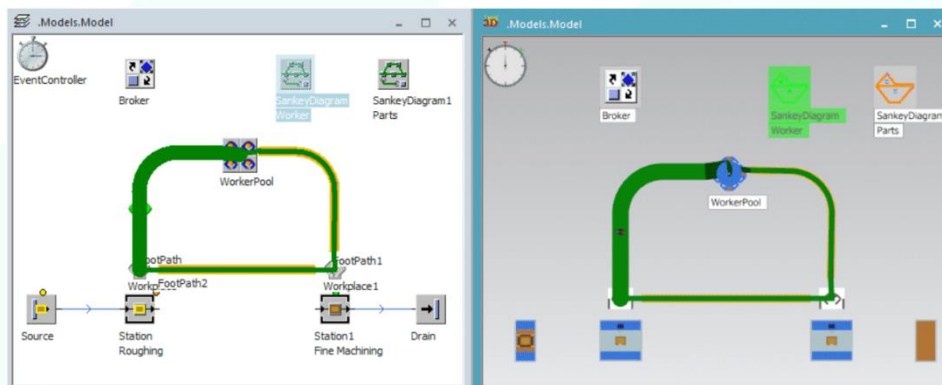


Figure 32 Sankey Diagram in Plant Simulation to visualise the strength of certain flows

3.2.10. Conclusions

Based on the state-of-the-art overview of existing commercial solutions, we conclude that these typically offer a variety of visualisation charts (e.g., pie charts for breaking down an aggregate value into its subcomponents, trend charts of a Key Performance Indicator - KPI etc.) and reports for getting useful insights on energy performance. Nevertheless, these only rely on historical and real-time data for energy consumption, while the prediction of the effect of improvement actions on energy sustainability, the identification of critical processes and mitigation actions are not typically supported.

4. USER REQUIREMENTS

The successful design of any information system strongly depends on correctly understanding and prioritising the user requirements. In this section we document the user requirements of the EnerMan visualisation platform that were elicited so far based on the responses of pilot users to the end-user requirements, which were collected in D1.2 [13].

User requirements can be categorised into functional and non-functional. The former ones are responsible for system behaviours or functions, while the latter refer to the properties that these functions should have, such as security.

Each user requirement is identified using the following format: **<UR-FunctionalAreaX-ShortName>**, where:

- **UR** stands for User Requirement
- **FunctionalArea** refers to any of the following acronyms:
 - EA for Energy Analysis
 - EM for Energy Management
 - DM for Dashboard Management
 - UM for User Management
 - SEC for Security
- **X** is the incremental number of the functional area and
- **ShortName** is a distinctive name.

Section 4.1 provides a list of functional requirements, while Section 4.2 presents the non-functional ones.

4.1. Functional

The functional requirements identified can be grouped in 4 categories: Energy Analysis in subsection 4.1.1, Energy Management in subsection 4.1.2 and Dashboard Management in subsection 4.1.3.

4.1.1. Energy Analysis

UR-EA01-HistoricalAnalysis: As an energy manager, I want to be able to visualise the evolution of energy consumption KPIs in time, so that I can manually identify patterns (e.g., energy drifts) or focus on certain key periods (e.g., in order to confirm an incoming alert).

UR-EA02-RealTimeAnalysis: As an energy manager, I want to be able to view the status of different energy consumption KPIs, so that I can manually identify anomalies in terms of energy consumption, or periods of high costs, etc. to take some action.

UR-EA03-SpatialAnalysis: As an energy manager, I want to be able to visualise the location of events, so that I can identify patterns related to the spatial dimension or focus on certain industrial areas and rooms.

Providing information on energy consumption KPIs and other alerts on a 2-dimensional visual representation of an assembly line, e.g., the manufacturing process that takes place on a factory floor, is an intuitive way to achieving energy awareness for personnel that are accustomed to the industrial area and the processes that are taking place.

UR-EA04-AdvancedFiltering: As an energy manager, I want to be able to filter the results using several properties at the same time, so that I can test a wide range of hypotheses.

Filters are key in reducing the voluminous data during analysis, as hiding unnecessary subprocesses or individual machines can help identify the root of the sudden spike in energy consumption. Filters should be applied on all properties of the machines and when multiple filters are defined only those nodes that pass all active entity filters shall appear. Similarly, when multiple filters are activated on events, only elements that meet all constraints shall be visible. When both entity and event filters are activated, results that do not meet any of the constraints should be hidden.

UR-EA05-StatisticalAnalysis: As an energy manager, I want to be able to visualise statistics about energy KPIs, so that I can identify patterns based on data attributes.

Visualising statistics about entities and events using pie charts, bar charts, histograms etc is important for analysts in identifying:

- Patterns related to a target process, or individual machine.
- Emerging issues in an area and by acting promptly to prevent a situation from deteriorating or developing.
- Longer-term/strategic issues.

UR-EA06-MultidimensionalAnalysis: As an energy manager, I want to be able to see several diagrams at the same time, so that I can combine different types of data referring to the same industrial process and along several dimensions.

Putting information together from various sources and viewpoints can greatly help an energy manager in gaining situational awareness and choosing the appropriate action. For example, a sudden spike in energy costs could be attributed to a significant increase in energy prices, even though the energy consumption was considered normal.

UR-EA07-PredictedOutcomesAssessment: As an energy manager, I want to be able to judge the quality of predicted properties, so that I can assess the accuracy of EnerMan outputs.

Given that technologies are not error-free, energy managers should be able to judge the quality of EnerMan outputs, especially the ones that employ AI techniques. For example, EnerMan can predict the energy consumption of different machines in the near term for a given production plan, environmental conditions etc. and thus the user should be able to see the accuracy of the prediction

(in terms of mean absolute percentage error). A similar approach would be useful for other EnerMan predictions, such as price forecasting.

UR-EA08-Reporting: As an energy manager, I want to be able to generate a report of the analysis, so that I can use it offline.

The energy manager should be able to automatically compile a report that includes graphs, tables or charts with statistical information on current and historical energy consumption, energy prices and resulting costs. These reports are useful for communicating the findings to other colleagues so that next steps are decided or conformance to regulatory commitments can be presented.

UR-EA09-PredictedEnergyConsumptions: As an energy manager, I want to be able to view the predicted values of different energy consumption KPIs, so that I can better plan my future (and current) activities.

UR-EA10-Alerting: As an energy manager, I want to be able to see alerts when an anomaly has been detected or the user-defined thresholds have been exceeded, so that I can immediately react.

UR-EA11-DetailedInformation: As an energy manager, I want to be able to see detailed information about the status of the industrial equipment, the energy consumption, indoor conditions, etc. as well as about the generated alert, so that I can take the appropriate action.

UR-EA12-EnvironmentalInformation: As an energy manager, I want to be able to see detailed information about the outdoor conditions, e.g., temperature and humidity, so that I can take the appropriate action.

4.1.2. Energy Management

UR-EM01-SystemSuggestions: As an energy manager, I want to be able to get system suggestions, so that I can optimise energy consumption and consequently reduce costs and/or environmental footprint.

Energy managers could make use of system suggestions regarding, for example:

- the production plan to be followed by taking into account predicted energy prices and other constraints such as earliest production start and latest production finishing time
- the temperature setpoints over time of heating/cooling equipment that minimises the expected energy costs while making sure that the indoor conditions in terms of temperature and humidity are within the desired range.

UR-EM02-UserDefinedScenarios: As an energy manager, I want to be able to define custom scenarios by suggesting values for a list of attributes based on my own experience.

Energy managers should be able to manually configure key properties of a scenario, e.g., by restricting the machines to be adjusted or by supplying an existing production plan that needs to be improved.

UR-EM03-InformedUserDecision: As an energy manager, I want to be able to choose the most appropriate course of action based on key information for each alternative option.

Energy managers should be able to choose the preferred production plan or energy consumption profile by comparing the alternative options according to various Energy PIs, such as total hourly production costs, total unit cost, energy savings (if applicable) and other indicators like CO2 emissions avoided. If no outcome deemed acceptable, the user should be able to get additional suggestions or define further custom scenarios.

UR-EM04-SemiAutomatedControlLoop: As an energy manager, I want to be able to automatically activate the desired configuration on the target machine (if remote actuation is supported by the latter).

Energy managers should be able to trigger the activation of the chosen production plan or energy consumption profile.

UR-EM05-ConfirmedControlLoop: As an energy manager, I want to be able to check that the desired configuration on the target machine was successfully activated (or see a failure message).

Energy managers should be able to track the status of user actions, e.g., whether these were successfully activated, are pending or failed.

4.1.3. Dashboard Management

UR-DM01-AdjustDashboardView: As an energy manager, I want to be able to adjust the contents of the dashboard so that I can customise it to my ever-changing needs. This includes adding, hiding, repositioning, resizing the charts.

UR-DM02-SaveDashboardView: As an energy manager, I want to be able to save the current dashboard view so that I can enable it again when needed.

UR-DM03-LoadDashboardView: As an energy manager, I want to be able to load a previously saved dashboard view so that I can change to another one when needed.

4.2. Non-functional

The non-functional requirements identified can be grouped in the following 2 categories: User Management in sub-section 4.2.1 and Security in subsection 4.2.2.

4.2.1. User Management

UR-UM01-UserAccountCreation: As an energy manager, I want to be able to create my personal account, so that I can use all features offered by the EnerMan platform.

Energy management can be considered critical activity and thus only authorised personnel should be allowed to monitor and optimise consumption. Having individual user accounts following the organisation's security policy is important for achieving:

- confidentiality - degree to which a product or system ensures that data are accessible only to those authorised to have access
- integrity - the degree to which a system, product or component prevents unauthorized access to, or modification of, computer programs or data
- non-repudiation - degree to which actions or events can be proven to have taken place so that the events or actions cannot be repudiated later
- accountability - the degree to which the actions of an entity can be traced uniquely to the entity and
- authenticity - the degree to which the identity of a subject or resource can be proved to be the one claimed.

UR-UM02-UserAccountView: As an energy manager, I want to be able to view my personal account, so that I can check that my information is up to date.

Users should be able to check that they have logged-in using their own account, especially in offices that are shared by several employees. Furthermore, users' personal information should reflect their status.

UR-UM03-UserAccountEdit: As an energy manager, I want to be able to edit my personal account, so that I can have an up-to-date personal profile which reflects my current profile.

Users should be able to update their personal details, so that their colleagues can recognise them.

UR-UM04-UserAccountDelete: As an energy manager, I want to be able to delete my personal account, so that I can no longer use the EnerMan platform.

Retired users should have no longer access to the final EnerMan system for security purposes.

UR-UM05-ListAuthorisedServices: As an energy manager, I want to be able to see the features supported by EnerMan and choose the appropriate one based on my duties.

Energy managers should be able to see a list of all analysis and management capabilities available in order to improve their energy awareness and eventually to deal with energy issues in terms of costs and environmental feedback. These capabilities should be available even if no anomaly in energy consumption or cost, environmental conditions was identified by EnerMan.

UR-UM06-EditManagementOption: As an energy supervisor, I want to be able to define appropriate access privileges to my colleagues (e.g., energy managers) based on their duties and capacities.

4.2.2. Security

UR-SEC01-ConfidentialCommunications

As an energy manager, I want to be confident that the data and information exchanged between the EnerMan framework components is protected from unauthorized access, so that I can safeguard sensitive company information.

UR-SEC02-Restricted Access

As an energy manager, I want to be confident that the data and information stored by EnerMan framework components is protected from unauthorized access, so that I can safeguard sensitive company information.

5. INDUSTRIAL MANAGEMENT VISUALISATION (IMV) SYSTEM

In this section, we present the transformation of the user expectations and requirements to technical specifications for the EnerMan visualisation platform, i.e., a detailed description of how the functional and non-functional requirements listed in chapter 4 should be implemented. Then, we associate system requirements to target visualisation features of the EnerMan platform and present the internal architecture of the Industrial Management Visualisation System. Finally, we demonstrate the historical analysis service for one indicative pilot use-case in subsection 5.4.

5.1. IMV System Requirements

The system requirements span the following categories:

- user management (analysed in subsection 5.1.15.1.1)
- energy analysis (elaborated in subsection 5.1.2)
- energy management (analysed in subsection 5.1.3)
- dashboard management (elaborated in subsection 5.1.4)

Each system requirement is identified using the following format: **<SR-FunctionalAreaX-ShortName>**, where:

- **SR** stands for System Requirement
- **FunctionalArea** refers to any of the following acronyms:
 - UM for User Management
 - EA for Energy Analysis
 - EM for Energy Management
 - DM for Dashboard Management
- **X** is the incremental number of the functional area and
- **ShortName** is a distinctive name.

5.1.1. User Management

In this section we will document the system requirements related to user management.

SR-UM01-NewUserAccountRequest

The EnerMan GUI shall allow an unregistered user to create an account by providing the appropriate administrative details. This non-functional requirement is related to UR-UM01-UserAccountCreation user requirement.

SR-UM02-NewUserAccountRegistration

The EnerMan backend will create a new user and store the relevant details. This non-functional requirement is related to UR-UM01-UserAccountCreation user requirement.

SR-UM03-UserAuthenticationRequest

The EnerMan GUI shall allow a registered user to log-in to the system by providing the appropriate security details. This non-functional requirement is related to UR-UM02-UserAccountView and UR-SEC02 -Restricted Access.

SR-UM04-UserAuthenticationResponse

The EnerMan backend will authenticate the user. This non-functional requirement is related to UR-UM02-UserAccountView and UR-SEC02 -Restricted Access.

SR-UM05-UserDetailsRequest

The EnerMan backend will supply the details of a particular user. This non-functional requirement is related to UR-UM02-UserAccountView.

SR-UM06-UserDetailsView

The EnerMan GUI shall allow a registered user to view details about her/his account. This non-functional requirement is related to UR-UM02-UserAccountView.

SR-UM07-UserDetailsUpdateRequest

The EnerMan GUI shall allow a registered user to update its own account details. If the registered user has administrator privileges, then she/he will be able to update other users' details, e.g., the services that they can have access to. This non-functional requirement is related to UR-UM03-UserAccountEdit.

SR-UM08-UserDetailsUpdateConfirmation

The EnerMan backend will update the user's details. This non-functional requirement is related to UR-UM03-UserAccountEdit.

SR-UM09-UserDeleteRequest

The EnerMan GUI shall allow a registered user to delete her/his account. This non-functional requirement is related to UR-UM04-UserAccountDelete.

SR-UM10-UserDeleteConfirmation

The EnerMan backend will delete an existing user. This non-functional requirement is related to UR-UM04-UserAccountDelete.

SR-UM11-UserServicesRequest

The EnerMan GUI shall request a list of all existing services a registered user has access to. This functional requirement is a response to UR-UM05-ListAuthorisedServices and UR-SEC01-ConfidentialCommunications.

SR-UM12-AuthorisedServicesRetrieval

The EnerMan backend will list the services she/he is authorised to view. This functional requirement is related to UR-UM05-ListAuthorisedServices and UR-SEC01-ConfidentialCommunications.

SR-UM13-AuthorisedServicesListing

The EnerMan GUI shall present all existing services she/he has access to, along with a high-level description of each one. This functional requirement is a response to UR-UM05-ListAuthorisedServices and UR-SEC01-ConfidentialCommunications.

SR-UM14-AccessGrantingRequest

The EnerMan GUI shall enable an administrator to grant other registered users access to the selected services. This functional requirement is a response to UR-UM06-EditManagementOption and UR-SEC01-ConfidentialCommunications.

SR-UM15-AccessGrantingConfirmation

The EnerMan backend will update the target user's privileges, so that that she/he can have access to selected services via the EnerMan GUI. This functional requirement is related to UR-UM06-EditManagementOption and UR-SEC01-ConfidentialCommunications.

SR-UM16-AccessRevokingRequest

The EnerMan GUI shall enable an administrator to restrict other registered users from accessing the selected services. This functional requirement is a response to UR-UM06-EditManagementOption.

SR-UM17-AccessRevokingConfirmation

The EnerMan backend will update the target user's privileges, so that she/he can no longer have access to additional services via the EnerMan GUI. This functional requirement is related to UR-UM06-EditManagementOption.

SR-UM18-ServiceExecutionRequest

The EnerMan GUI shall trigger the execution of the selected service, e.g., real-time energy management, historical analysis of energy performance, optimal scheduling of production, optimal energy control, etc. Such a request may be decomposed to one or more requests to EnerMan backend

and, for each one, the user may need to supply the appropriate parameters. This functional requirement is related to UR-EA01-HistoricalAnalysis, UR-EA02-RealTimeAnalysis, UR-EA09-PredictedEnergyConsumptions, UR-EM01-SystemSuggestions and UR-SEC01-ConfidentialCommunications.

SR-UM19-ServiceExecutionResponse

The target EnerMan backend components, upon a valid request, shall execute the service in question and return the outputs to EnerMan GUI. This functional requirement is related to UR-EA01-HistoricalAnalysis, UR-EA02-RealTimeAnalysis, UR-EA09-PredictedEnergyConsumptions, UR-EM01-SystemSuggestions and UR-SEC01-ConfidentialCommunications.

The following figure presents the mapping of the user requirements related to user management to the relevant system requirements. We observe that all user requirements are mapped to one or more system requirements.

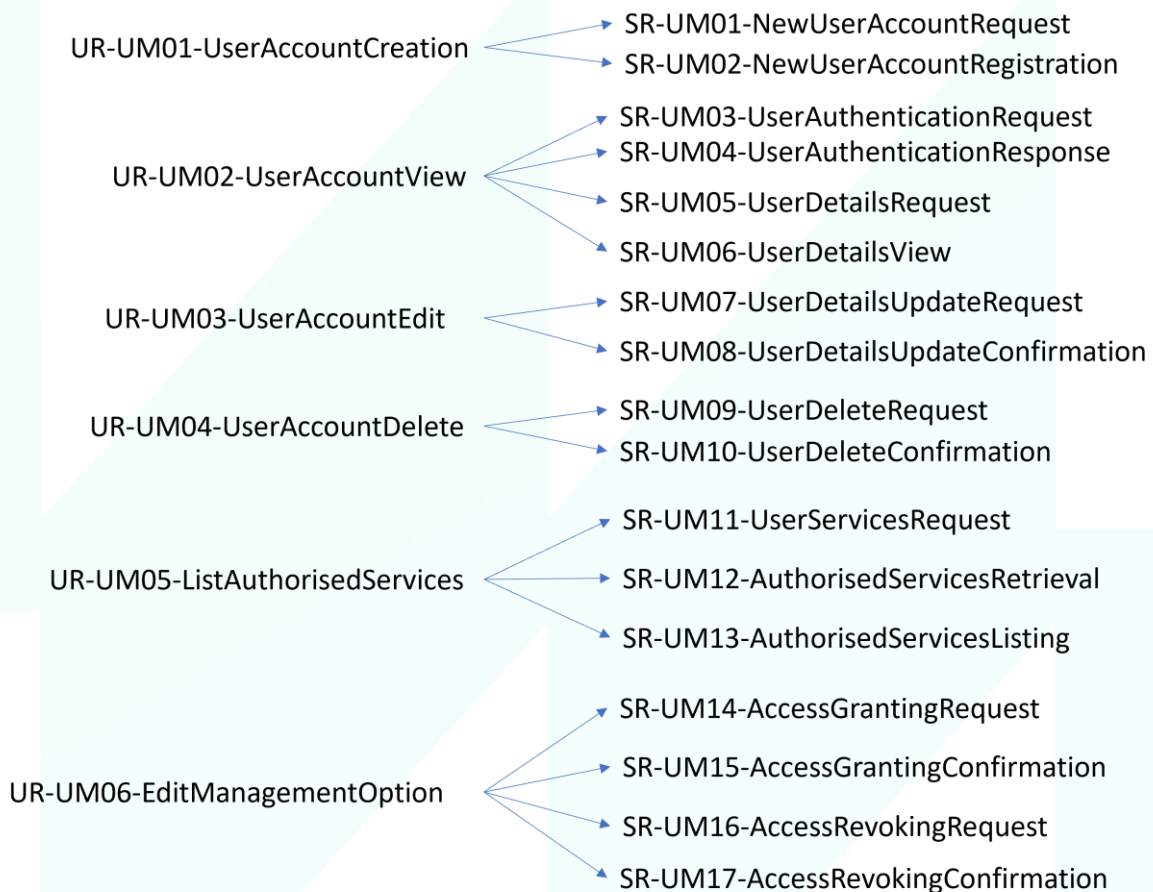


Figure 33 The mapping of the user requirements related to user management to the relevant system requirements

5.1.2. Energy Analysis

In this section we will document the system requirements related to energy analysis user requirements.

SR-EA01-PresentRealTimeEnergyPerformanceIndicators

The EnerMan GUI shall be able to present the current evolution of several Energy Performance Indicators based on timestamp information. These Performance Indicators can be disaggregated per process, industrial area, device, etc. This functional requirement is related to UR-EA02-RealTimeAnalysis and UR-EA06-MultidimensionalAnalysis.

SR-EA02-PresentEnergyPerformanceIndicatorsHistoricalEvolution

The EnerMan GUI shall be able to present the historical evolution of several Energy Performance Indicators for the selected time window. Furthermore, the user should be able to control the evolution in time (i.e., start, pause, reposition the playback slider, move back and move forward) in order to focus on the desired timings. As in the case of *SR-EA01-PresentRealTimeEnergyPerformanceIndicators*, these indicators can refer to processes, industrial areas, devices, etc. This functional requirement is related to UR-EA01-HistoricalAnalysis and UR-EA06-MultidimensionalAnalysis.

SR-EA03-PresentPredictedEnergyPerformanceIndicators

The EnerMan GUI shall be able to present the predicted values of several Energy Performance Indicators for certain devicesSR-EA01-, areas or processes. This functional requirement is related to UR-EA09-PredictedEnergyConsumptions and UR-EA06-MultidimensionalAnalysis.

SR-EA04-ShowRealTimeHighLevelDeviceStatus

The EnerMan GUI shall be able to present high-level and real-time status information about individual devices, such as industrial machines, industrial sensors etc., on mouse hover. This functional requirement is related to UR-EA02-RealTimeAnalysis and UR-EA06-MultidimensionalAnalysis.

SR-EA05-ShowPastHighLevelDeviceStatus

The EnerMan GUI shall be able to present high-level status information about individual devices that was previously recorded on mouse hover. This functional requirement is related to UR-EA01-HistoricalAnalysis and UR-EA06-MultidimensionalAnalysis.

SR-EA06-ShowRealTimeDetailedDeviceStatus

The EnerMan GUI shall be able to present detailed information about selected devices. This functional requirement is related to UR-EA02-RealTimeAnalysis, UR-EA11-DetailedInformation and UR-EA06-MultidimensionalAnalysis.

SR-EA07-ShowRealTimeAlert

The EnerMan GUI shall be able to present high-level status information about individual alerts, such as high energy consumption, high room temperature, etc., on mouse hover. This functional requirement is related to UR-EA02-RealTimeAnalysis, UR-EA10-Alerting and UR-EA06-MultidimensionalAnalysis.

SR-EA08-ShowPastAlerts

The EnerMan GUI shall be able to present high-level information about individual alerts that were logged in the selected time window. This functional requirement is related to UR-EA01-HistoricalAnalysis, UR-EA10-Alerting and UR-EA06-MultidimensionalAnalysis.

SR-EA09-ShowPredicedAlerts

The EnerMan GUI shall be able to present high-level information about future alerts that may happen in the selected time window. These alerts could refer to high electricity prices or high room temperatures as these were predicted from other EnerMan components. This functional requirement is related to UR-EA09-PredictedEnergyConsumptions, UR-EA10-Alerting and UR-EA06-MultidimensionalAnalysis.

SR-EA10-ShowRealTimeAlertDetails

The EnerMan GUI shall be able to present detailed information about alerts generated during the current user session. This functional requirement is related to UR-EA02-RealTimeAnalysis, UR-EA10-Alerting, UR-EA11-DetailedInformation and UR-EA06-MultidimensionalAnalysis.

SR-EA11-PresentRealTimeFloorPlanStatus

The EnerMan GUI shall be able to show the present status of the industrial floorplan, containing machines (as nodes), as well as the current flow of goods and/or energy (as directed edges). This functional requirement is related to UR-EA02-RealTimeAnalysis, UR-EA03-SpatialAnalysis and UR-EA06-MultidimensionalAnalysis.

SR-EA12-PresentPastFloorPlanStatus

The EnerMan GUI shall be able to show the historical status evolution of industrial floorplan machines, as well as the flow of goods and/or energy. This functional requirement is related to UR-EA01-HistoricalAnalysis, UR-EA03-SpatialAnalysis and UR-EA06-MultidimensionalAnalysis.

SR-EA13-AdjustFloorPlanAppearance

The EnerMan GUI shall be able to adjust the appearance of the industrial floor plan (e.g., reposition nodes). This functional requirement is related to UR-EA03-SpatialAnalysis.

SR-EA14-FilterInformationByMachineProperties

The EnerMan GUI shall filter energy-related information (e.g., energy consumption, energy cost, room temperature, room humidity) based on the machines' properties, such as location, type, etc. This

functional requirement is related to UR-EA04-AdvancedFiltering and UR-EA06-MultidimensionalAnalysis.

SR-EA15-FilterAlertsByTiming

The EnerMan GUI shall support filtering on the timing of alerts. This functional requirement is related to UR-EA04-AdvancedFiltering, UR-EA10-Alerting and UR-EA06-MultidimensionalAnalysis.

SR-EA16-FilterEventsByLocation

The EnerMan GUI shall support filtering on the location of alerts. This functional requirement is related to UR-EA04-AdvancedFiltering, UR-EA03-SpatialAnalysis and UR-EA06-MultidimensionalAnalysis.

SR-EA17-ActivateSyncedFilters

The EnerMan GUI shall be able to adjust the content of visible charts based on all activated filters. This functional requirement is related to UR-EA04-AdvancedFiltering.

SR-EA18-DeactivateFilters

The EnerMan GUI shall be able to reset all activated filters. This functional requirement is related to UR-EA04-AdvancedFiltering and UR-EA06-MultidimensionalAnalysis.

SR-EA19-ShowRealTimeStatisticalResults

The EnerMan GUI shall present energy performance indicators at real-time, including energy consumption, energy cost, energy price using statistical charts (e.g., pie charts, bar charts, gauge charts etc.) for different attributes (such as energy type, room area, machine type, etc.). This functional requirement is related to UR-EA02-RealTimeAnalysis, UR-EA05-StatisticalAnalysis and UR-EA06-MultidimensionalAnalysis.

SR-EA20-CompareEnergyPerformanceIndicators

The EnerMan GUI shall be able to compare energy performance indicators in different settings, e.g., before and after EnerMan has been introduced. This functional requirement is related to UR-EA07-PredictedOutcomesAssessment, UR-EA05-StatisticalAnalysis, UR-EA09-PredictedEnergyConsumptions and UR-EA06-MultidimensionalAnalysis.

SR-EA21-ShowRealTimeWeatherConditions

The EnerMan GUI shall present the current local weather conditions, e.g., outside temperature, outside relative humidity, etc. so that users can examine alerts or take decisions. This functional

requirement is related to UR-EA12-EnvironmentalInformation, UR-EA02-RealTimeAnalysis and UR-EA06-MultidimensionalAnalysis.

SR-EA22-ShowProductionLog

The EnerMan GUI shall present the scheduled production plan of a target industrial process for the selected time window. This functional requirement is related to UR-EA01-HistoricalAnalysis, UR-EA03-SpatialAnalysis and UR-EA06-MultidimensionalAnalysis.

SR-EA23-GenerateEnergyReport

The EnerMan GUI shall be able to export analysis results as a report. This functional requirement is related to UR-EA08-Reporting.

SR-EA24-ViewProductionDetails

The EnerMan GUI shall allow the user to view details about a certain scheduled production job. This functional requirement is related to UR-EA11-DetailedInformation, UR-EA03-SpatialAnalysis and UR-EA06-MultidimensionalAnalysis.

SR-EA25-PredictEnergyConsumption

The EnerMan GUI shall allow the user to get an (updated) energy consumption prediction, e.g., for a certain device. This functional requirement is related to UR-EA09-PredictedEnergyConsumptions and UR-EA11-DetailedInformation.

Figure 34 presents the mapping of the user requirements related to energy analysis to the relevant system requirements. Again, we observe that all user requirements are mapped to one or more system requirements.



Figure 34 The mapping of the user requirements related to energy analysis to the relevant system requirements

5.1.3. Energy Management

Energy Management is considered to be one of the key advantages of the EnerMan solution compared to existing commercial solutions, since the prediction of the effect of improvement actions on energy sustainability, the identification of critical processes and mitigation actions were features supported by only one of those studied in section 3.2.

SR-EM01-MinimiseEnergyCostByOptimisingDeviceConsumptionProfile

The EnerMan GUI shall allow the user to choose the appropriate consumption profile of the target device(s), e.g., temperature set points of Heating Ventilation and Air Conditioning (HVAC) units over the selected time window, by taking into account predicted energy costs of alternative options (as generated from EnerMan iDSS). This functional requirement is related to UR-EM01-SystemSuggestions, UR-EM03-InformedUserDecision and UR-EM05-ConfirmedControlLoop.

SR-EM02-OptimiseProductionScheduling

The EnerMan GUI shall guide the user in choosing the optimal production schedule by taking into account predicted energy costs of alternative options, as these are generated from the EnerMan iDSS. The alternative options can combine various objectives, such as energy cost, delay penalties, etc., while considering several constraints (including production deadlines and machine availability). This

functional requirement is related to UR-EM01-SystemSuggestions, UR-EM03-InformedUserDecision and UR-EM05-ConfirmedControlLoop.

SR-EM03-OnDemandDeviceConfiguration

The EnerMan GUI shall allow the user to configure a certain device, e.g., setting a temperature setpoint to a HVAC unit. This functional requirement is related to UR-EM02-UserDefinedScenarios and UR-EM05-ConfirmedControlLoop.

SR-EM04-FinetuneAlgorithmParameters

The EnerMan GUI shall allow the user to adjust the parameters of the algorithms implementing the EnerMan services, such as optimal scheduling of production and optimal energy control. This functional requirement is related to UR-EM04-SemiAutomatedControlLoop and UR-EM05-ConfirmedControlLoop.

Figure 35 presents the mapping of the user requirements related to energy analysis to the relevant system requirements. Again, we observe that all user requirements are mapped to one or more system requirements.

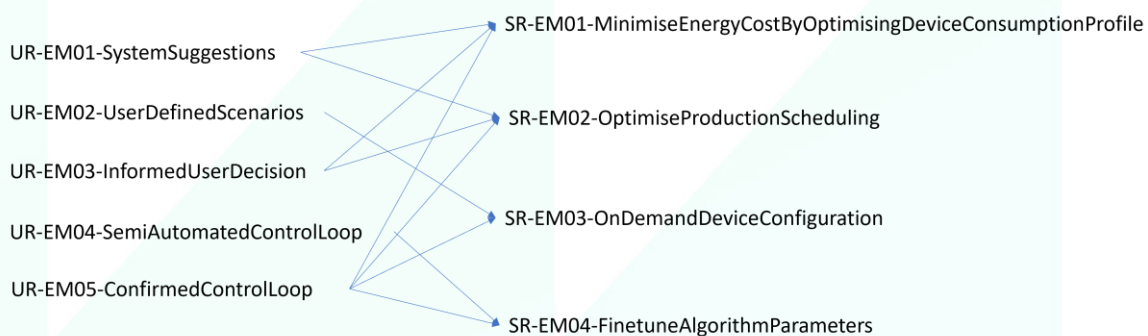


Figure 35 The mapping of the user requirements related to energy management to the relevant system requirements

5.1.4. Dashboard Management

In this section we will document the system requirements related to dashboard management.

SR-DM01-ChooseVisibleCharts

The EnerMan GUI shall allow charts to be deactivated for saving screen estate or improving responsiveness. This functional requirement is related to UR-DM01-AdjustDashboardView and UR-EA06-MultidimensionalAnalysis.

SR-DM02-ResizeVisibleCharts

The EnerMan GUI shall allow charts to be resized according to user preferences/needs and technical constraints. This functional requirement is related to UR-DM01-AdjustDashboardView and UR-EA06-MultidimensionalAnalysis.

SR-DM03-RelocateVisibleCharts

The EnerMan GUI shall allow charts to be relocated for customising screen real estate. This functional requirement is related to UR-DM01-AdjustDashboardView and UR-EA06-MultidimensionalAnalysis.

SR-DM04-SaveDashboardConfiguration

The EnerMan GUI shall be able to save the configuration of the dashboard. This functional requirement is related to UR-DM02-SaveDashboardView.

SR-DM05-LoadDashboardConfiguration

The EnerMan GUI shall be able to load a previously saved dashboard configuration. This functional requirement is related to UR-DM03-LoadDashboardView.

Figure 36 presents the mapping of the user requirements related to dashboard management to the relevant system requirements. Again, we observe that all user requirements are mapped to one or more system requirements.

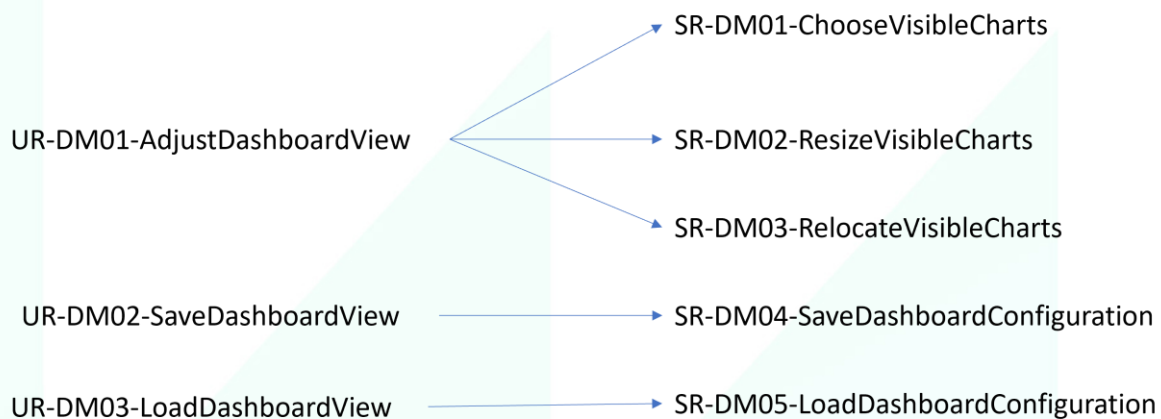


Figure 36 The mapping of the user requirements related to dashboard management to the relevant system requirements

5.2. IMV System Features

This subsection will associate system requirements to target visualisation features of the EnerMan platform.

5.2.1. Services Dashboard

Figure 37 presents a mockup of the EnerMan welcome page, where the user can log in or signup and is associated with the system requirements below:

- *SR-UM01-NewUserAccountRequest (primary)*
- *SR-UM02-NewUserAccountRegistration (primary)*
- *SR-UM03-UserAuthenticationRequest (primary)*
- *SR-UM04-UserAuthenticationResponse (primary)*
- *SR-UM05-UserDetailsRequest (primary)*
- *SR-UM06-UserDetailsView (primary)*
- *SR-UM07-UserDetailsUpdateRequest (primary)*
- *SR-UM08-UserDetailsUpdateConfirmation (primary)*
- *SR-UM09-UserDeleteRequest (primary)*

- *SR-UM10-UserDeleteConfirmation (primary)*
- *SR-UM11-UserServicesRequest (primary)*
- *SR-UM14-AccessGrantingRequest (primary)*
- *SR-UM15-AccessGrantingConfirmation (primary)*
- *SR-UM16-AccessRevokingRequest (primary)*
- *SR-UM17-AccessRevokingConfirmation (primary)*

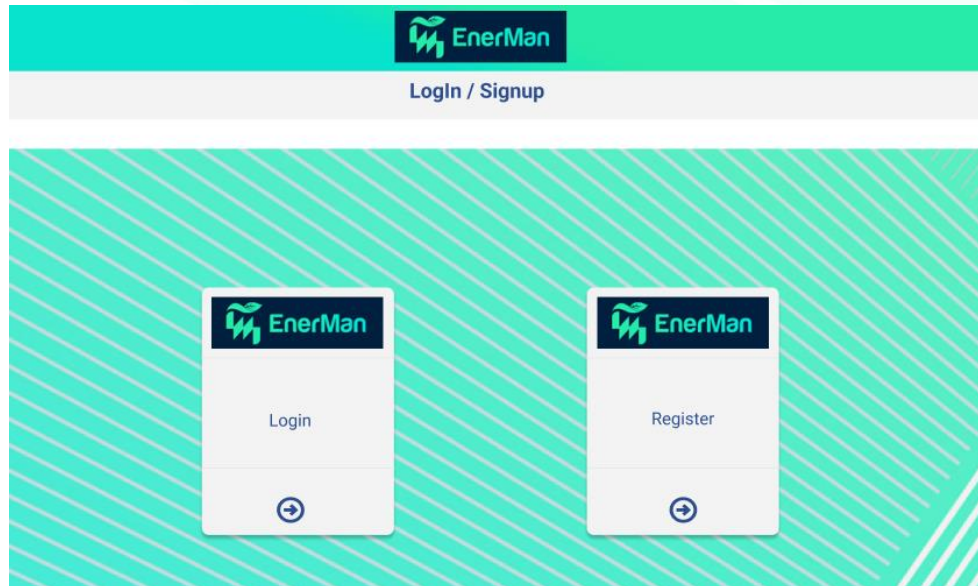


Figure 37 A mockup of the EnerMan Industrial Visualisation Management (IVM) welcome page

Furthermore, the Services Dashboard shows all EnerMan features that a particular user has access to and thus responds to the following system requirements:

- *SR-UM11-UserServicesRequest*
- *SR-UM12-AuthorisedServicesRetrieval (primary)*
- *SR-UM13-AuthorisedServicesListing (primary)*
- *SR-UM18-ServiceExecutionRequest (primary)*
- *SR-UM19-ServiceExecutionResponse (primary)*

Note that although the Industrial Management Visualisation system can support User Management, integration with the required backend security services will happen in the next phase of EnerMan project.

The following figure presents a mockup of the Services page, where three services are supported for the Bodyshop Heating use-case of the CRF factory.

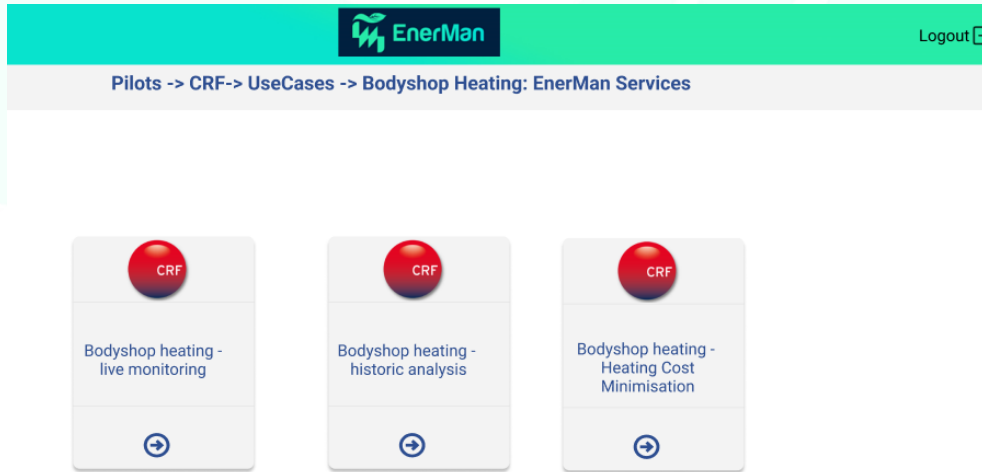


Figure 38 A mockup of the EnerMan IVM Services page

5.2.2. Timeline Analysis

The Timeline Analysis widget provides the ability to “travel back in time” and identify groups of events that occurred close together in time, as well as compare the current situation with older events.

In order to show such an “events” chart to the user, the Industrial Management Visualisation system already implements the following system requirements (as will be demonstrated in Figure 51):

- *SR-EA02-PresentEnergyPerformanceIndicatorsHistoricalEvolution* (primary)
- *SR-EA03-PresentPredictedEnergyPerformanceIndicators* (primary)
- *SR-EA05-ShowPastHighLevelDeviceStatus* (primary)
- *SR-EA08-ShowPastAlerts* (primary)
- *SR-EA09-ShowPredicedAlerts* (primary)
- *SR-EA14-FilterInformationByMachineProperties*
- *SR-EA15-FilterAlertsByTiming*
- *SR-EA16-FilterEventsByLocation*
- *SR-EA22-ShowProductionLog*
- *SR-DM02-ResizeVisibleCharts*
- *SR-DM03-RelocateVisibleCharts*

The following figure presents a mockup of the Timeline Analysis widget.

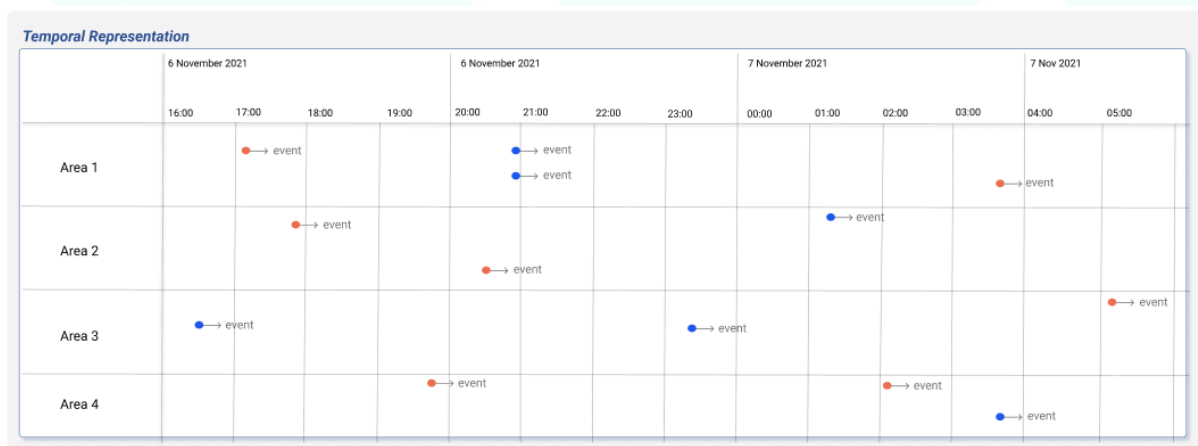


Figure 39 A mockup of the EnerMan IVM Timeline Analysis widget showing events of interest

5.2.3. Statistical Analysis

The Statistical Analysis widget provides the ability to view data distributions based on categories of data using bar charts, pie charts, histograms, etc.

The following figure presents a mockup of the Statistical Analysis widget. It presents the distributions of different energy-related properties (such as breakdown of total energy consumption, breakdown of total energy costs, percentage of areas found in each temperature region, etc.) based on the data that EnerMan components collected and the information these produced.

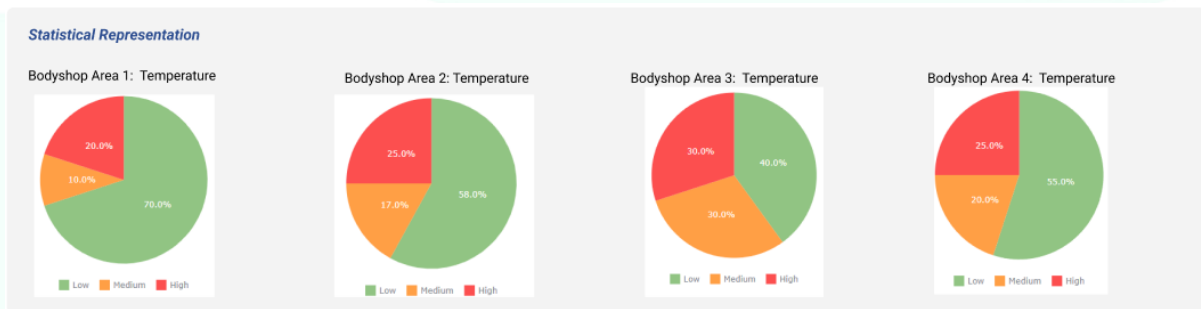


Figure 40 An example of the Statistical Analysis widget showing the percentage of areas found in each temperature region

The following system requirements are relevant to this widget, which is already available for users:

- *SR-EA01-PresentRealTimeEnergyPerformanceIndicators*
- *SR-EA14-FilterInformationByMachineProperties*
- *SR-EA16-FilterEventsByLocation*
- *SR-EA19-ShowRealTimeStatisticalResults (primary)*
- *SR-EA20-CompareEnergyPerformanceIndicators*
- *SR-DM02-ResizeVisibleCharts*
- *SR-DM03-RelocateVisibleCharts*

5.2.4. Floorplan status

The floorplan status widget provides a 2-dimensional visual representation of an assembly line, e.g., the manufacturing process that takes place on a factory floor.

This widget is able to visualise:

- The floor plan area with support for subareas (i.e., rooms), e.g., a rectangle or square with user-configurable dimensions.
- A set of “node types” (i.e., a group of similar equipment where processing takes place) that are characterized by a set of properties (e.g., name, description, a set of pictures for different states such as healthy, alarm, critical, off, etc.). Each node instance has a certain location, as well as other “dynamic” properties (e.g., energy consumption, max capacity, current capacity, health status, etc.) that should be visualised (e.g., on mouse hover). Dynamic locations (i.e., moving nodes) are also supported.
- Directed links that connect pairs of node instances describing the flow of materials/goods. Apart from static properties like name, startingNodeId, endingNodeId, etc, each link has a set of dynamic properties, e.g., max capacity, current capacity, temperature, etc. The floor plan may contain 0 or more links, i.e., in the former case only nodes appear while in the latter case

links are present only for a subset of node pairs. 2 or more links may share the same startingNodeId or endingNodeId.

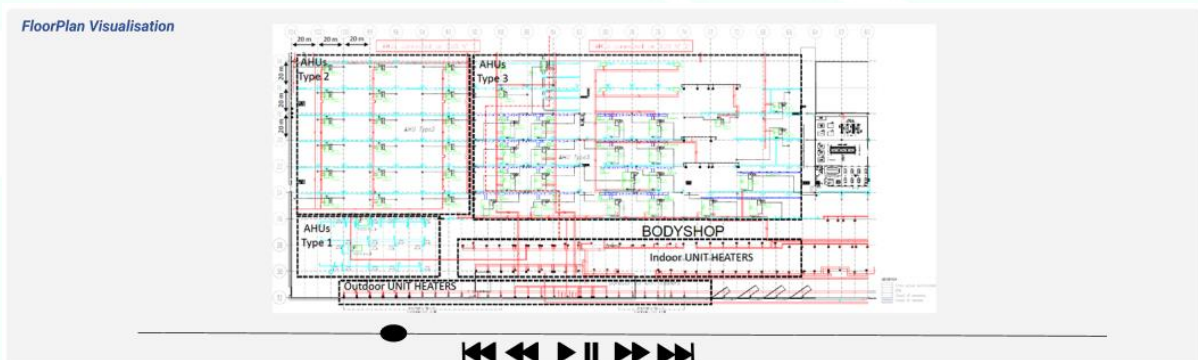


Figure 41 A mockup of the EnerMan IVM Floorplan widget

The following system requirements are relevant to this widget, which is already available for users:

- *SR-EA02-PresentEnergyPerformanceIndicatorsHistoricalEvolution*
- *SR-EA03-PresentPredictedEnergyPerformanceIndicators*
- *SR-EA04-ShowRealTimeHighLevelDeviceStatus*
- *SR-EA05-ShowPastHighLevelDeviceStatus*
- *SR-EA07-ShowRealTimeAlert*
- *SR-EA08-ShowPastAlerts*
- *SR-EA09-ShowPredicedAlerts*
- *SR-EA11-PresentRealTimeFloorPlanStatus (primary)*
- *SR-EA12-PresentPastFloorPlanStatus (primary)*
- *SR-EA13-AdjustFloorPlanAppearance (primary)*
- *SR-EA14-FilterInformationByMachineProperties*
- *SR-EA15-FilterAlertsByTiming*
- *SR-EA16-FilterEventsByLocation*
- *SR-DM02-ResizeVisibleCharts*
- *SR-DM03-RelocateVisibleCharts*

5.2.5. Details

The Details widget is used to present information about the current status of selected entities (such as equipment, room, production batch etc.) and/or events (e.g., both past and new alerts), as well as to trigger the execution of related EnerMan services.

The following figure presents a mockup of the Details widget for the current status of an Air Handling Unit. An initial version of this widget is already available for pilot users, as will be demonstrated in Figure 51 (see Section 5.4).

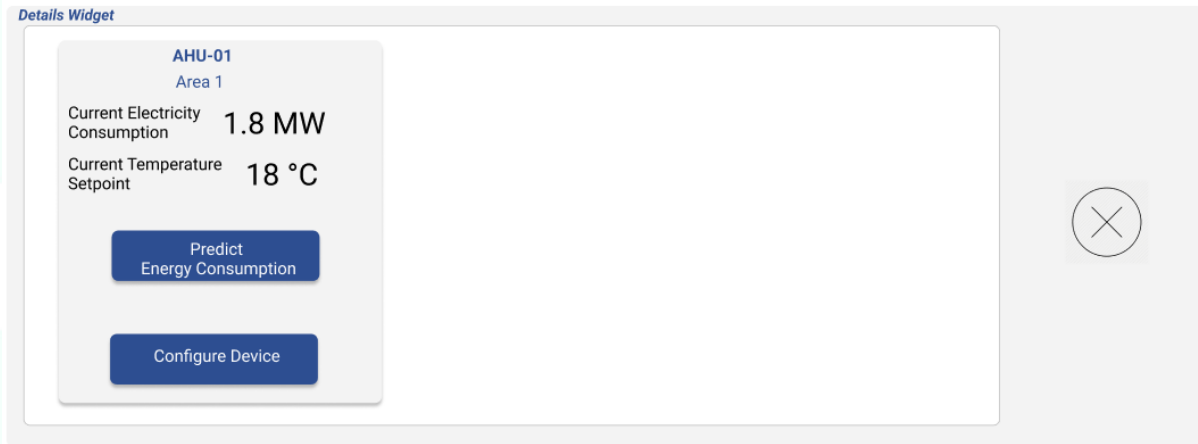


Figure 42 A mockup of the EnerMan IVM Details widget

In order to realise this widget, the visualisation engine already implements the following system requirements):

- *SR-EA01-PresentRealTimeEnergyPerformanceIndicators*
- *SR-EA03-PresentPredictedEnergyPerformanceIndicators*
- *SR-EA06-ShowRealTimeDetailedDeviceStatus (primary)*
- *SR-EA07-ShowRealTimeAlert*
- *SR-EA09-ShowPredicedAlerts*
- *SR-EA10-ShowRealTimeAlertDetails (primary)*
- *SR-EA20-CompareEnergyPerfomanceIndicators*
- *SR-EA22-ShowProductionLog*
- *SR-EA23-GenerateEnergyReport*
- *SR-EA24-ViewProductionDetails*
- *SR-EA25-PredictEnergyConsumption*
- *SR-EM02-OptimiseProductionScheduling*
- *SR-EM03-OnDemandDeviceConfiguration*
- *SR-DM02-ResizeVisibleCharts*
- *SR-DM03-RelocateVisibleCharts*

5.2.6. Weather Details

The Weather Details widget is used to present information about current environmental conditions in a certain geographical area, focusing on outside temperature and outside relative humidity (see following figure for a mockup).

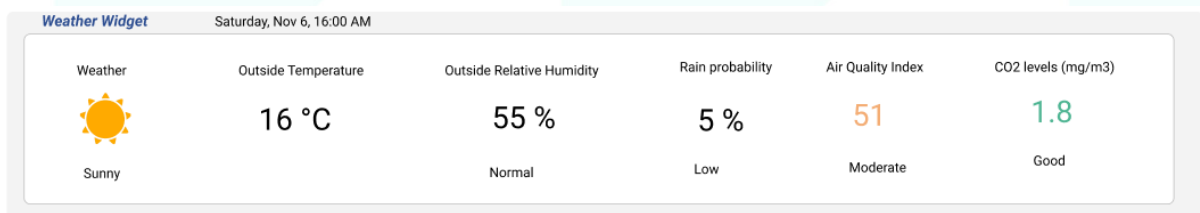


Figure 43 A mockup of the EnerMan IVM Weather Details widget

The following system requirements are relevant to this widget:

- *SR-EA21-ShowRealTimeWeatherConditions (primary)*
- *SR-DM02-ResizeVisibleCharts*
- *SR-DM03-RelocateVisibleCharts*

Note that although the weather details widget is already supported by Industrial Management Visualisation system, integration with the relevant backend service will take place in the next phase of EnerMan project.

5.2.7. Energy Details

The Energy Details widget is used to present information about energy prices, energy consumption and energy costs, where the latter two can be broken down per area. Furthermore, information regarding own generation will be supported for the pilot users that produce one or more energy types (electricity and hot steam). The following figure provides a mockup of this visualisation widget for real-time conditions, while Figure 45 gives a mockup image of the historical view (for the selected time window). These widgets are already available for energy managers to use.

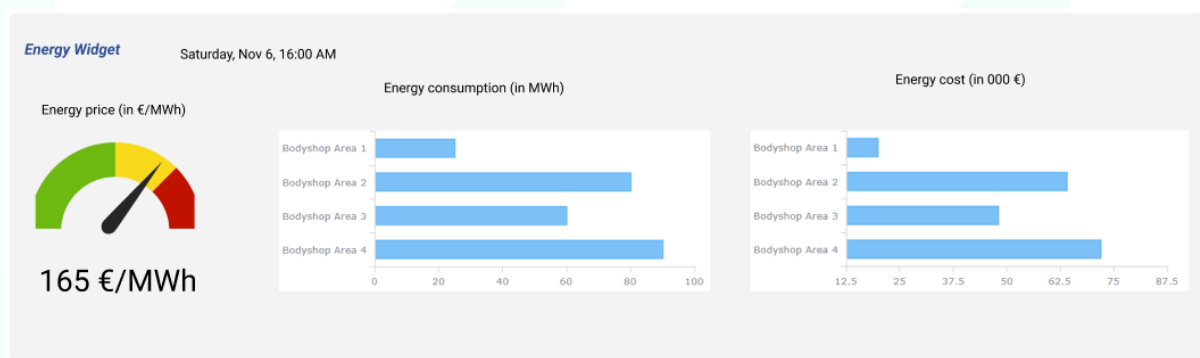


Figure 44 A mockup of the EnerMan IVM Energy Details widget

The following system requirements are relevant to this widget:

- *SR-EA01-PresentRealTimeEnergyPerformanceIndicators (primary)*
- *SR-EA02-PresentEnergyPerformanceIndicatorsHistoricalEvolution (primary)*
- *SR-EA03-PresentPredictedEnergyPerformanceIndicators (primary)*
- *SR-EA14-FilterInformationByMachineProperties*
- *SR-EA20-CompareEnergyPerformanceIndicators*
- *SR-EA25-PredictEnergyConsumption*
- *SR-DM02-ResizeVisibleCharts*
- *SR-DM03-RelocateVisibleCharts*



Figure 45 A mockup of the EnerMan IVM Energy Price widget

5.2.8. Synced filters

Synced filters is a feature allowing the user to narrow down the results that appear across all visualisation widgets (e.g., timeline analysis, statistical analysis, etc.). Figure 46 presents a mockup of the set of filters that could be enabled for a particular use-case. This feature is already available for energy managers to use.

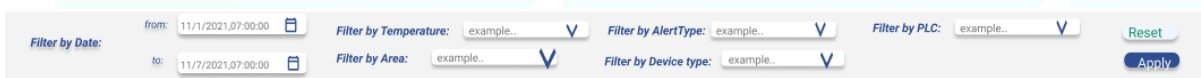


Figure 46 A mockup of the Synced Filters feature

The following system requirements are relevant to this feature:

- SR-EA14-FilterInformationByMachineProperties (primary)
- SR-EA15-FilterAlertsByTiming (primary)
- SR-EA16-FilterEventsByLocation (primary)
- SR-EA17-ActivateSyncedFilters (primary)
- SR-EA18-DeactivateFilters (primary)
- SR-EA23-GenerateEnergyReport

5.2.9. User Inputs

Some EnerMan services can be fine tuned based on user selected input parameters and options. Figure 47 provides a mockup of the User Inputs ribbon that allows the user to run EnerMan services with user-defined inputs; in this case the desired temperature for the chosen area and for a certain time window.

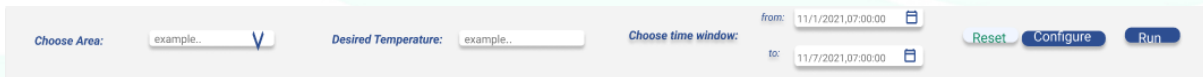


Figure 47 A mockup of the User Inputs feature

The following system requirements are relevant to this feature, which is already available for users:

- *SR-EM01-MinimiseEnergyCostByOptimisingDeviceConsumptionProfile*
- *SR-EM02-OptimiseProductionScheduling*
- *SR-EM03-OnDemandDeviceConfiguration*
- *SR-EM04-FinetuneAlgorithmParameters (primary)*

5.2.10. Custom Workspace

The “Custom Workspace” feature allows the user to adjust the screen real estate in a convenient way. Relevant system requirements include:

- *SR-DM01-ChooseVisibleCharts (primary)*
- *SR-DM02-ResizeVisibleCharts*
- *SR-DM03-RelocateVisibleCharts*
- *SR-DM04-SaveDashboardConfiguration (primary)*
- *SR-DM05-LoadDashboardConfiguration (primary)*

The following figure presents a mockup of the “Custom Workspace” feature that is activated by pressing the “Widgets Bar” button, positioned on the top-right part of the IMV System. This feature is already available for energy managers to use.

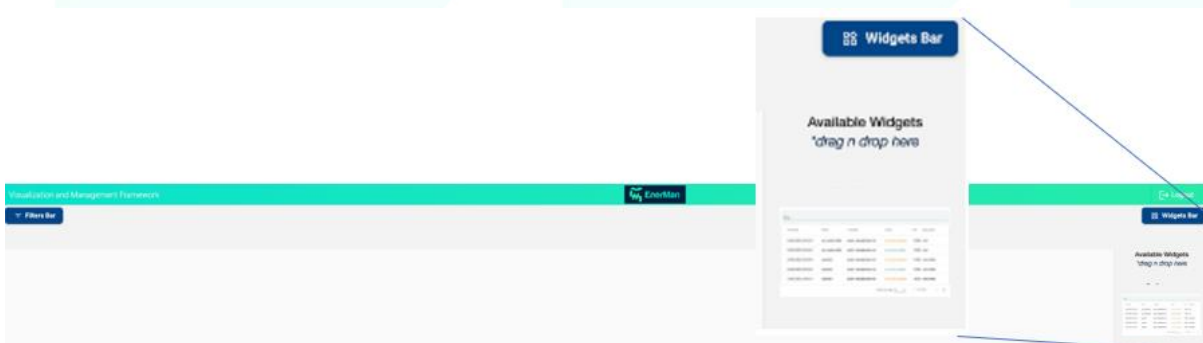


Figure 48 A mockup of the “Custom Workspace” feature

5.3. IMV System Architecture

The IVMS builds upon the Advanced Visualisation Toolkit (AVT) [14], which is a sophisticated set of visualisation tools, capable of connecting with state-of-the-art streaming platforms and databases, while it can be tuned to consume different kinds and formats of data, providing essential, interactive and user-friendly visualisations.

The AVT is provided as a framework that consists of a web application, accompanied by a dedicated server to handle all the external connections, real time messaging and user management (Figure 49). Both components are provided as docker containers with two separate docker images. The AVT frontend is based on the Angular.io [15] framework in conjunction with a set of visualisation libraries that are interchangeably used to cover specific needs and particularities of the analysed data. These include interactive timeline representations for time-dependent data, graph-based visualisations, chord diagrams, geospatial representations, etc.

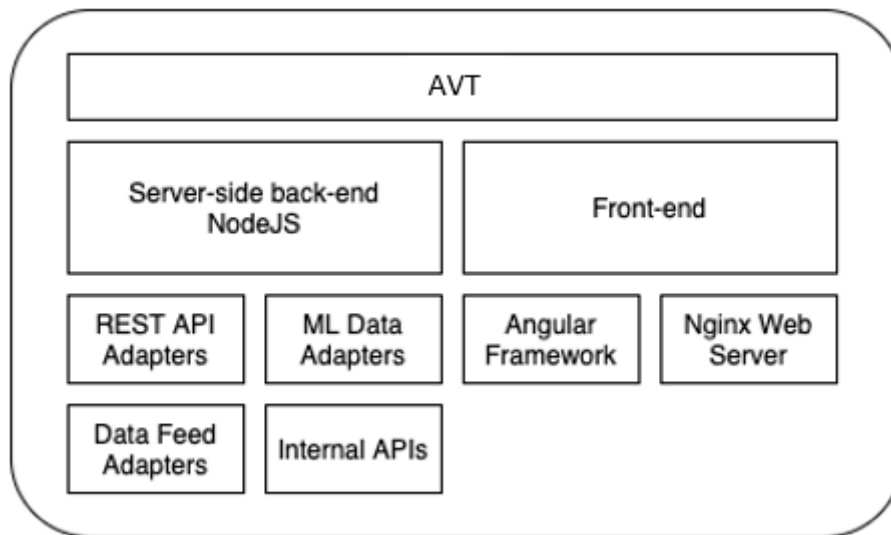


Figure 49 The architecture of the Forensics Visualisation Toolkit (AVT) that is the basis of IVMS

The supporting backend of AVT is built on top of the ElasticSearch (ES) [16] search engine. Using a number of tailor-made converters, raw data are transformed to the AVT-internal representation format that is subsequently stored on one or more indexes in ES. Data are pulled using the ES search Application Programming Interface (API) and displayed in the AVT's frontend visualisation elements. The latter process is also supported by a middleware build on node.js [17] which performs business logic activities required for the smooth operation of AVT.

The internal architecture of a deployed AVT solution is as follows: The front-end container contains the main User Interface (UI) of AVT and the complementary web server that serves it. The interface's internal proxy configurations are handled inside this container. The back-end container contains the AVT's server-side middleware, which is responsible for handling all the necessary external communications in the deployed environment and the processing activities of the toolkit. Several adapters are integrated in this core-component in order to support real-time data streams (e.g., Apache Kafka [18] connector), database connections (e.g., Elastic, MongoDB [19] etc.), different kind of data formats (e.g., JSON files), Representational State Transfer (REST) Application Programming Interfaces (APIs) and more. The implementation of the required data queries and the needed pre-processing activities are taking place within this component. Continuous communication and data

transmission between these components coordinate the AVT’s completed flow. Docker Volume mechanisms and environment variables are available to support data persistence flexibility and acquire dynamic inputs, respectively.

5.4. IMV System Selected scenario

In this subsection we will demonstrate the IMV system for an indicative EnerMan pilot use-case. In particular, we selected the historical analysis service for the scheduled 3d printing jobs of 3DNT.

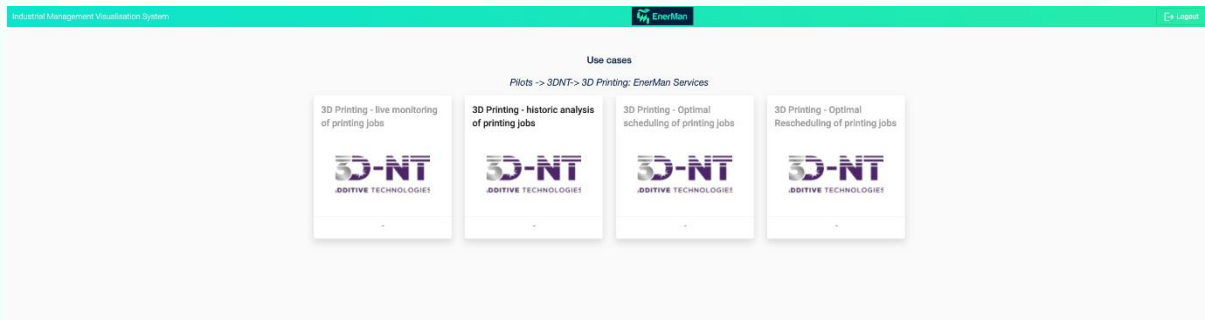


Figure 50 The services dashboard for 3DNT Use-Case

Figure 50 presents the available services for the user in the 3DNT pilot. In the final version of the EnerMan platform, the user will be able to choose from the following options:

- live monitoring of printing jobs
- historic analysis of printing jobs
- optimal scheduling of printing jobs
- optimal rescheduling of printing jobs

Figure 51 presents the historical analysis view for the 3DNT Use-Case, where the user can view a timeline of all jobs that were scheduled for the selected time window (using the respective time filter on the top). In the temporal representation widget, each available 3D printer appears on a distinct row and the orders that were assigned to it. For each order, the user can see its duration and whether the printing job was completed in the desired timeframe. If a printing job either started after the earliest starting time or finished after the latest completion time, the order is marked with a red colour. The rest orders appear in blue colour. Furthermore, when the pointer is moved onto an order, the user can see some high-level details about that particular job.

By double-clicking on a particular order, the user can see additional information on the “Details representation” widget (see Figure 52 also). Furthermore, the user can see the evolution of the wholesale energy prices in the selected time window in the Energy Price Timeline (see Figure 53)

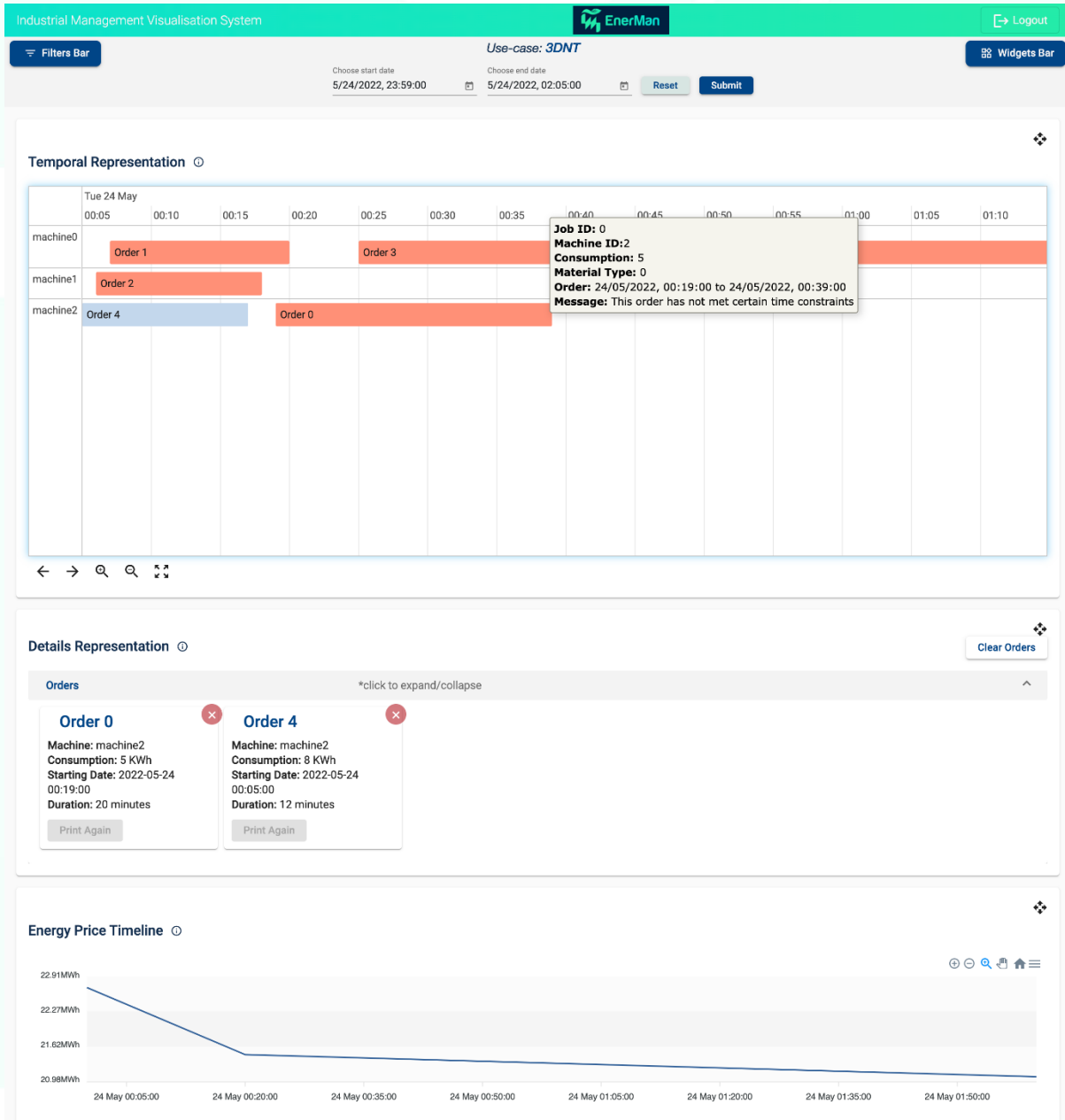


Figure 51 The historical analysis view for the 3DNT Use-Case

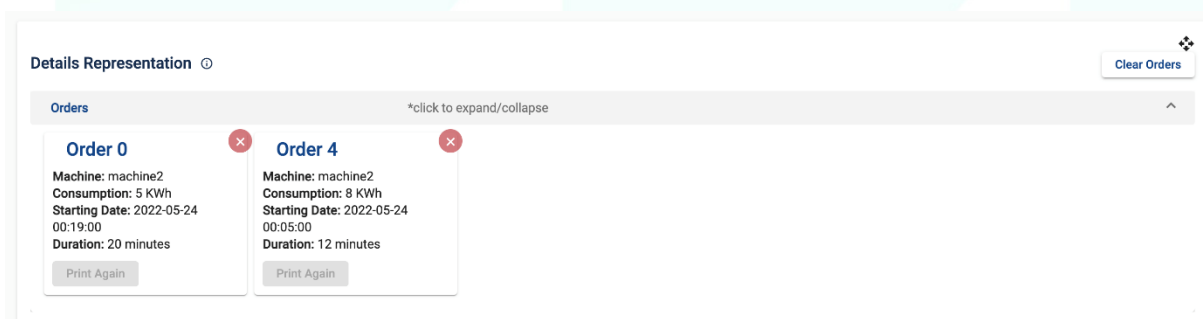


Figure 52 The details widget for the 3DNT Use-Case

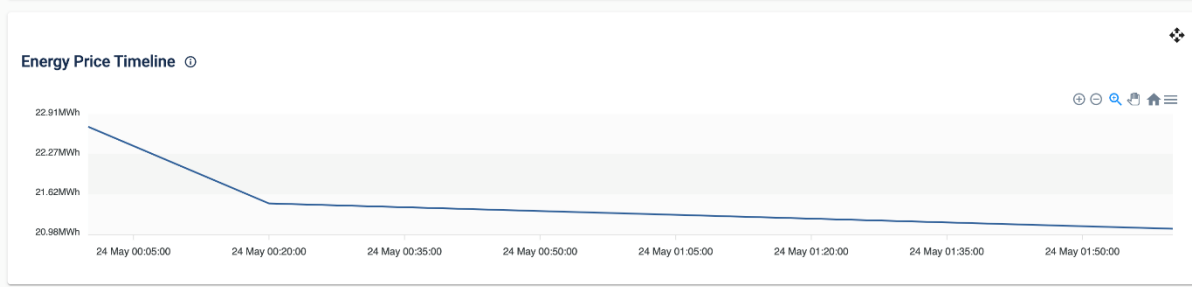
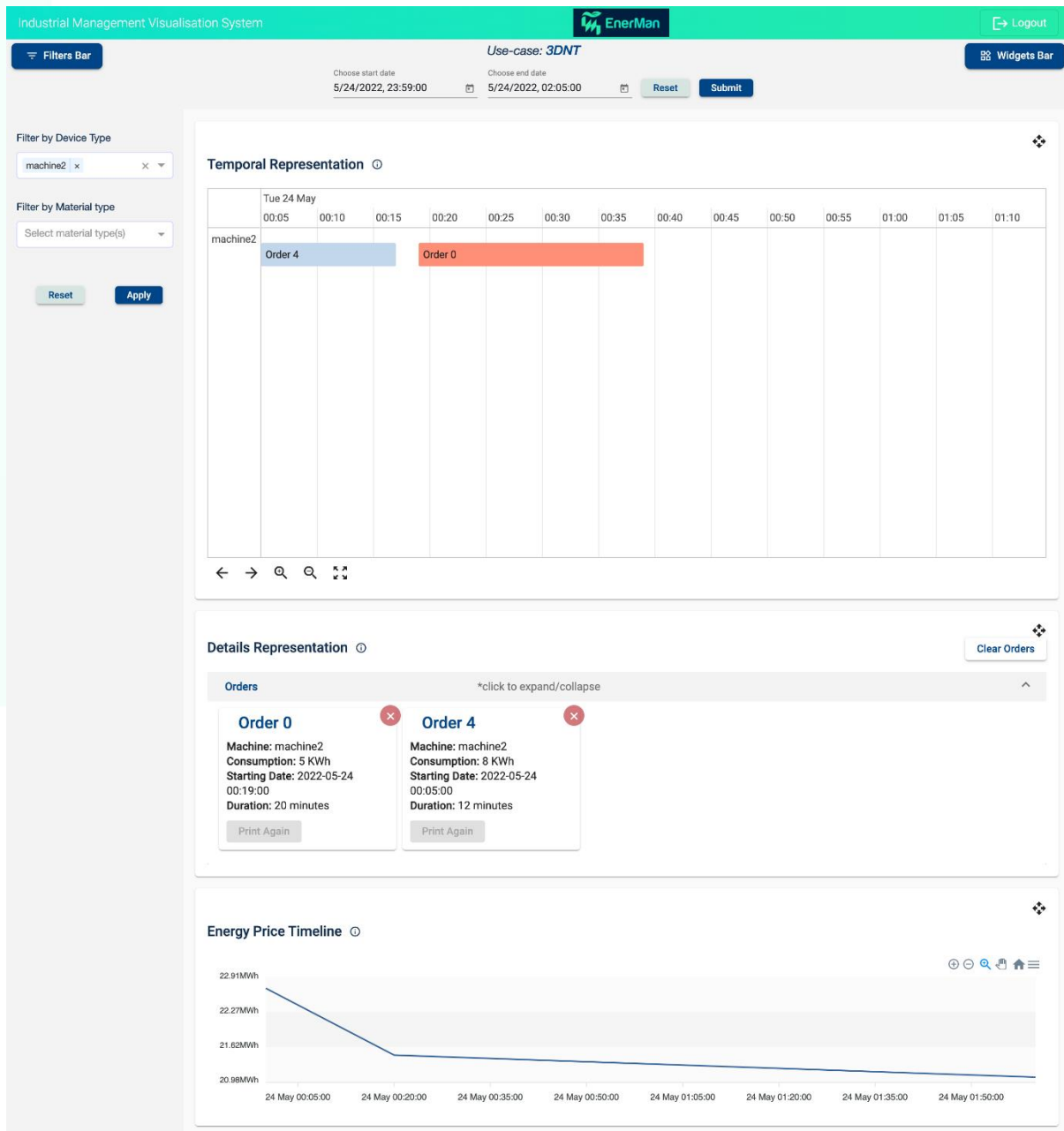


Figure 53 The energy price timeline widget for the 3DNT Use-Case



The screenshot shows the "Industrial Management Visualisation System" interface. At the top, it says "Use-case: 3DNT". There are filters for "machine2" and "Select material type(s)". The main area is divided into three sections:

- Temporal Representation:** A Gantt chart for "Tue 24 May" showing two orders: "Order 4" (blue bar, 00:05 to 00:15) and "Order 0" (orange bar, 00:19 to 00:31).
- Details Representation:** A summary of the two orders:
 - Order 0:** Machine: machine2, Consumption: 5 KWh, Starting Date: 2022-05-24 00:19:00, Duration: 20 minutes.
 - Order 4:** Machine: machine2, Consumption: 8 KWh, Starting Date: 2022-05-24 00:05:00, Duration: 12 minutes.
- Energy Price Timeline:** A smaller version of the line graph shown in Figure 53.

Figure 54 The services dashboard for the 3DNT Use-Case when synced filters are applied

If the user wants to focus on a particular machine ID or machine type, she/he can use the synced filter feature that appears on the left-hand side of Figure 54. As soon as the user selects the Apply button, the temporal representation widget is updated to exclude the rest machines, which is particularly useful when there are several machines and orders.

6. CONCLUSIONS AND NEXT STEPS

This report presented the Industrial Management Visualisation System, which is the main user interface to the EnerMan system and aims at providing all necessary means for the intuitive visualisation of information on energy consumption, energy cost and environmental impact. Furthermore, it can alert users when anomalies are detected (or foreseen) and supports them during the efficient management of the target processes by interfacing with other EnerMan modules, such as the intelligent Decision Support System.

The Industrial Management Visualisation system was integrated with a number of EnerMan components, such as the Big Data Analytics Engine and the Electric Energy Price Forecasting, in order to populate the visualisation widgets with information on energy-related performance indicators and events for a subset of use-case pilots.

As the EnerMan modules are finalised and integration activities are accelerated, additional services will become available, and more use-case pilots will be supported. Furthermore, feedback obtained from the end-users during the pilot activities will improve the usability of the Industrial Management Visualisation. These activities are expected to result in adjustments to the existing visualisation widgets and workflows.

7. REFERENCES

- [1] <https://cim.io/the-peak-platform/>
- [2] Siemens, SIMATIC Energy Manager PRO – Energy efficiency begins with transparency, accessed online on June 2022 from the following URL: <https://assets.new.siemens.com/siemens/assets/api/uuid:55fed442b4f3e3a47c35caad92a3620241aea8c9/dffa-b10256-01-7600-energy-manager-pro.pdf>
- [3] SIMATIC Energy Management – Integrated energy management from the field to the management level, accessed online on June 2022 from the following URL: <https://assets.new.siemens.com/siemens/assets/api/uuid:ade5bc2e-52d3-4747-adf3-1a05b90c6dba/difa-i10050-00-7600-simatic-energymanagement-ipdf-en.pdf>
- [4] SENTRON Powermanager – Identifying hidden potential for energy optimization and savings, accessed online on June 2022 from the following URL: <https://support.industry.siemens.com/cs/document/109801718/powermanager-energy-management-software-brochure?dti=0&lc=en-ww>
- [5] <https://vpt.com.au/smappee-infinity/>
- [6] <https://www.enelx.com/it/it/aziende/servizio-energia/enelx-connect/energy-management>
- [7] <https://new.abb.com/low-voltage/it/soluzioni/abb-ability/energy-and-asset-manager>
- [8] https://www.gegridsolutions.com/panels_engineered/digital-control-systems/iems.htm
- [9] <https://www.brightlysoftware.com/products/energy-manager>
- [10] <https://www.plm.automation.siemens.com/global/de/products/manufacturing-planning/plant-simulation-throughput-optimization.html>
- [11] Siemens, “SENTRON & SIMATIC software solutions for power monitoring and energy management” chart, accessed online on June 2022 from the following URL: https://cache.industry.siemens.com/dl/files/725/109744725/att_1054932/v1/2021-02-24_QSG_Energiemonitoring_EN_final_3_Web_202102251102092125.pdf
- [12] Factory Energy Management Solution, Centralized Monitoring and Data Management for Energy Efficiency Optimization, accessed online on June 2022 from the following URL: https://advcloudfiles.advantech.com/ecatalog/2020/04140952.pdf?_ga=2.32727290.556941045.1652973324-1696652779.1652973324&_gac=1.195417438.1652973324.Cj0KCQjw1ZeUBhDyARIsAOzAqQJDHVkxaxlO1UU5tFCWeeqYvLXS8tREyn4o9cnltQ68pX-8hE-mLgaAqw4EALw_wcB
- [13] EnerMan D1.2 EnerMan pilot requirements and use case report
- [14] <https://aegisresearch.eu/solutions/advanced-visualization-toolkit/>
- [15] <https://angular.io/>
- [16] <https://www.elastic.co/>
- [17] <https://nodejs.org/en/>
- [18] <https://kafka.apache.org/>
- [19] <https://www.mongodb.com/>

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