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EnerMan

Energy Efficient Manufacturing System Management

D6.1 – Pilot Trials Assessment Approach

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EnerMan

Short Description
This document is a deliverable of the EnerMan project, and its purpose is to provide a documented account for the specifications and metrics of the pilot trials, i.e., to provide a context for the evaluation process of the EnerMan framework.

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EXECUTIVE SUMMARY

The implementation of a framework of the complexity and high-level of intricacy that characterises EnerMan, requires significant effort. It is, therefore, evident that the justification for the deployment of such framework must be substantiated by evidence collated from a thorough verification and evaluation process. Hence, this deliverable presents a summary and high-level approach for implementing the trial scenarios within the context of which the EnerMan framework will be assessed. The deliverable follows a structure, which allows for laying out the key performance indicators for performance assessment as well as the implementation context for each pilot. Finally, it is important to stress that the information included in this document are an account of the corresponding state of the technical which, unfortunately, is at a mismatch with the actual end date of T6.1. Consequently, the information included in D6.1 do not cover the full extent of the material that would have been included in the event where the end dates for the two items, i.e., D6.1 and T6.1, were in agreement.

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GLOSSARY OF ACRONYMS

AI	Artificial Intelligence
CES	CO2 Emissions Savings
DoA	Description of Action
DT	Digital Twin
EnPI	Energy Performance Indicator
FPGA	Field Programmable Gate Array
GA	Grant Agreement
I2DS	Industrial Intrusion Detection Systems
IP	Intellectual Property
KPI	Key Performance Indicator
MPSoC	Multi-Processor System-on-Chip
OEE	Overall Equipment Effectiveness
OS	Operating System
PES	Primary Energy Savings
PL	Processing Logic
RFC	Reduced Fuel Consumption
WP	Work Package
XRT	Xilinx RunTime

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1. INTRODUCTION

1.1. Purpose and scope of the deliverable

The main purpose of the deliverable is to document the work carried out in the context of T6.1 "*Pilot trials specifications and Assessment Protocol*". Similarly, the purpose of this task is to define and lay out the details of the scenarios for the EnerMan framework evaluation trials. This is made specific by addressing a number of more specific information such as key performance indicators. The scope of task is explained in the project's DoA and it has to address the following topics, i.e. i) Definition of experiments that cover a wide area of the developed system modules and aim to evaluate the performance of the individual modules in controlled environments, ii) Definition of the proof of concept scenarios in the three pilots categories, aiming to show the performance of the integrated various EnerMan planes, iii) Definition of an evaluation methodology for the technical aspects of individual technologies, iv) Transition from lab testing system to demonstrator system for the three pilot categories, v) Set trial goals in light of project objectives and KPIs and, finally, vi) Refine planning for trial (timing, procedures, people, and equipment. Out of the six items, Section 2 addresses i), iii) and vi) from the point-of-view of the individual technologies that will be integrated within the context of the EnerMan framework and Section 3 provides an initial skeleton for items ii) and vi).

1.2. Structure of the document

This deliverable is structured in the following way:

- Section 2 addresses evaluation information regarding the individual technologies that will be incorporated into the EnerMan framework. The information pertains to success/fail criteria, technical prerequisites and more.
- Section 3 includes up-to-date information as to the use case scenarios that will be implemented for framework validation.
- Section 4 summarises the high-level objectives KPIs and, finally,
- Section 5 is the Conclusions section

1.3. Relationship to other project outcomes

This document is linked with the technical work that is under development within the context of work packages two, three and four. Each of those is responsible for the development of the technical work on each of the three EnerMan framework planes, i.e. i) the Data Control Plane, ii) the Management Plane, and, finally, iii) the Simulation and Prediction Plane. The information documented in D6.1 reflects the level of progress that has been reached by the other three work packages and the content of this deliverable is to assist in the completion of the remaining pilot trials-related tasks of WP6., i.e. tasks T6.2 to T6.5.

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2. DEFINITION OF EXPERIMENTS FOR INDIVIDUAL MODULES

This section addresses the following T6.1 targets, i) Definition of experiments that cover a wide area of the developed system modules and aim to evaluate the performance of the individual modules in controlled environments, ii) Definition of an evaluation methodology for the technical aspects of individual technologies, iii) Refine planning for trial (timing, procedures, people, and equipment)

2.1. Edge node Data Harmonization

Table 1: EDH -related test setup information

Component: *Edge node Data Harmonization*	
Test ID: *EDH.01*	***Operational performance of EDH***
Description	*Data harmonization as a component of the EnerMan platform aims to bridge data collection requirements between the edge node and the cloud infrastructure, addressed in WP2 and WP3 respectively. The data harmonization component facilitates the data collection between the end users and the Big Data Analytics Engine (BDAE) in the cloud (WP3-T3.1), by implementing a data pipeline from raw data provided by the use cases to structured time-series data, available for downstream tasks. The tests to be conducted for this component aim to validate the accurate harmonization process, the quality of the harmonized dataset (evaluating the compliance with the training performed at the system layer of the EnerMan platform). Also, the efficiency of the data harmonization will be tested.*
Technical Prerequisites	*Test infrastructure:* ● *A Linux capable embedded system with python library installed* ● *Optionally, the EnerMan execution environment* ● *IP Network connectivity* ● *Pilot collected datasets need to be provided* *Personnel: 1 person for the setup and test execution*
Technical Description	*Test are conducted for critical components of the harmonization package described in D2.1 as follows:* ***Harmonizers:*** *A Python class that takes a use case specific Data Model as an argument and provides methods for loading the data, pre-processing it with the harmonization functions that correspond to the specific use case, and applying the quality checks on the harmonized data. The Data Model contains information to be used by the class methods, e.g., the expected feature names, data types, localization information. The tests on the harmonizer will be focused on the compliance of the python class results with the data model that has been prescribed.* ***Harmonization utils:*** *A library of pre-processing functions to harmonize the data. For example, there are functions to replace the missing data indication with a standardized form, to transform local timestamps to UTC+00 and datetime formats to ISO 8601 (yyyy-MM-dd'T'HH:mm:ssZ). It also provides functions to transform attributes' names and data types according to a given list provided by the Harmonizer class as described in the Data Model. The*

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	tests on the harmonizer will be focused on the accuracy of the python util results and the usability for the big data analysis performed in WP3 eg. when used in ML/DL training to produce accurate ML.DL models *In the above tests, the Data quality checks library will be used in order to run basic data quality checks.*
Success / Fail Indicators	*Provide the metric under which the component will be evaluated and the success/fail threshold* ● *90% harmonization accuracy compared to the modelled format after quality check* ● *Less than 2msec processing time for the harmonization process*
Related Use Case(s)	*Associated with all pilots apart from 3DNT and IFAG*
Execution Plan	
1st Scheduled Execution Date	M17-18

2.2. Edge node Execution Environment

Table 2: EEE -related test setup information

Component: *Edge node Execution Environment*	
Test ID: *EEE.01*	***Validation of the Edge node Execution Environment***
Description	*The component constitutes the backbone of the EnerMan edge node since it will host all the edge node components in order for those components to be executed correctly. The execution environment consists of three modules: the container software configuration mechanism, the python based PYNQ hardware reconfiguration mechanism and the hardware reconfigurable Linux OS (Petalinux) environment using Xilinx Runtime (XRT). The tests to be conducted for this component will be focused on the functional validation of the above modules*
Technical Prerequisites	*Test infrastructure:* ● *Available Hardware or software application components to be loaded in the execution environment* ● *IP Network connectivity* ● *Pilot collected datasets need to be provided* *Personnel: 1 person for the setup and test execution*

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Technical Description	*The aim of this test is to validate the functionality of the EnerMan edge node execution environment for the various applications for data collection and processing that are going to be made there. The execution environment of the EnerMan end/edge node includes structures that will allow the hardware and software support of the EnerMan edge functionality. Given that the EnerMan project aims at providing reconfiguration of the EnerMan edge functionality, the EnerMan execution environment will be tested for its capability to support such service at the hardware level (using FPGA programmable logic) and at the software level. The EnerMan software agents, which constitute, the operations to be executed in the EnerMan end/edge nodes will rely exclusively on the capabilities of such execution environment.* *The tests to be made are linked with the following capabilities of the environment.* ● *The execution environment hosted in the EnerMan MPSoC unit runs on a Linux-based OS, i.e. Petalinux, on its software side and uses its Programmable Logic (PL) to implement specific types of IP cores, i.e. functional modules, with optimized processing and energy consumption metrics, on its FPGA hardware fabric. The software and hardware reconfigurability of the execution environment are going to be tested using various applications of T2.2 and T2.3/T2.4* ● *Naturally, the OS is equipped with all the necessary firmware for software to hardware communication provided by the Xilinx Runtime (XRT) library that accompanies the embedded OS distribution. On top of the OS, however, we have implemented and configured additional reconfigurability/flexibility features to support the EnerMan node requirements. To achieve software reconfigurability we need to validate in the execution environment the Docker based Containerization, i.e. Docker containers, that will allow for the support of input from the other EnerMan planes such as the Management plane as well as support of functionality that cannot be offered by the Xilinx Petalinux OS.* ● *Given that many Machine Learning and Deep Learning core software libraries are implemented in the python programming language, in the EnerMan execution environment we integrate the PYNQ python library offered by the Xilinx tool into the Petalinux OS environment as an alternative mechanism of supporting hardware (FPGA PL) reconfiguration. This mechanism is going to be tested for each capability to deploy ML/DL applications.*
Success / Fail Indicators	*Provide the metric under which the component will be evaluated and the success/fail threshold* ● *Load and operate correctly at least two different docker containers on the execution environment* ● *Load and operate correctly at least two different python-based ML/DL applications (in line with T2.2) using PYNQ library* ● *Load and operate correctly at least two different hardware assisted data pre-processing applications using the PYNQ library or the XRT execution flow.*

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Related Use Case(s)	*Associated with all pilots apart from 3DNT and IFAG*
Execution Plan	
1st Scheduled Execution Date	M17-18

2.3. Train N/N client with and without constraints

Table 3: ClientNN -related test setup information

Component: *Train N/N client with and without constraints*	
Test ID: *ClientNN.01*	***Validation of the federated training process from the client perspective***
Description	***Train N/N client:*** *The aim of this test is to validate the performance of federated learning approaches with and without constraints from the client (user) perspective. In the federated learning framework, the clients and server collaborate in order to obtain a global model without sharing any information regarding the local data of the clients. At best, this component should produce an accurate machine learning model.*
Technical Prerequisites	*Test infrastructure:* ● *A Linux capable embedded system with python library installed* ● *Optionally, the EnerMan execution environment* *Personnel: 1 person for the setup and test execution*
Technical Description	*Please describe the steps to execute the test.* 1. *Receive the model from the server* 2. *Train the received model based on a local dataset* 3. *After some predefined epochs, stop the training session and evaluates the accuracy of the model* 4. *Send back the updated model to server*
Success / Fail Indicators	*Provide the metric under which the component will be evaluated and the success/fail threshold* ● *The client evaluates the accuracy of the trained model based on a local validation dataset. The accuracy should be above a predefined threshold*
Related Use Case(s)	*Not yet available*
Execution Plan	
1st Scheduled Execution Date	M17-18

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2.4. Aggregator N/N server with and without constraints

Table 4: AVT-related test setup information

Component: *Aggregator N/N server with and without constraints*	
Test ID: *AggrNN.01*	***Validation of the federated training process from the server perspective***
Description	***Train N/N client:*** *The aim of this test is to validate the performance of Federated Learning approaches with and without constraints from the server (user) perspective. In the federated learning framework, the clients and server collaborate in order to obtain a global model without sharing any information regarding the local data of the clients. At best, this component should produce an accurate machine learning model.*
Technical Prerequisites	*Test infrastructure:* ● *A Linux capable computer system* *Personnel: 1 person for the setup and test execution*
Technical Description	*Please describe the steps to execute the test.* 1. *Initialize a global model and broadcast it to clients* 2. *Receive the updated models from the clients* 3. *Aggregate all models into one global model* 4. *Send the global model to clients*
Success / Fail Indicators	*Provide the metric under which the component will be evaluated and the success/fail threshold* ● *After the communication rounds, the server evaluates the accuracy of the global model based on a validation dataset. The accuracy should be above a predefined threshold*
Related Use Case(s)	*Not yet available*
Execution Plan	
1st Scheduled Execution Date	M17-18

2.5. 3DMRT

Table 5: 3DMRT-related test setup information

Component: *3-D MRT map extractor*	
Test ID: 3DMRT.01	***Validation of the 3-D MRT map extractor***

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Description	***3-D MRT map extractor:*** *The goal of this test is to generate detailed maps concerning the Mean Radiant temperature (MRT) distribution of indoor spaces. Based on the temperatures of the indoor surfaces provided by the infrared (IR) camera and the 3D geometry of the space, the estimation of MRT values in various points inside the is feasible via an efficient and non-intrusive way. At best, the component should produce accurate MRT.*
Technical Prerequisites	*Test infrastructure:* ● *An Infrared camera* ● *A Linux capable embedded system* ● *Optionally, the EnerMan execution environment* *Personnel: 1 person for the setup and test execution*
Technical Description	*Please describe the steps to execute the test.* 1. *Employ the IR camera to capture the surface temperatures of the indoor space* 2. *Send the images to the embedded system* 3. *Estimate the MRT map of the space using the received temperatures and the geometry of the examined space*
Success / Fail Indicators	*Provide the metric under which the component will be evaluated and the success/fail threshold* ● *Send and received data should be the same.* ● *The estimated MRT map should be the accurate and in accordance with the air temperature.*
Related Use Case(s)	*Not yet available*
Execution Plan	
1st Scheduled Execution Date	M17-18

2.6. Industrial Intrusion Detection System

The trial setup for the I2DS individual module technology is shown in the figure below, Figure 1. This technology is going to be used for the purpose of filtering the content of data packets travelling within a plant’s local area network in order to flag potential malicious activity embedded within them. This process acquires special significance in the cases whereby the data concerned have been imported from or exposed to activities from the outside world.

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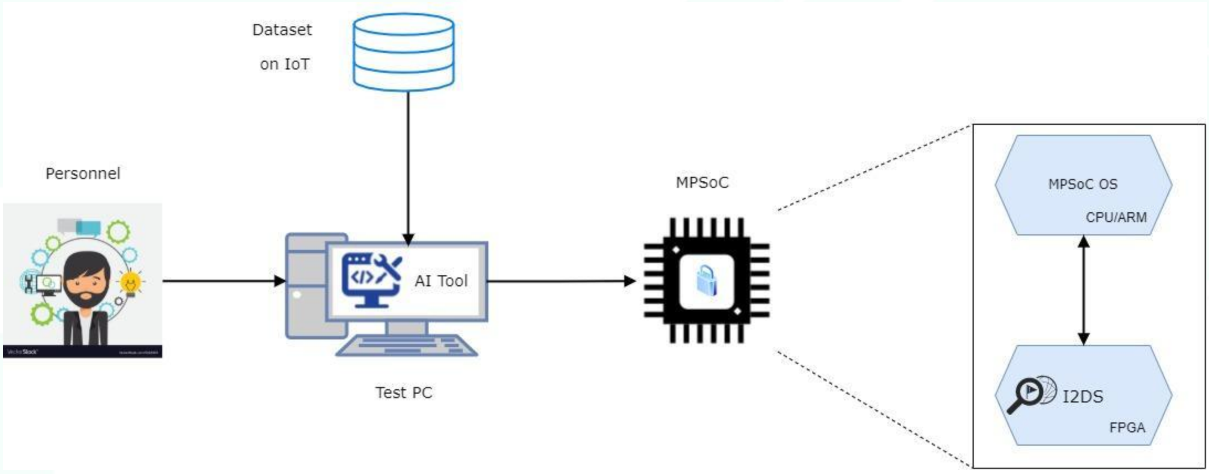

Figure 1: The I2DS individual module test setup

Regarding the evaluation process for the particular intrusion detection technology (I2DS), it is based on the implementation of an AI-based hardware module inside the programmable logic fiber of a Xilinx MPSoC. Hence, initially, an AI tool is used at a Test PC in conjunction with the AI-model that is to be implemented on hardware. The model is trained at the Test PC and as soon as the performance achieved is satisfactory, it can then be offloaded on the FPGA of the MPSoC. There, measurements are once more obtained using the same dataset as before at the training phase.

Table 6 presents information on the I2DS test procedure including information on the evaluation procedure steps, major technical prerequisites, success/fail indicators and more.

Table 6: I2DS-related test setup information

Component: *Industrial Intrusion Detection System*	
Test ID: *I2DS.01*	***Speedup and accuracy evaluation of I2DS.01***
Description	*The aim of this test is to validate that the IDS component of the EnerMan framework meets certain criteria, which constitute it suitable for deployment. These criteria relate to the component's detection accuracy as well as its performance improvement against a purely software implementation. At best, the component should achieve a 90% accuracy at a speedup of x4 over SW, while acceptable performance figures are specified at 80-90% accuracy at a speedup between x1 to x4 over SW.*
Technical Prerequisites	*Name the technical requirements needed for the test to take place along with an expected duration and personnel's profiles. Eg.* *Test PC: Linux-based host PC for the test* *Evaluation board: Xilinx-based host MPSoC ZCU104 evaluation board* *MPSoC OS: Pynq-based image* *Tool: Custom AI FPGA architecture generation framework, e.g. FINN* *Dataset: EnerMan-related dataset, e.g. TON_IoT* *Duration:* *Personnel: Engineer with expert knowledge on FPGA and MPSoC technology*

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Technical Description	*Please describe the steps to execute the test.* *1. Programme host evaluation board with the hardware (HW) AI-model/architecture under test* *2. Execute SW model on host PC* *3. Execute HW model on ZCU104 evaluation board* *4. Compare results*
Success / Fail Indicators	*Provide the metric under which the component will be evaluated and the success/fail threshold* *Accuracy level* *Success > 90%* *Partial Success 80-90%* *Fail < 80%* *HW-based model's Speedup Over SW:* *Success > x4* *Partial Success x1 to x4* *Fail < x1*
Related Use Case(s)	*Not yet available*
Execution Plan	
1st Scheduled Execution Date	M15-16

2.7. Secure Gateway

SGIDS is the EnerMan security component that also provides an IDS mechanism, however, this time it is at the software level, i.e. at the heart of the framework's gateway nodes. The details relating to the approach that will be followed in order to test this individual technology are included in Table 7.

Table 7: SIDS-related test setup information

Component: *Secure Gateway*	
Test ID: *SGIDS.01*	***Evaluation of the protection offered by the secure gateway***
Description	***Protection offered by the secure gateway:*** *The aim of this test is to validate that the security gateway will protect the communication between the data aggregator and the EnerMan. The evaluation criteria relate to the component's functionality to safeguard data in transit between the data aggregator and the EnerMan's backend. At best, the component should allow API call only from the data aggregator application over an encrypted channel*
Technical Prerequisites	*Test infrastructure:* • *A Linux-based VM or PC* • *A Laptop or PC to perform test on the SG* *Personnel: Engineer with knowledge on CyberSecurity*

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Technical Description	*Please describe the steps to execute the test.* 1. *deploy the secure gateway to the server PC/VM, setup the required exposed APIs, Subscribe the data aggregator application, get an APIkey* 2. *execute a subscribed API call from the application to the GW with correct APIkey* 3. *execute a subscribed API call from the application to the GW with wrong APIkey* 4. *execute an unsubscribed API call from the application to the GW* 5. *execute an API call from another application (e.g. postman)* 6. *capture packets during a successful communication*
Success / Fail Indicators	*Provide the metric under which the component will be evaluated and the success/fail threshold* ● *Send and received data should be the same.* ● *Unsubscribed API call should be declined* ● *API call with wrong API key should be declined* ● *API call to unsubscribed APIs should be declined* ● *API call from other Applications should fail* ● *Captured packets during successful API call should be encrypted*
Related Use Case(s)	*Not yet available*
Execution Plan	
1st Scheduled Execution Date	M17-18

2.8. Hardware Security Token

Table 8: HST-related test setup information

Component: *Hardware Security Token*	
Test ID: *HST.01*	***HST.01***
Description	*The test aims at validating the functionality of the Hardware security token secure data storage and secure transfer from the edge devices to the system layer of the* EnerMan *architecture. This will include validation of data encryption mechanisms, secure session establishment, secure authentication, key generation, certificate management etc.*
Technical Prerequisites	*Test infrastructure:* ● *The* EnerMan *execution environment on an edge device* ● *IP Network connectivity* ● *Pilot collected datasets need to be provided* *Personnel: 1 person for the setup and test execution*

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Technical Description	*Based on the design approach of the security functionality in the* EnerMan *architecture, the Hardware Security Token, which offers security primitive services with hardware assistance (in line with theMAN edge node execution environment) will be connected to a purely software-based version of the HST that is deployed in the EnerMan system layer (in the secure gateway as this is described in D2.1). Using IP network connectivity (TCP or UDP based networks) the edge layer HST will establish a secure connection with the system layer software HST and the following functional validation scenarios will be executed:* ● *Secure session establishment using the TLS 1.3 protocol (preferably with postquantum cryptography support). This will involve tests with various cipher modes, key sizes, and different payload sizes.* ● *Encryption and decryption of data that is stored in the HST (at the edge level) under the presence of attackers* ● *Generation and validation of certificates using various cryptography algorithms*
Success / Fail Indicators	*Provide the metric under which the component will be evaluated and the success/fail threshold* ● *Establish and validate TLS 1.3 connection and secure transmission using at least two different strong security cipher modes* ● *Establish TLS1.3 handshake time in less than 2 msec* ● *Store securely data using at least two encryption algorithms and under 2 msec* ● *Generate and validate X509 certificates using at least 2 different digital signature algorithms and under 2 msec*
Related Use Case(s)	*Associated with all pilots that require secure data transmission and storage*
Execution Plan	
1st Scheduled Execution Date	M17-18

2.9. Visualization and Management

The EnerMan framework is going to feature a mechanism that allows for the visualisation and management of its various components and features. This technology is going to be tested and evaluated according to the criteria and strategy listed in Table 9. This table presents information on the test procedure of component AVT.01 such as, technical prerequisites, execution steps, success/fail indicators, and more.

Table 9: AVT-related test setup information

Component: *Visualization and Management*	
Test ID: *AVT.01*	***Operational performance of AVT***
Description	*The aim of this test is to validate that the AVT component, which acts as the EnerMan Visualization and Management framework, meets certain* <u>*objective*</u> *performance criteria that significantly affect user experience.*

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	These criteria relate to the component's responsiveness, availability and reliability.
Technical Prerequisites	*<u>Server:</u> Computer with at least 6 cores, 32 GB DDR4 RAM, 1Tb of SSD, 10Gbps Ethernet* *<u>Test PC</u>: Host PC/laptop running Windows 10 (or newer), Mac OS 10.10 (or newer) or Linux Ubuntu desktop with up-to-date browser (e.g., Chrome) installed* *<u>Dataset</u>: EnerMan pilot pre-processed dataset, e.g. CRF Bodyshop* *<u>Personnel</u>: EnerMan pilot user(s)*
Technical Description	*Please describe the steps to execute the test.* *1. Deploy latest version of AVT with hardcoded dataset on local server* *2. Open a browser on test PC and navigate to the AVT URL* *3. Submit more than 100 requests on the "data view" functionality for visualizing the energy consumption, energy cost and environmental impact (if/when supported) for different granularity levels (e.g., full production line, or at machine level) and for different time periods over the evaluation period (a time window of at least 1 week)* *4. Submit more than 100 requests on the "model view" functionality for depicting the floorplan status, presenting prognosed energy sustainability issues and/or viewing configurations on machines and processes (if/when supported)* *5. Submit more than 100 requests on the "service view" functionality for all supported EnerMan services like virtual customization of the machinery equipment (if/when supported)* *6. Collect data during the evaluation period (at least 1 week) on Response time of each individual page, AVT uptime and Fault Tolerance in case of data errors* *7. Compute average values of Response time, AVT uptime and Fault Tolerance*
Success / Fail Indicators	*Provide the metric under which the component will be evaluated and the success/fail threshold* *<u>Average Response Time</u>* *Success <=7 sec* *Partial Success >7 sec and <=10 sec* *Fail > 10 sec* *<u>Average Uptime</u>* *Success >= 98%* *Partial Success <98% and >=95%* *Fail < 95%* *<u>Fault Tolerance</u>:* *Success >= 95% of data errors are successfully handled (AVT remains responsive and/or informative messages are presented)* *Partial Success <95% and >=90% of data errors are successfully handled* *Fail < 90% of data errors are successfully handled*
Related Use Case(s)	*Not yet available*
Execution Plan	

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1st Scheduled Execution Date	M17-18

2.10. Big Data Analytics Engine API

The Big Data Analytics engine is also an invaluable piece of the EnerMan framework. In addition, the characteristics of this feature are such that they require the evaluation/test procedure to be split into two major components, i.e. BDAE.01 and BDAE.02. The former focuses on the data themselves and, in particular, on the validation of the harmonised data that have been collated from various sources of architecture. The latter, BDAE.02, focuses on a different aspect of the data and that has to do with their storage as a harmonised time-series. It is, therefore, imperative to be able to count on the fact that the timeseries have been created correctly and dependable, which is what the second BDAE test focuses on. Table 10 and Table 11 contain the relevant information regarding the test procedures for the two BDAE components including technical prerequisites, test steps and fail/success indicators.

Table 10: BDAE_1-related test setup information

Component: *Big Data Analytics Engine API*	
Test ID: BDAE.01	***Data quality of harmonized data***
Description	*The Big Data Analytics Engine API aims to provide data ingestion and storage functionalities. The raw sensors' data are consumed either in batches or streams and harmonized before they are stored in a time-series database (TSDB).* *The goal for the BDAE.01 test suite is to validate the quality of the harmonized data before they are imported to the database to become available for downstream tasks.* *The expected outcome is to obtain data that which are complete, consistent, and valid according to the use case definitions.*
Technical Prerequisites	*Python environment with Great Expectations, pandas, TSDB client module installed* *Indicative personnel: junior data analyst* *Duration: ~15min*
Technical Description	*The test suite is implemented as a script that executes the following steps:* *1. Loads the harmonized data as data frames* *2. Runs data quality checks* *Prints the results per test*

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Success / Fail Indicators	*Completeness: Missing values have been imputed* *Success 100%* *Partial Success >50% and <100%* *Fail < 50 %* *Consistency: Data types conform to the data types defined in the data model* *Success 100%* *Partial Success >50% and <100%* *Fail < 50 %* *Validity: The data schema attributes conform to the use case attributes as described in the data model.* *Success 100%* *Partial Success >50% and <100%* *Fail < 50 %*
Related Use Case(s)	*Horizontal*
Execution Plan	
1st Scheduled Execution Date	*M16*

Table 11: BDAE_2-related test setup information

Component: *Big Data Analytics Engine API*	
Test ID: BDAE.02	***Availability and timeliness of harmonized time-series data for downstream tasks***
Description	*The Big Data Analytics Engine API aims to provide data ingestion and storage functionalities. The harmonized time-series data are stored in time-series databases (TSDB).* *The goal for the BDAE.02 test is to ensure that the time-series data are properly stored and can be retrieved on demand to downstream tasks.* *The expected outcome of this test suite is to verify the accessibility and timeliness of the time-series data retrieval.*
Technical Prerequisites	*Python environment with TSDB client installed* *TSDB endpoint access* *Indicative personnel: junior data analyst* *Duration: ~10min*
Technical Description	*The test suite is implemented as a script that executes the following steps:* *1. Accesses the TSDB with the provided credentials* *2. Calculates the TSDB uptime* *3. Runs TSDB queries* *4. Logs the return latency*

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Success / Fail Indicators	*Accessibility:* 1. *Uptime of the TSDB [Number of hours TSDB is up and running divided by total scheduled hours x 100]* *Success >70%* *Partial Success >50% and <70%* *Fail < 50%* 2. *Users to support* *Success >= 12* *Partial Success <2 and >10* *Fail < 2* *Timeliness:* 1. *Amount of time required to retrieve timely data (database-to-destination latency)* *Success < 10,000 ms* *Partial Success >10,000 ms and <180,000 ms* *Fail > 180,000 ms*
Related Use Case(s)	*Horizontal*
Execution Plan	
1st Scheduled Execution Date	*M16*

2.11. Simulation Engine

Table 12: SIM -related test setup information

Component: Simulation Engine	
Test ID: SIM.01	***Energy-aware Value Streams can be modelled and simulated***
Description	*Aim of this test is to validate the Value Stream modelling and simulation capabilities of the Simulation Engine, developed as part of the EnerMan Digital Twin Backend. This test assesses the capability of pilot users to model a typical value stream of their application domain including media/energy consumptions. Besides a base model also different scenarios can be modelled and analysed.* *This test performs the typical steps of users to interact with the system. Each step is evaluated using a scoring scheme:* ● *3 points: step performed without problems,* ● *2 points: step completed with minor problems,* ● *1 point: step could be performed, but major refinements necessary;* ● *0 points: step could not be executes.* *This gives a total maximum score of at 30 points. A scoring of at least 22 points is required to pass this test.*
Technical Prerequisites	*Technical requirements needed for the test to take place along with an expected duration and personnel's profiles:* *<u>Test PC</u>: PC with a recent Web Browser and Internet Access* *<u>Duration</u>: 2-3 hours* *<u>Personnel</u>: Engineer/Process Expert, if possible, with simulation experience*

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Technical Description	*Steps to execute the test:* 1. *Log in to the system* 2. *Create a new value stream model* 3. *Add energy/sustainability-related information to the model* 4. *Submit the model for detailed analysis using the Backend of the EnerMan Simulation Engine* 5. *Inspect and analyse logistic KPIs such as cycle time reported by the Simulation Engine* 6. *Inspect and analyse energy related KPIs such as energy costs, calculated by the Simulation Engine* 7. *Save the model and create different test scenarios using it* 8. *Submit different scenarios for simulation-based evaluation* 9. *Compare results in the GUI* 10. *Export results for further analysis in,. e.g., Excel*
Success / Fail Indicators	*Provide the metric under which the component will be evaluated and the success/fail threshold* *Accuracy level* *Success > 26 points* *Partial Success 22-26* *Fail < 22 points*
Related Use Case(s)	*Not yet available*
Execution Plan	
1st Scheduled Execution Date	*M18*

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3. DEFINITION OF THE PILOTS' PROOF OF CONCEPT SCENARIOS

This section addresses the following T6.1 targets, i) Definition of the proof-of-concept scenarios in the three pilots categories, aiming to show the performance of the integrated various EnerMan planes, ii) Refine planning for trial (timing, procedures, people, and equipment). Finally, due to confidentiality reasons, it has not been possible to include the information pertaining to all use cases and it has been, therefore, possible to include those pertaining to some of the EnerMan pilots' use cases.

3.1. DPS

In this section, the information related to the two target use case scenarios of DPS are presented. The overall target domain along with information on setup characteristics, are presented in Table 13.

Table 13: Main focus and key characteristics of DPS use case(s)

Main product(s) description	Medical implants, primarily hips and knees. Materials used are metals and plastics. Metals are cast into their basic shape. The parts are then machined and polished to a precise tolerance level before being sterilized, packaged, and shipped.
Target (sub)process description/ Scope	Compressed air is used by many pieces of equipment on site, primarily for pneumatic values, pumps, actuators, and cleaning. For this work we are focusing on the low pressure Compressed Air system of Building 2 in the Depuy Synthes campus. There are two compressors on the CA system and they all feed into a unified header which assets can tap into. .
Initial State	Compressed air in the low-pressure CA line is held at 6.4 bar. Air compressors are run to achieve this set point. Much of the energy lost in the system is due to CA which is used for cleaning important cameras and sensors in milling machines and lathes. This cleaning CA can be always running irrespective of the operational status of the equipment.

3.1.1. Use Case 1

Current state

- Each dust extraction system has several production assets attached
- Need to maintain a minimum flow
- Flow is constant irrespective of what the assets are doing

Propose to monitor Dust 1001 in Building 1 in Depuy

Current data available / required

- Electrical consumption of Dust 1001
- Electrical consumption of assets (from buzz bar)
- Vortex flow meter via BMS
- Production data (historical and forecasted)
- Rework figures (historical)
- Machine downtime

Outcome

- Model that can optimize the flow rate of the system depending on assets in use, and expected production figures
- Control the VSD to drive rates up and down

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- Suggest closing extract in areas when not being used and demonstrate (simulated) savings that could present in energy

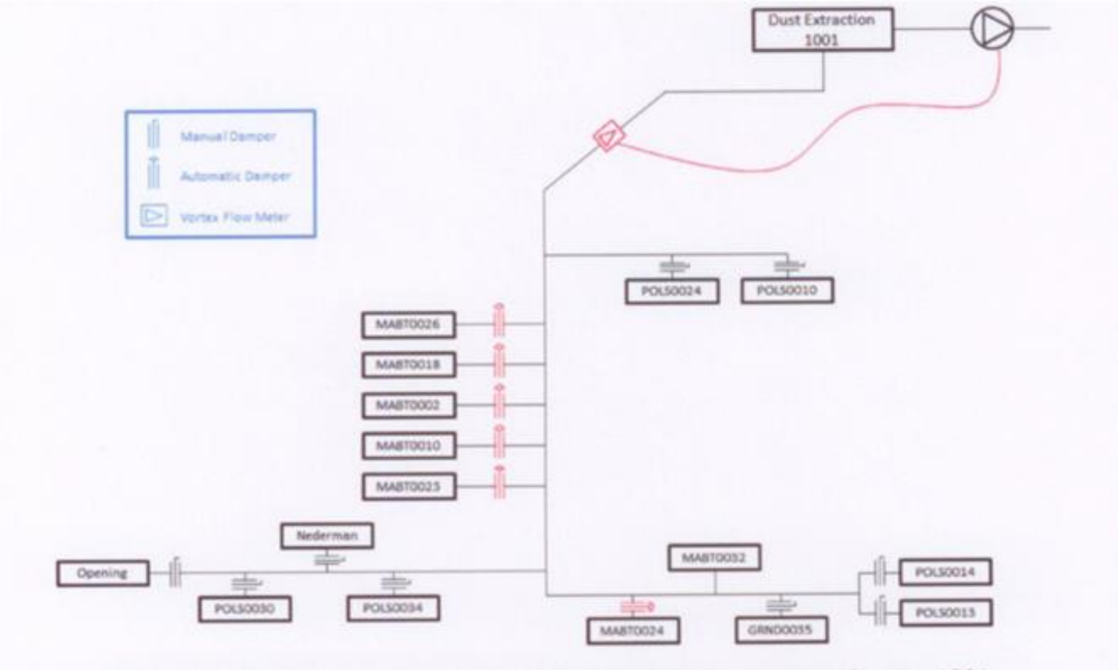

Figure 2: Architecture of DPS use case 1

3.1.2. Use Case 2

Current State

- Compressed air lines have a number of assets running off each one (exact number to TBC)
- Assets are left on even when idle / drawing compressed air
- Leaks in the system also causing drains

<u>Propose to monitor</u> COMP_1010_250kW Building 2

- Electrical consumption of Dust 1001
- Electrical consumption of assets (from buzz bar)
- Scheduling of assets
- Forecasted production
- Supply pressure
- Air flows

<u>Outcome</u>

- Model that can identify estimate the actual "work" performed by the compress air, and indicate what savings could be made by shutting off idle assets
- Suggest machine shutdowns when not in use

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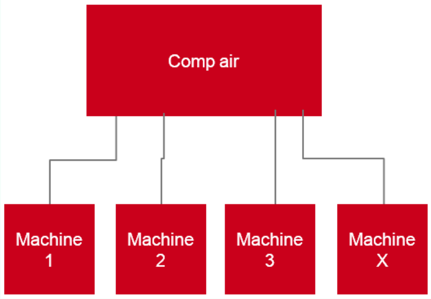

Figure 3: Architecture of DPS use case 2

3.2. CRF

In this section, the information related to the two target use case scenarios of CRF are presented:
1. Bodyshop environmental heating;
2. Paintshop process utilities.
The overall target domain with information on setup characteristics are presented in Table 14.

Table 14: Main focus and key characteristics of CRF use case(s)

Main product(s) description	1. Construction of car bodies, made by personnel and robot, in order to send them to paintshop for subsequent painting. 2. Painting of car bodies applying different protective layers in order to give the final aesthetic appearance in terms of colour and clarity.
Target (sub)process description/ Scope	1. Environmental heating and air conditioning of the industrial building portion related to the Bodyshop working area. The heating consumption of the HVAC system is necessary to keep an indoor air temperature of the working area of the building around 18°C in order to ensure the personnel health. 2. Maintenance of the process required condition to ensure product quality of two utilities that are object of study: ● Degreasing Tank of Pre-treatment, in which the body car is washed and cleaned into a tank with spray by using hot water before the paint application, and the tank water temperature is maintained around 50°C. ● Air Handling Unit of Topcoat Booth, in which the paint is applied to the body car into a booth regulated by specific conditions of temperature and humidity, kept around 24°C and 50% respectively.
Initial State	1&2. Basic regulation of indoor air temperature or process parameters based on defined set-point and switching on/off derived from operator's experience.

3.2.1. Use Case 1

Current state

- There are 4 different kinds of monitoring and regulation of building indoor air temperature related to the 4 different type of building macroarea. Each area is characterized by different heating system and regulation (e.g. type of heating devices and actuation logics)
- Need to maintain indoor air temperature condition of working areas around 18°C
- Regulation and application is managed basically with indoor air temperature set-point and switching on/off derived from operators experience

Propose to monitor all parameters that affect the environmental heating regulation and actuation.

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Current data available / required (real and/or forecast)

- Indoor air temperature acquired by meters
- Hourly weather condition (outdoor air temperature, RH, solar radiation)
- Production shift scheduling
- Operational and set point scheduling of HVAC system
- ON/OFF status of devices signal
- Monthly energy consumption for heating
- Energy market cost fluctuations

Outcome

- Real-time collection and elaboration of data for a better optimization scheduling of environmental heating control proposed by system to operators or direct control action on the devices for a better maintenance of indoor temperature condition in the working area
- Development of predictive model based on Machine Learning - Deep Learning and artificial intelligence (AI) allowing individuation of best scheduling for environmental heating management and thus avoid problems and energy losses

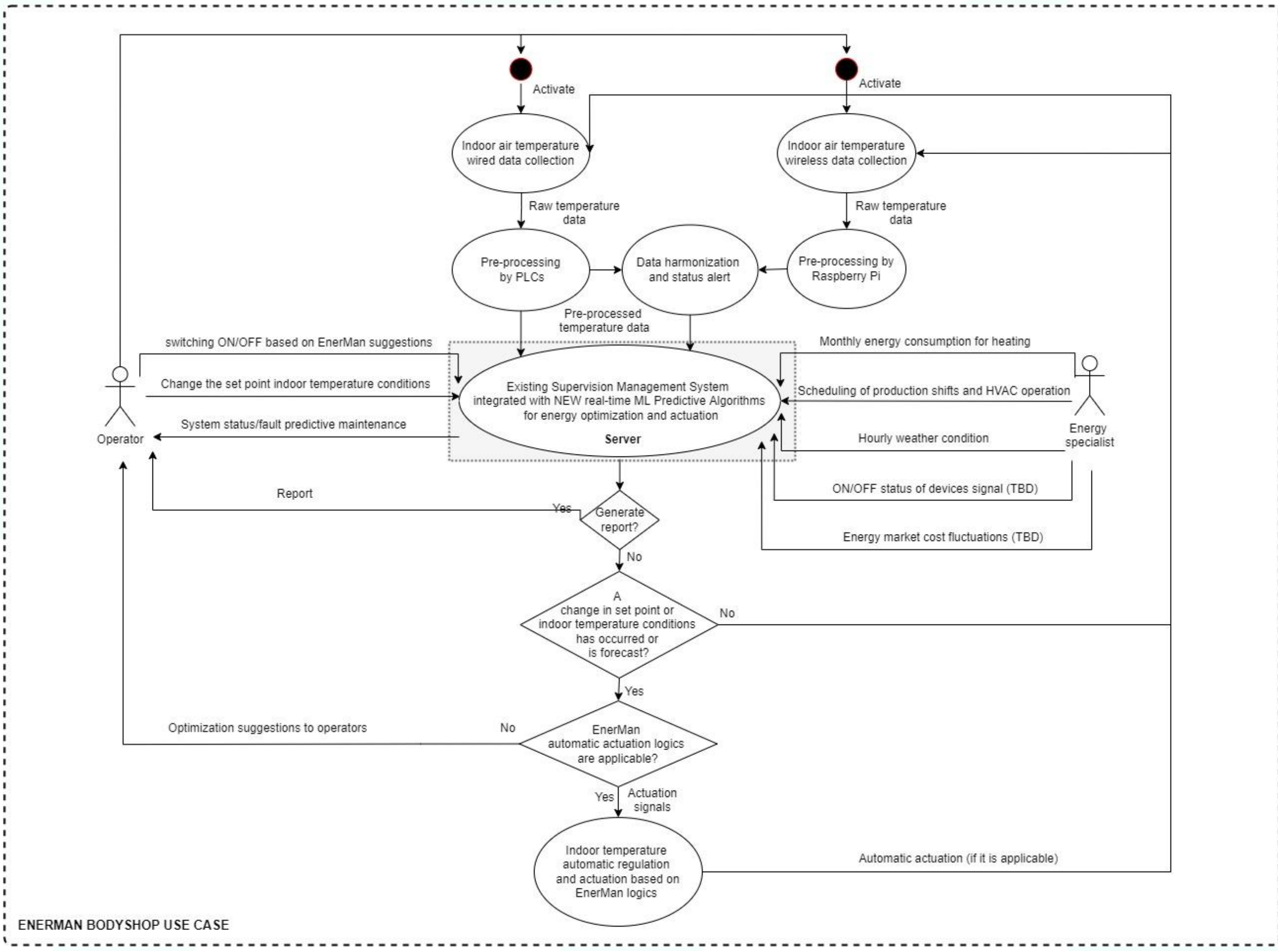

Figure 4: Architecture of CRF use case 1 project prospect

3.2.2. Use Case 2

Current State

- Need to maintain the Degreasing Tank water temperature around 50°C.

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- Need to maintain the Air Handling Unit of Topcoat Booth temperature and humidity condition around 24°C and 50% respectively.
- A basic regulation and actuation is used for the two utilities based on defined set-point and switching on/off derived from operators experience in order to ensure a right warming-up before the start of production.

Propose to monitor all parameters that affect the process condition maintenance and the heat/cooling power demand and supply needed to maintain those desired conditions.

Current data available / required (real and/or forecast)

- Air and hot/chilled water process temperature
- Air and hot/chilled water flow rate
- ON/OFF status of devices signal
- Operational and set point scheduling of utilities (real and/or forecast)
- Production scheduling
- Outdoor weather condition
- Heat/cooling power demand and supply for utilities maintenance

Outcome

- Real-time collection and elaboration of data for a better optimization scheduling of process control proposed by system to operators or direct control action on the utilities for a better maintenance of process parameters with consequent maintenance of product quality and energy saving.
- Development of predictive model based on Machine Learning - Deep Learning and artificial intelligence (AI) allowing individuation of best scheduling for process energy control.

3.3. AVL

3.3.1. TB402/ TB403

Current State

- HVAC/chiller-system installed to have constant conditions of temp and humidity in test cell
- Due to outside conditions different control systems ensure that enough cooling or heating power is available
- Control system ensure appropriate accuracy of demands
- Energy monitoring system (calculation and visualization of energy consumption, data export via CSV)
- Data evaluation and plant visualization
- Data storage
- Data export to various systems
- OPC interface
- Data acquisition via PLC input modules
- Control of testbed
- Interface to sub-PLCs
- Uplink to wincc server

Propose to monitor

- All parameters to get an overview of energy flows
- All parameters to be able to control the system in an efficient way

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Current data available / required (real and/or forecast)

- General: temperatures (external, supply), pressure supply air, humidity supply air, status of chiller circuit
- TB402
    - Temperature ext. Supply air testbed
    - Difference Pressure ext. Supply air testbed
    - Temperature and Humidity exhaust air testbed
    - Temperature and Humidity supply air testbed
    - Temperature and Humidity supply air to vehicle
    - Temperature sensor room testbed
    - Temperature exhaust gas vehicle
    - Difference pressure vehicle speed
    - All media supply temperatures
    - All media return temperatures
    - All temperatures before, between and after the coils
    - Electrical power of ventilation
- TB403
    - Temperature ext. Supply air testbed
    - Temperature and Humidity supply air to vehicle
    - Difference Pressure ext. Supply air testbed
    - Temperature exhaust gas vehicle
    - All media supply temperatures
    - All media return temperatures
    - All temperatures before, between and after the coils
    - Electrical power of deep cooling chiller system
    - All Temperature, pressure levels of deep cooling chiller system
    - Electrical power of ventilation
- Outlook:
    - Additional datapoints not yet completely defined
    - measurement points and sensors in discussion
    - Suitable sensors for flexibility

Outcome

- Investigation / simulation of exchange of equipment eg. Frequency converter
    - Less electrical power losses
    - New technology with energy recovery system at breaking
- Optimize temperature/humidity control AHU including outside air temperature and humidity for cooling/heating/humidify control testbed AHU
- Optimize time management of test cycles
- Optimize control recirculation cooler TB403
- Optimize deep cooling chiller system
- Detailed data on real energy consumption to optimize monitoring (flows, power, temperatures)
- Digital twin model, including different test cycles, simulating planning of tests (Optimize time management of test cycles), predicting energy consumption

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4. TRIAL GOALS

The definition of an evaluation scheme for the different EnerMan pilots and use cases requires a fundamental knowledge of the types of technology objectives and their definitions. These objectives play a significant role since they influence the nature and context of the pilot schemes and setups that will allow for the evaluation of particular EnerMan framework aspects and technology parameters. Hence, the trial goals have been shaped in accordance with the KPIs for the eight different use cases that fall under the categorisation of three major pilot scenarios, Table 15.

Table 15: The three pilots and eight different EnerMan use cases

Pilot Category	Use case owner	Use case title
#1 Appliances and industrial components manufacturing industry	Centro Ricerche Fiat (CRF)	#1.1 The painting process and body shop working area
	AVL List GmbH (AVL)	#1.2 A testing factory for engines, powertrains and vehicles
	Infineon Technologies AG (IFAG)	#1.3 An energy-optimized global virtual factory
#2 Food industry	YIOTIS Anonimos Emporiki & Viomixaniki Etaireia (YIOTIS)	#2.1 Chocolate processing and manufacturing
#3 Metal manufacturing and processing industry	Asas Aluminyum Sanayi Ve Ticaret Anonim Sirketi (ASAS)	#3.1 Autonomous trigeneration facility for aluminium industry
	Johnson & Johnson Vision Care (DPS)	#3.2 Titanium and CoCr alloys manufacturing for medical device industry.
	Stomana Industry SA (STN)	#3.3 Energy consumption in iron and steel manufacturing industry
	Prima Electro SPA (PE) & 3D New Technologies SRL (3DNT)	#3.4 Additive manufacturing for processing metal components.

As a first layer of KPIs, there exist those that are linked to the objectives of the project. These are as follows:

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- Objective 1: Design an intelligent, autonomous, flexible, and reconfigurable energy sustainability manufacturing closed control loop manager that constantly adapts the manufacturing processes, product lines, equipment functionality in order to always comply with operator determined energy sustainability indicators.
- Objective 2: Provide an intelligent, holistic, secure, and trusted sensor data collection and analysis mechanism that can process energy data from heterogeneous factory actors, equipment and processes in order to extract accurate energy sustainability metrics.
- Objective 3: Structure a FOF digital twin that can simulate the factory operation and predict holistically, based on historical and real collected data, a factory energy sustainability fingerprint. The Digital Twin should take into account the energy impact of human operator behaviour.
- Objective 4: Consider throughout the EnerMan lifecycle human users and operators and provide extended reality solutions that increase their situational awareness on energy sustainability well practices for the industrial process.
- Objective 5: Integrate the EnerMan various tools into a unified solution αand realize industrial manufacturing opportunities in energy consuming environments by validating tools and techniques in real-world settings.
- Objective 6: Specify a standardized regulation framework for energy sustainability optimization achievement in multiple industry manufacturing environments. Also, specify a certification strategy for industrial manufacturing energy sustainability.
- Objective 7: To define evidence-based business and financing models along with a business plan for the post-project sustainable exploitation of the EnerMan framework.

It must be noted that the first five objectives are linked directly to technology KPIs whereas the latter two, i.e. objectives six and seven, have to do more with the standardization and exploitation of the project. Nonetheless, these objectives are directly linked to a set of KPIs, which provide a first level of context and shape to the performance specifications that will have to be met by the EnerMan framework and are presented in Table 16.

Table 16: Objectives' KPIs

Objective No	**Target KPIs per Objective**			
Objective 1	Automatic & adaptable control loop reconfigurability for at least 3 use case scenarios	Achieve complaint reconfigurable configuration with 80% accuracy	Achieve 80% positive acceptance by factory personnel	
Objective 2	Demonstrate that almost 50% of computing can be achieved locally on the CPSs, thus reducing computation time 20%	Demonstrate that 50% better accuracy can be achieved by collecting and processing sensor data at the edge	Availability of library of at least 3 SW and at least 3 HW components with variable functional requirements	Working prototype node on at least two different sensor collection entities within the manufacturing process and on associated demonstration in use cases
Objective 3	Accuracy of simulations to exceed 80% compared to real measurements. Possible	5% increase in accuracy due to training AI algorithms with the generation data		

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	improvement towards 90% with real physical nodes	provided by the simulation and prediction engine		
Objective 4	Development of tools for optimising User Experience for the manufacturing operators	More than 75% of the Trainees reporting that the real-time information from several sources is provided in a user-friendly way		
Objective 5	Accomplishment of at least 75% of the validation metrics in terms of overall KPIs	Target users reporting >30% improvement on adopting specific behaviours and understanding complex concepts		
Objective 6	Organise 3 standardization workshops	Contribute to 1 industrial standardisation process per pilot category	Provide a standardisation, regulation and certification recommendations handbook	
Objective 7	Business model canvas for 2 types of business and financing models	IPR agreements between project partners; Agreement on individual/ joint exploitation plans and business plan preparation activities		

As before, the KPIs related to objectives six and seven, which have to do with standardisation and exploitation, have been greyed out since they do not have to do with the pilot and use cases trials. These are not technical KPIs and are not going to be evaluated within the context of an evaluation trial. However, the KPIs mentioned for the objectives one to five constitute actual performance metrics that need to be assessed and evaluated during the project trials. Moreover, some of the technical KPIs have to do with the edge node technology of the EnerMan framework, some with the management system and some with the analysis prediction engines.

Subsequently, each of the use cases KPI is presented in more detail as to its requirements, which serves as the second layer of insight regarding the target metrics that need to be evaluated and assessed. Hence, these are presented below according to the pilot scheme and, subsequently, the use case description.

4.1. Pilot #1: Appliances and industrial components manufacturing industry

4.1.1. Use case #1.1. Automotive manufacturing: The painting process

The KPIs for use case #1.1 are as follows: According to the existing energy simulations, using other static average-monthly models, it is demonstrated that the adoption of new and additional control models and algorithms on the utility, can bring energy savings per utility, which can lead to *i)* degreasing of tank saving about 16.9% and *ii)* base topcoat Air Handling Unit savings of about 32%. The saving estimation has been obtained by considering a dynamic correction of many parameters' set points and its achievement can be reached with a strategy related to all three of the following

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aspects, *i)* the early detection of anomalous consumption trends and cause identification for avoidance, *ii)* the avoidance of peaks, and, finally, *iii)* the optimization of production scheduling. The percentages presented here are indicative and relate only to two single utilities. By performing an extrapolated estimation, e.g. the adoption of the saving logic to all paint utilities with similar characteristics, the kW weighted average can be brought to an estimated saving of 27% assuming that the method is applied to the whole number of paintings.

4.1.2. Use case #1.2. Automotive manufacturing: a testing factory for engines, powertrains and vehicles.

The KPIs for use case #1.2 are as follows: The overall energy consumption data are going to be tracked and, therefore, known due to internal audits and measurement data. Hence, it is estimated that within the next four years, the energy efficiency will be increased by 20% while the environmental footprint will be decreased by at least 15%.

4.1.3. Use case #1.3. Semiconductor industry: an energy-optimized global virtual factory

The KPI for use case #1.3 is as follows: The target is the ecological unit cost, which is measured in grams of CO_2 per product. Overall, however, it is often quantified as an overall carbon footprint, which is eventually measured in tons of CO_2 emitted. With regard to EnerMan, using the flexibility and improvements facilitated by the framework, it is estimated that a saving of 5g of CO_2 per product will be achieved.

4.2. Pilot #2: Food industry

4.2.1. Use case #2.1. Food industry: Chocolate processing and manufacturing

The KPIs for use case #2.1 are as follows: A Reduced Fuel Consumption (RFC), i.e. the amount of fuel consumed for thermal energy needs per kilogram of final product. The current value will be determined through data acquisition and though the actions taken within EnerMan, it is expected that it will become zero. Moreover, the Primary Energy Saving (PES) is expected to increase by 10%, while the CO_2 Emissions Savings (CES) is anticipated to decrease by at least 5%.

4.3. Pilot #3: Metal manufacturing and processing industry

4.3.1. Use case #3.1. Autonomous trigeneration facility for aluminium industry.

The KPIs for use case #3.1 are as follows: A Primary energy saving increase in the order of 15% while the CO_2 emissions savings to decrease by at least 5%. Moreover, the energy cost reduction must be observed by at least 5%. Also, the framework must support the prediction on a daily basis of hourly energy cost with respect to the day-ahead energy load prices of the market with an accuracy of at least 90%. Furthermore, the management of energy consumption in production lines according to the purchased energy must be with an accuracy of at least 95%. Finally, the operation of trigeneration facilities must be optimised for at least four different scenarios of avoiding peaks and energy wastes.

4.3.2. Use case #3.2. Titanium and CoCr alloys manufacturing for medical device industry.

The KPIs for use case #3.2 are as follows: Reduce the energy consumption from equipment by 20% through optimising parameters and reducing non-value-added activity. Moreover, improve the EnPIs (Energy Performance Indicators) for each asset/system to demonstrate continuous improvements in line with ISO 50001 requirements.

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4.3.3. Use case #3.3. Energy consumption in iron and steel manufacturing industry.

The KPIs for use case #3.3 are as follows: The system to be developed should be able to track and monitor a set of process parameters. As an example, it should be able to optimally control the tapping temperature after the VD processing and reduce the current superheat temperature by an average of 10^{o} C. This may result in 5-7 kwh reduction and a significant positive impact to the product quality (microstructure and surface defects).

4.3.4. Use case #3.4. Additive manufacturing for processing metal components.

The KPIs for use case #3.4 are as follows: Achieve an energy efficiency level of at least 10% while reducing the operative costs by 15% and increasing OEE by 5%.

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5. CONCLUSIONS

The way with which the project's objectives will be achieved is characterised by a phase during which the proposed EnerMan framework will be tested and evaluated within the context of a selection of given scenarios. These scenarios have to represent the project's use case and, therefore, have an indirect link to the project's pilots themselves. This deliverable provides an account of what the major points of focus for those evaluation scenarios ought to be, starting from the EnerMan framework's architectural elements and finishing with the target KPIs that represent the technical specifications of the solution when applied to the different use case and pilot scenarios.

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