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EnerMan

Energy Efficient Manufacturing System Management

D1.3 – Preliminary EnerMan Technical Specifications and end-to-end Architecture

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EnerMan

Short Description
This deliverable contains the Preliminary technical specifications and end-to-end architecture for EnerMan project. Specifically, this document provides a simplified version of the initial EnerMan high-level architecture, the data requirements needed for the development and deployment of the components in each EnerMan plane, and the identified limitations and mitigation actions in the first year of the project following the technical and use case owners' bilateral discussions. A generic and modular approach is then presented to allow room for a scalable and sustainable development thus comprising the first version of the EnerMan framework.

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1. EXECUTIVE SUMMARY

The current document provides an overview of the preliminary technical specifications and end-to-end architecture for the EnerMan project, as these were identified through questionnaires and bilateral telco meetings with the technical and end-user partners. Given the heterogeneity of cases and the envisioned impact of the EnerMan system to the everyday operations of the end user plants, a thorough understanding of the requirements, the data collection mechanisms, the data characteristics and the attributes to be shared had to be made.

Deliverable 1.3 (D1.3) provides a simplified version of the initial EnerMan high-level architecture, the data requirements needed for the development and deployment of the components in each EnerMan plane, and the identified limitations and mitigation actions in the first year of the project following the technical and use case owners' bilateral discussions. A generic and modular approach is then presented to allow room for a scalable and sustainable development thus comprising the first version of the EnerMan framework.

1.1. GLOSSARY OF ACRONYMS

Table 1 Acronyms used throughout T1.3

Acronym	Definition
AI	Artificial Intelligence
API	Application Programming Interface
BDAE	Big Data Analytics Engine
CPS	Cyber Physical System
CSV	Comma Separated Values
GDPR	General Data Protection Regulation
IDSS	Intelligent Decision Support System
IIoT	Industrial Internet of Things
IMVS	Industrial Management Visualization System
npm	Node Package Manager for JavaScript platform
PAADR Principle	Prediction Assessment Adaptation Design Redesign Recommendation, Sustainability Awareness and Training Principle
pub/sub	Publisher/Subscriber
Rpi	Raspberry Pi
SPE	Simulation and Predictive Engine
UI	User Interface
VF	Virtual Factory
VR	Virtual Reality

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2. INTRODUCTION

Task 1.3 (T1.3) of the EnerMan project has the objective of deriving the EnerMan framework requirements and specifications to lead the overall system architecture of the EnerMan solution.

According to the Grant Agreement (GA) Document, T1.3 has the following description:

"Using the results of T1.1 and the pilot requirements of T1.2, the objective of this task is to derive the EnerMan framework requirements/specifications that will lead to the overall system architecture of the EnerMan solution. A technical risk analysis will also be considered, aiming to assess risks associated with technologies selection, technical approaches adopted, the relation and influence of each developed technology on achieving technical objectives, and, in conclusion, on satisfying overall system objectives. Following the definition of the EnerMan architecture and its break-down into functional modules and components, detailed specifications will be derived for each of them including functional and operational requirements, as well as detailed software requirements and interfaces. It should be emphasized that in order to best use the evaluation results of the EnerMan prototype by the pilots this task will have a long lifetime. By month 12 the first version of the system architecture will be provided matching the EnerMan prototype to be tested by the pilots. Then, after analysing the initial results of the assessment and evaluation tasks (WP6) in this task we will reiterate/update/ fine-tune the architecture. This methodology is driven from the partner's large experience in projects that dictates that a revised version of system architecture is often needed in challenging and innovative research projects like EnerMan"

The main purpose of the current document is to describe a first version of the system architecture that is going to be developed by the technical partners and subsequently tested by the pilots. Moreover, it will describe a preliminary technical risk analysis, to address identified risks that have been presented throughout the first year of the project, in relation to the adoption of technical approaches and the functional operational requirements needed to proceed over the next years.

The rest of the document is structured as following:

- Section 2 provides an introduction to the framework with an overview of the various blocks in which it is structured and the interconnections with other WPs.
- Section 3 provides the characteristics of the data that have been provided and will continue to be the basis for future developments.
- Section 4 presents a high-level overview of the architecture including the various technologies that can be implemented in the EnerMan framework along with the various requirements for each use case.
- Section 5 provides an overview of the organization of the framework, detailing the various modules and blocks.
- Appendix I includes the questionnaire that was used in terms of T1.3 purposes.

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2.1. T1.3 TIMEPLAN

Figure 1 presents the T1.3 Timeplan along with Key Points in relation to other tasks.

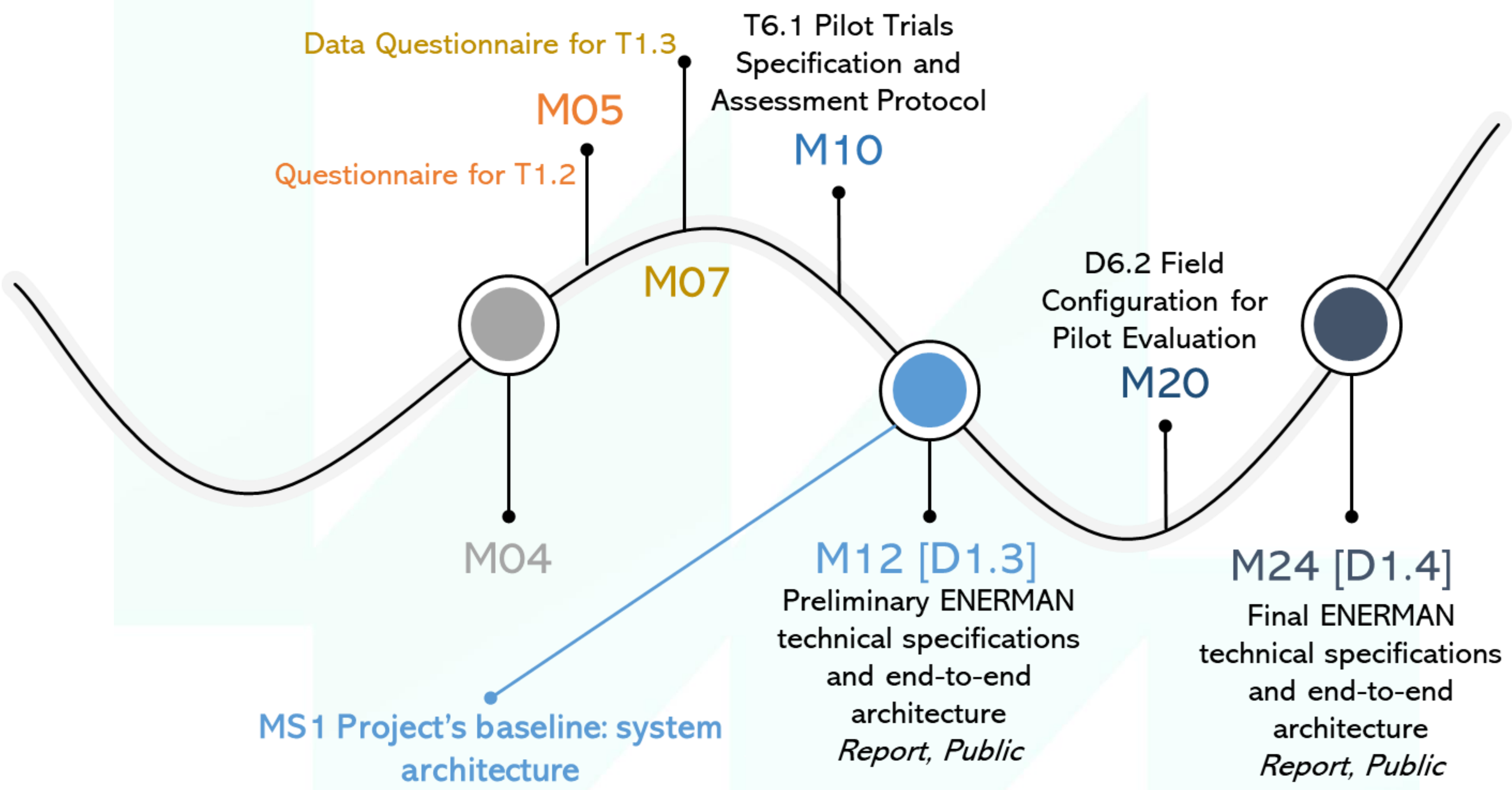

Figure 1 Task 1.3 Timeplan and Key Points until M12

2.2. SIMPLIFICATION OF THE ENERMAN ARCHITECTURAL FRAMEWORK

The initial EnerMan concept architecture that is in the GA document is shown in Figure 2.

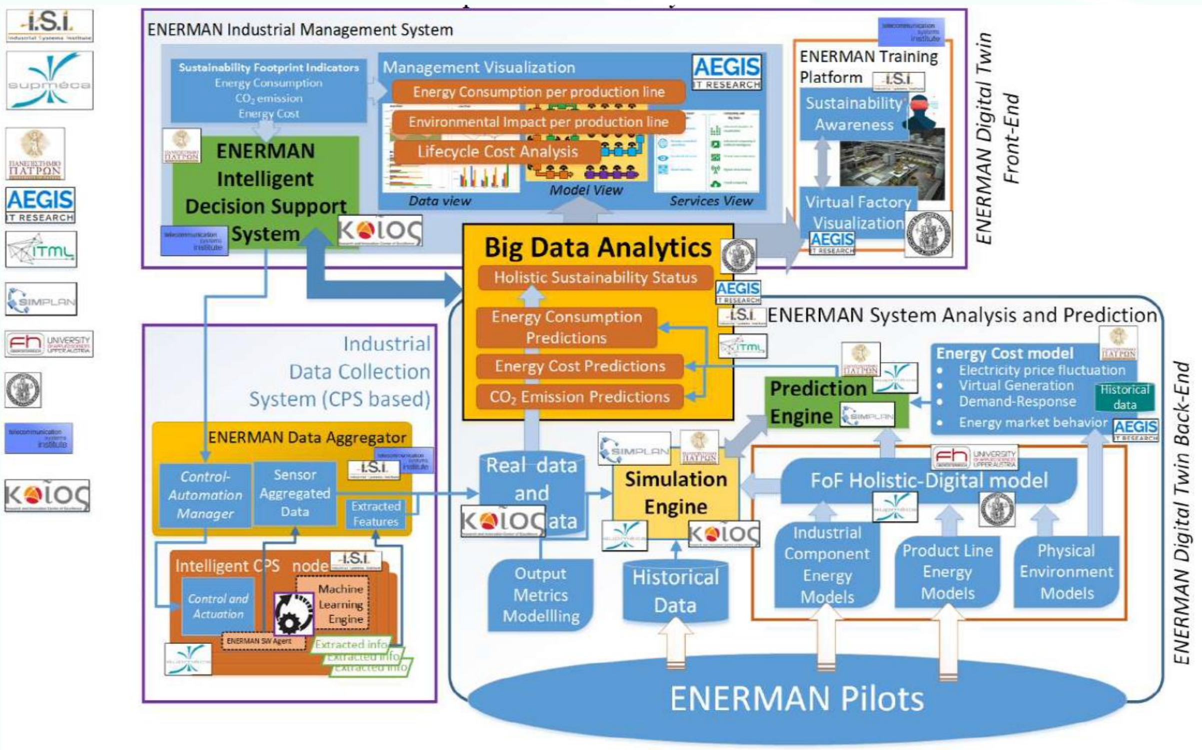

Figure 2 Initial Version of EnerMan Concept Architecture

Given the complexity of this high-level architecture, due to the large number of detailed features that make up the entire structure in ordert to address the project needs, a redesign was deemed necessary for simplification and comprehensibility purposes. Figure 3 depicts the new version of EnerMan architecture. The new version is based on systems design and systems theory principles, where a larger and complex system is decomposed isnto smaller and easier-to-handle subsystems, retaining its initial purpose and reason.

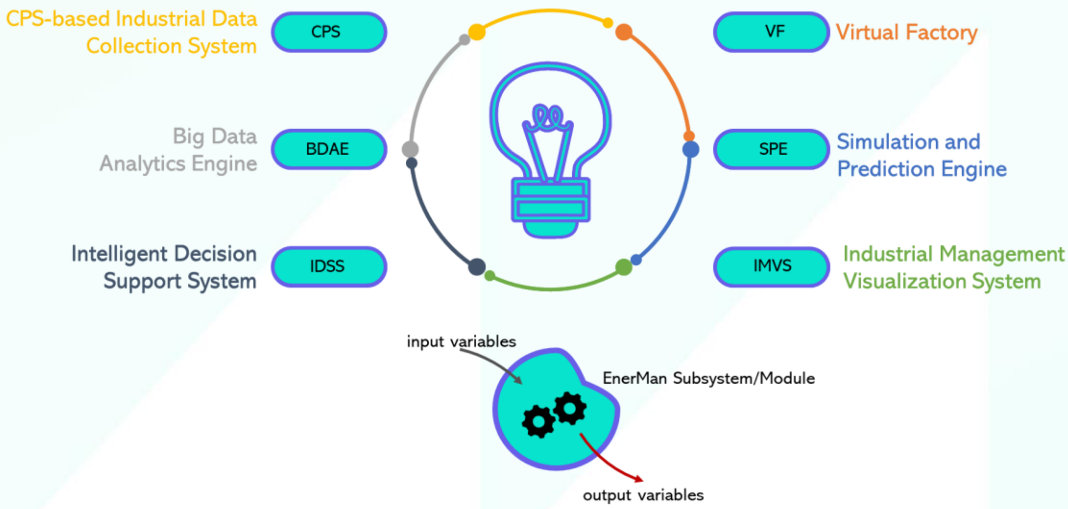

Figure 3 Simplified Version of the EnerMan architecture

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The matching points between Figure 2 and Figure 3 along with the key points of the T1.3 timeline are shown in Figure 4.

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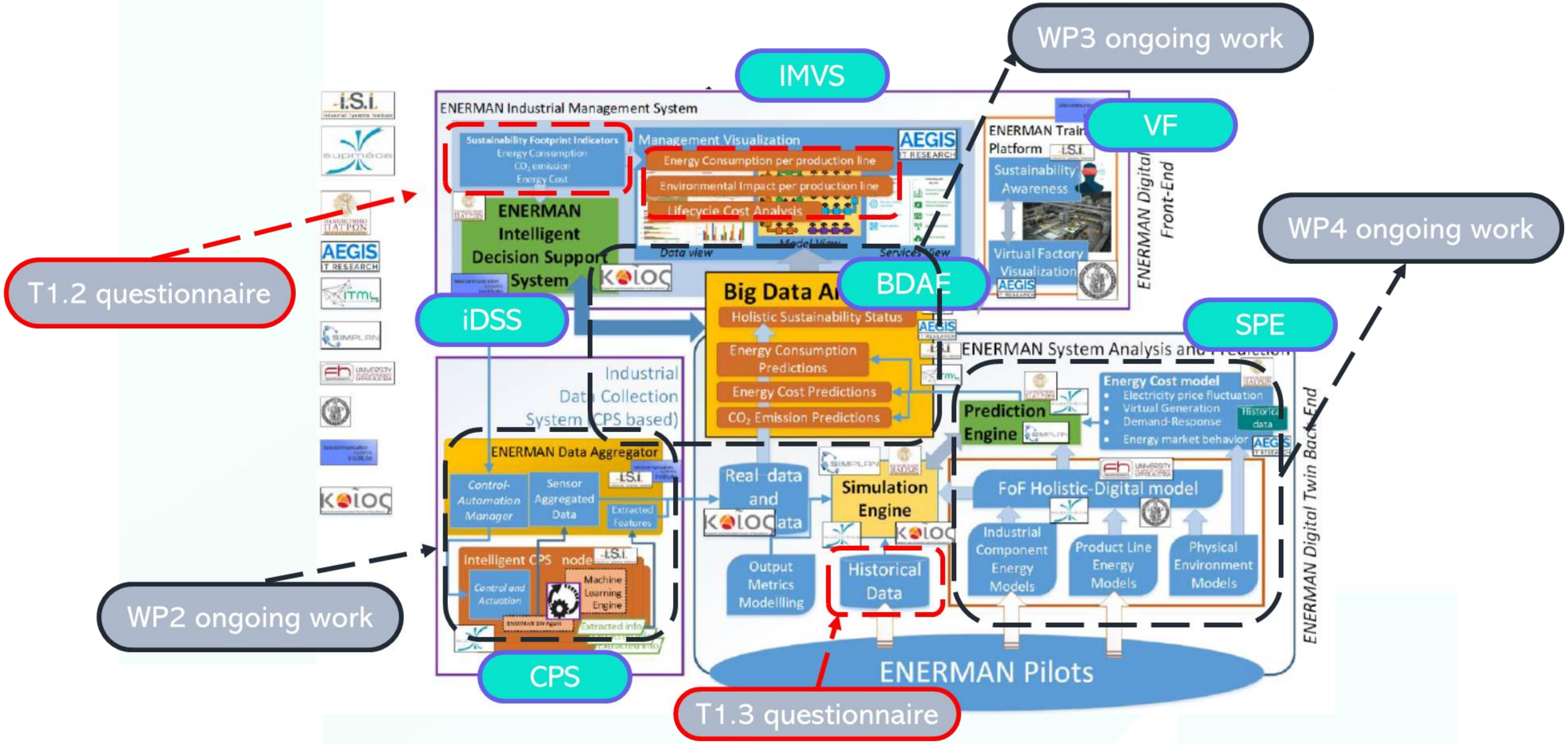

Figure 4 Connecting Initial and Simplified Version of the High-Level EnerMan Architecture along with T1.3 timeline key points

3. DATA AVAILABILITY FROM END-USERS' PERSPECTIVE

Given the questionnaire that was circulated In T1.2 (shown in D1.2), another questionnaire was deemed necessary in order to get an overview of the data availability along with any characteristics relevant to the datasets that were to be obtained. For this purpose, a questionnaire was circulated (Appendix I) among the end users to get the necessary information.

This data questionnaire had the following structure:

- Q1-Q6 refer to descriptive characteristics of the available dataset
- Q6-Q15 refer to the data involved (e.g., content, data characteristics, labels)
- Q16-Q22 refer to the data collection system/equipment (hardware and software details)
- Q23-Q28 refer to regulation issues (e.g., GDPR, data privacy and safety mechanism)

Some of the key points that were elucidated from the answers given by the end users are:

- Actual Measurements datasets referring mostly to
    - per minute measurements in ordinal scale
    - with headers/labels (annotated data)
    - in CSV format
- Approximately 60% of datasets are not under any restrictions
- 40% of data contents are pre-processed however
- Additional data pre-processing is suggested from all participants
- Data will be made available either offline or by repository deposition
- Most datasets are securely stored within the end users' premises

Following the completion of the questionnaires by all end users, bilateral telcos were set up to discuss the results with the end-users. These bilateral meetings with each end-user were deemed necessary to clarify needs for building and adjusting the key systemic components of the EnerMan framework. Participation in these telcos was open to all partners. The aggregated results from these discussions were the following:

- While commonalities in data appear, these should be further examined to propose a concrete solution under a common framework.
- Gaps in understanding how EnerMan-related processes and settings will be applied in pilots should be covered as upcoming tasks lack details necessary for their progress.
- Some initial data analysis based on the data received by end users and the existing work done by technical partners in terms of simulation, prediction, decision making would prove beneficial.
- Narrowing down the scope of the EnerMan approach from a technical perspective should be discussed as an option given the fact that limitations and restrictions in applicability issues are becoming evident.

Given the aforementioned points, a bottoms-up approach was suggested to cover the requirements needed from an end-to-end perspective of the high-level architecture of the EnerMan framework.

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4. ENERMAN HIGH-LEVEL ARCHITECTURE OVERVIEW

4.1. INITIAL ASSUMPTIONS

The envisioned EnerMan architecture, as described in the GA text is hereby provided:

The framework architecture consists of three main components:

- ***The Data Collection and Control Plane**: Using the Industrial Internet of Things (IIoT) paradigm, deployed industrial sensors are collecting data from various sources inside a factory (end IIoT nodes) and aggregating them in a data aggregation points. In EnerMan, heterogenous data are being preprocessed locally. With use of machine learning techniques, data are been fussed and features are extracted so that can achieve accurate energy status results at the edge/fog IIoT level. This mechanism considerably increases responsiveness and reliability thus enabling near real time information gathering. Thus, results are fed at near real time to the EnerMan IIoT "cloud" level (consisting of the EnerMan Industrial Management System plane and the System Analysis and Prediction plane) to extract holistic, systemic energy sustainability metrics across the whole manufacturing chain. In this plane, the control loop IIoT actuator processes have also been realized following the PAADR adaptation and design principles. In EnerMan, we introduce the concept of adaptable, flexible closed control loops in the factory automation procedures that based on analyzing collected sensor data, should be holistically reconfigured to fit an overall, system based, energy sustainability plan. The current trends of energy consumption will be investigated by means of monitoring and analysis of big data. Smart sampling methods and numerical uncertainty/sensitivity analysis will be applied to identify the most influential variables on energy consumption.*
- ***The EnerMan Industrial Management System Plane**: This plane collects data from various sources and using big data analytics processes them and visualizes them to structure a unified energy sustainability viewpoint. Also, collecting predicted values from the System Analysis and Prediction plane, the Management System plane visualizes predicted values and following the PAADR assessment and adaptation principles assesses current and future overall energy sustainability footprint of a factory. More specifically, in this plane, the administrators can orchestrate the industrial control loop based on energy patterns scenarios and considering energy pattern predictions coming from the EnerMan digital twin adapt the system accordingly using recommendation for automated redesign of the manufacturing control loop. They also can use Virtual/Extended Reality based human interfaces that visualizes the current and future predicted energy consumption in various, factory production lines and equipment with in the EnerMan virtual factory. This plan constitutes the front end of the EnerMan energy aware Digital Twin conception.*
- ***The System Analysis and Prediction plane**: The EnerMan framework prediction plane is structured around a cognitive, artificial intelligence that can use the current collected data, metadata and features from the Data collection plane as well as historical data and simulated data in order to assess/predict the energy sustainability footprint of the overall factory manufacturing. This plane realizes the core (back end) of the EnerMan energy sustainability aware Digital Twin, which facilitates the simulation of possible scenarios and predicts possible outcomes on energy consumption, environmental impact (CO2 emissions) and energy cost, allowing one to try new strategies without impacting the actual manufacturing production. In particular, such prediction method will combine energy modelling and Artificial Intelligence (AI) in order to predict energy consumption metrics for current scenario and energy efficiency scenarios. The developed models will be continuously adapted and enhanced based on monitored data in order to maximize their robustness and reliability. Using this approach, the*

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factory administrator, in line with the principles of Industry 4.0, can identify possible flaws with a prospective energy consumption (and overall sustainability) strategy before it is deployed to the physical manufacturing process. The EnerMan digital twin includes an Artificial Intelligence (AI) that has been trained using real historical data in order to predict the energy consumption behaviour of factory processes in the future as well as provide short-term energy price forecasting in order to addresses price volatility problems in the factory financial sustainability. Overall, EnerMan offers a simulated environment where the operators can observe the cause-and-effect relationship in energy consumption that exist when changes in the production line/control loop/equipment are made or external/internal factors influence the cost of provided electricity.

These three planes will be the product of development and implementation of three respective WPs, namely **WP2: EnerMan Data Collection and Control Plane Design**, **WP3: EnerMan Management System** and **WP4: EnerMan System analysis and prediction**.

4.2. TECHNOLOGICAL OFFERINGS, DATA REQUIREMENTS AND IDENTIFIED LIMITATIONS

A necessary step towards realizing the EnerMan framework in terms of energy consumption, sustainabiltiy and environmental impact issues is to recognize the technological offerings of the partners involved in the three main technical WPs, namely WP2, WP3 and WP4. To provide an initial estimation of what and how the technical partners intend to address each pilot use cases (*Table 2* shows a summary of the pilot cases, as these were described in D1.2), a cross-WP communication with regular teleconference meetings was established, whereas input and discussion items were exchanged via e-mail communication among the WP2, WP3, WP4 and WP5 leaders (namely ISI as WP2 leader, AEGIS as WP3 leader, SIMPLAN as WP4 leader and MAG as WP5 leader and leading the Scientific and Technical Management of the project).

Table 2 Description of the to-be-deployed EnerMan Pilots

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

The results of this cross-WP communication is summarised in the next tables, where:

- Tables 2-4 concentrates all the technological offerings per WP and per use case
- Tables 5-7 shows the data requirements from a technical perspective as these were deemed necessary for development and implementation purposes

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- Tables 8-10 highlight the limitations identified along with the proposed mitigation actions for dealing with existing bottlenecks identified in first year of the EnerMan project.

Table 3 WP2 Technological Offerings per Use Case

<table>
<tr><th></th><th colspan="5">WP2 TECHNOLOGY OFFERINGS</th></tr>
<tr><th>Component</th><th colspan="2">Data Aggregator</th><th colspan="3">Intelligent CPS nodes</th></tr>
<tr><td>CRF</td><td>Secure Data aggregator for collecting and harmonizing sensor data from the paintshop / bodyshop edge device (Rpi) and the ENERMAN Thermal camera temperature detector/predictor.</td><td>Thermal camera-based ML based temperature detector and predictor</td><td>Federated Learning at the edge models for Machine faulty status (predictive maintenance)</td><td rowspan="6">Accelerated ML based Intrusion Detection System at the edge</td><td>Interpretable model synthesis for energy sustainability estimation</td></tr>
<tr><td>YIOTIS</td><td>Secure Data aggregator for collecting and harmonizing sensor data from the chocolate factory edge device (Rpi) and the ENERMAN Thermal camera temperature detector/predictor</td><td rowspan="2">Thermal camera-based ML based temperature detector and predictor</td><td>Federated Learning at the edge models for Machine faulty status (predictive maintenance)</td><td rowspan="5">Interpretable model synthesis for energy sustainability estimation</td></tr>
<tr><td>STN</td><td>Secure Data aggregator for collecting and harmonizing sensor data from the ladle cycle and the ENERMAN Thermal camera temperature detector/predictor</td><td>Federated Learning at the edge models for Machine faulty status</td></tr>
<tr><td>AVL</td><td rowspan="3">Secure Data aggregator for collecting and harmonizing sensor data from the pilot data collection point and the ENERMAN Thermal camera temperature detector/predictor</td><td rowspan="3">Thermal camera-based ML based temperature detector and predictor</td><td rowspan="3">Federated Learning at the edge models for Machine faulty status</td></tr>
<tr><td>PE/3DNT</td></tr>
<tr><td>DPS</td></tr>
</table>

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Table 4 WP3 Technological Offerings per Use Case

	WP3 TECHNOLOGY OFFERINGS		
Component	**BDAE**	**IMVS**	**VF**
CRF **YIOTIS** **STN** **ASAS** **PE/3DNT** **DPS** **IFAG** **AVL**	*The technologies mentioned here will be applied horizontally to all pilots* 1. "Data model": a standardized, programming language-agnostic description of pilot raw datasets. It specifies the format, data types, localization metadata (e.g., timezone in GMT where a daylight savings calculation will be applied, country/district of origin), structuring and harmonization requirements to be applied on the data for facilitating data ingestion and interoperability. 2. "Data storage": raw data stored to different databases according to their characteristics (unstructured, structured and time-series databases). 3. "Data preprocessing module": A Python module composed of transformation functions feature extraction/engineering 4. "Data analytics module": A Python module functions designed to draw useful insights in different modes of value-added services (diagnostic, predictive, descriptive). 5. "Feature store": operationalized data features to be used in ML downstream tasks and online/offline inference	1. The "data view" visualizing the energy consumption, energy cost, environmental impact, and internal/external environmental conditions for different granularity levels (e.g., both "target" subprocesses or for individual equipment) and for different time periods, presenting the cost of different energy types, identifying baseload, production-related load in terms of energy KPIs per factory, test, and subtask level 2. The "model view" presenting the status of the target process and configurations of machines as well as providing alerts if energy drifts are detected, providing alerts if anomalies are detected (or high economic/ environmental costs are foreseen or demand-response events are announced) or adjustments should be made based on the tracing of the condition, presenting the status of the target process alerting the user if anomalies are detected 3. The "service view" allowing the user to run "what-if" scenarios and choose the most appropriate mitigation action or approve the proposed one so that the relevant actuator is controlled, controlling setpoints (e.g. in terms of temperature, number of engines to be used) and optimizing scheduling (e.g. by suggesting production shifts)	*The technologies mentioned here will be applied horizontally to all pilots* 1. Adapt models that are representing the workspace environment. 2. VR/xR modules that will provide Task information streams, personalized reminders, Danger and hazards notifications. 3. Provide the API that makes it easy to support a variety of controllers and input devices in your VR application. This API will allow access to VR hardware from multiple vendors without requiring that applications have specific knowledge of the hardware they are targeting (This is viable only if the pilots can provide some initial model to work with)

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Table 5 WP4 Technological Offerings per Use Case

	WP4 TECHNOLOGY OFFERINGS
Component	**Simulation Engine**
CRF	Simulation of the paintshop production line (logistics and energy flow) Link/interfaces with detailed models for energy consumption prediction, environmental conditions, … (implemented by prediction engine)
YIOTIS	Enhanced value stream model of production line. Link/interfaces with detailed models for energy consumption prediction, environmental conditions, … (implemented by prediction engine)
STN	Simulation of ladle cycle Link/interfaces with detailed models for energy consumption prediction, environmental conditions, wear model (implemented by prediction engine)
IFAG	Integration of IFAG simulation models (AnyLogic) Simulation models of complex equipment (hierarchical models)
AVL	Maybe: model for test scheduling including energy aspects

Table 6 WP2 Data Requirements per Use Case

	WP2 DATA REQUIREMENTS	
	Data Aggreggator	**Intelligent CPS node**
CRF **YIOTIS** **STN** **ASAS** **PE/3DNT** **DPS** **IFAG**	• High sampling rate • Energy consumption data (provided by pilots) • Vibration data (accelerometer based) data	• Control interface API

Table 7 WP3 Data Requirements per Use Case

	WP3 DATA REQUIREMENTS	
	BDAE	**IMVS**
CRF **YIOTIS** **STN** **ASAS** **PE/3DNT** **DPS** **IFAG** **AVL**	• consistent dataset name conventions across pilots • feedback on preliminary data model per pilot (e.g., time resolution, process definition, features schema changes, GMT time zones, missing values indications, units)	• energy consumption data per sub-process or sub-component (historical, real-time and predictions) • production data (historical, real-time and predictions) • energy prices per sub-process or sub-component (historical, real-time and predictions) • environmental data (inside/outside) • energy mix data (historical, real-time and predictions) • alerts machine configurations

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Table 8 WP4 Data Requirements per Use Case

	WP4 DATA REQUIREMENTS	
	Simulation Engine	**Prediction Engine**
CRF	Detailed process description; maybe: ERP/MES data	• Sensors historical data • Physical model of each component of the test bench • Model Library defined from Use cases • Sensors specifications and technologies
YIOTIS	Detailed process description	
STN	Detailed process description maybe: ERP/MES data	
IFAG	Detailed process/scenario description	
AVL	Detailed process description maybe: ERP/MES data	

Table 9 Framework Architecture Restrictions and Mitigation Actions

Plane	Main Technical Partners Involved	Restrictions Identified	Mitigation Actions
Data Collection and Control Plane	ISI [WP2]	• Data provided by pilots not fully annotated. • Data collection software interface with Pilot industrial sensors is not well defined and not accessible from the EnerMan platform • Sensor Data are being uploaded manually by the pilot providers to factory data repositories (using csv files) • Communication network interface and network stack with Pilot industrial sensors and actuators is not available in the pilots' site since the control/actuation happens manually • Interfaces to communicate with Control devices (actuators) in pilot premises is not available/open	• Pilots should annotate the provided data • Work with publicly available annotated datasets to train and test EnerMan WP2 models • Manifest control loop using human in the loop mechanisms (xR/VR etc). Interface with the human personnel instead of the controllers/actuators • Data Harmonization to homogenize pilot provided data • Non automatic data provision to the EnerMan edge/end device aggregator • Create EnerMan based high-rate data collector (e.g., Thermal camera based) to interact with the EnerMan platform

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Plane	Main Technical Partners Involved	Restrictions Identified	Mitigation Actions
Industrial Management Plane	AEGIS, ITML [WP3]	• Offline pilot setup due to strict cyber-security policies • Partial/incomplete data provided by pilot sites • External sources of data (e.g., temperature data) not yet specified	• EnerMan solution that is locally deployable • Work with pilot sites to elaborate on data schema • Work with pilot sites to identify external sources of data
System Analysis and Prediction Plane	SIMPLAN [WP4]	• Insufficient process information from pilot users • Mismatch between use case partner requirements and technical (simulation) offering • MES/EPR data not accessible (due to technical or confidentiality constraints) • Integration with real-time monitoring data from shop floor not possible	• Use of publicly available data sets for production lines/factories of the respective industries • In-depth communication between use case owners and WP4 simulation providers • Use of synthetic data

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5. BIRD'S EYE DESCRIPTION OF ENERMAN FRAMEWORK BUILDING BLOCKS

Setting up and creating a maintainable and reusable framework, like the one envisioned in EnerMan, leads towards identifying requirements (whether defined or new) and adding a concise and solid plan towards its development. In order to keep up with the end-user differences as these are highlighted in the questionnaires distributed to them, one of the main concepts that can help define the overall approach is the Domain-Driven Development (DDD), where groups of similar features are grouped and decoupled as much as possible from other groups (e.g. modules).

This is also expected from a modern application like the EnerMan, which should do more and more of the heavy lifting. With this added complexity, bugs may be more frequent, because the end-users who will interact with the front-end, need a reliable architecture, that is both maintainable and scalable, so that changes can be applied in the current features but also add new features quicker.

When the EnerMan (and not only) end-users interact with the EnerMan framework, they should be directed to the correct module by the app routing. Every module is completely contained. But, as a user expects to use one application, not a few small ones, some coupling will exist. This coupling exists on specific features or business logic. Within this approach, the technical partners can share several features between modules, and this logic can be also put into the application layer. This means that each module will have the option to interact with the application layer. A good example is a setup requiring to connect to the back-end, or API gateway, through the client-side API. When looking at the EnerMan project structure, we can follow something like the following process: All code for the application layer lies in the app directory, while all modules have a directory in the modules directory. Reusable UI components (e.g. tables) that do not rely on business logic are in the components directory. The remaining directories hold the static assets (e.g. ML models or algorithms) or helper functions in lib. Helpers functions can be very simple, as they can be used to convert something to a certain format (necessary for preprocessing functionalities), or help to work with objects (e.g. prediction models). More complex code can be present in the lib directory. Working with schemas or graphs (e.g. algorithms to check for loops in directed graphs) are no exception.

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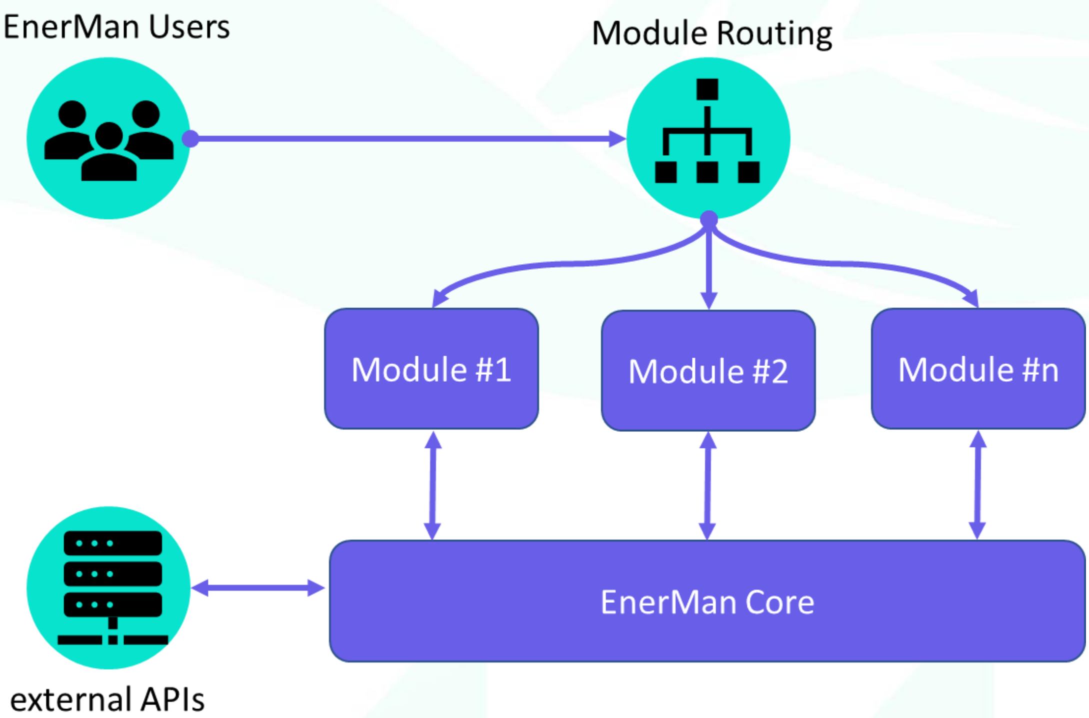

Figure 5 End-to-end view of the high-level architecture

The goal of the EnerMan end-to-end architecture is to provide value to the pilot owner users by letting them interact with the developed work. When they do, the application routing will guide the users to the correct module. Each module is a separate domain representing the work in each WP. Business logic shapes these domains. Various modules use this logic, such as retrieving data from a back-end service. This logic is thus placed in the application layer. This is the core setup of a scalable end-to-end architecture. The architecture resolves around two concept directories. The core directory holds all code for the displayed core layer, while the modules directory holds all the different modules based on the different identified domains.

The above schema highlights a standard modular approach for development (Figure 5). But, by zooming in on a module and the core layer, the inner architecture can be highlighted (Figure 6). Zooming on the core layer and a single module, we can see that EnerMan users will practically address their requests towards requesting access to the EnerMan different components [namely the CPS-based Industrial Data Collection System, the Big Data Analytics Engine, the Intelligent Decision Suppport System, the Virtual Factory, the Simulation and Prediction Engine and the Industrial Management Visualization System]. The dotted connections are optional connections that can be used should it deemed necessary.

In a case of a more complex API client, the schema gives the possibility to alter all outgoing requests through middleware (e.g. by adding authentication headers). This response can be altered using afterware (e.g. changing the data-structure). After altering the response, these are stored in the cache of the client cache, which is the EnerMan application store. Therefore, the cache will only handle incoming API data, while any data can be put in the application store.

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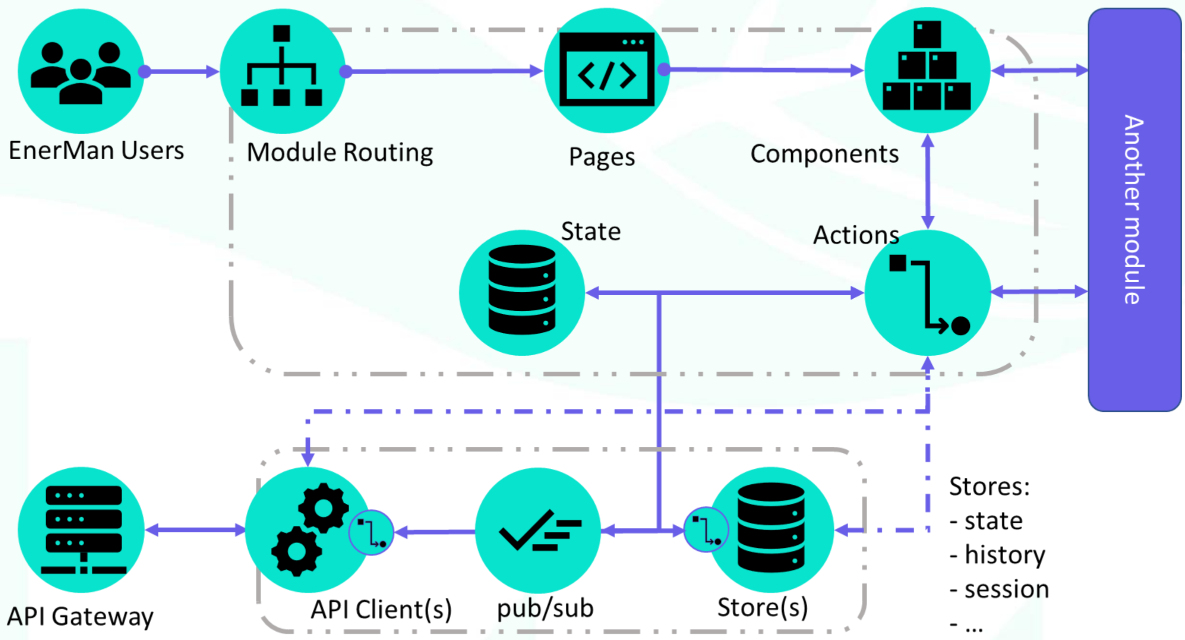

Figure 6 Access to the Components of the EnerMan Framework

5.1. THE APPLICATION BACKBONE

The core layer is the backbone of the architecture. The goal of this part of the application is to be scalable and framework-agnostic. There are a few main parts in this layer (*Figure 7*): API clients, a pub/sub and one or more stores. Stores come in many sizes and include, but not limited, the application state, navigation history, session management, API caches and logger history. These should reside on an application level. This also means that they should be configured here. Users should be able, for instance, to download the history package on npm and use this for navigation history. In the store, the packages can be expanded by adding related functions (e.g., based on each WP components). These can also be exposed to the rest of the EnerMan application.

On the other side, one or more API clients should exist. Some of the deployed components must have a dedicated back-end service to talk to, be it an API gateway on top of a Kubernetes cluster with many micro-services, or a single back-end. However, EnerMan users need to connect to different external services. Each of these services requires configuration (e.g. authentication). All these configurations and invoked clients reside in the core layer. This way they can be used by all modules.

Like many front-end applications have a dedicated back-end service to talk to, by achieving such an architecture, we can create many API clients. Each of the API clients can have a cache, middleware, and afterware. Different parts of the EnerMan application should be able to interact with each of these API clients.

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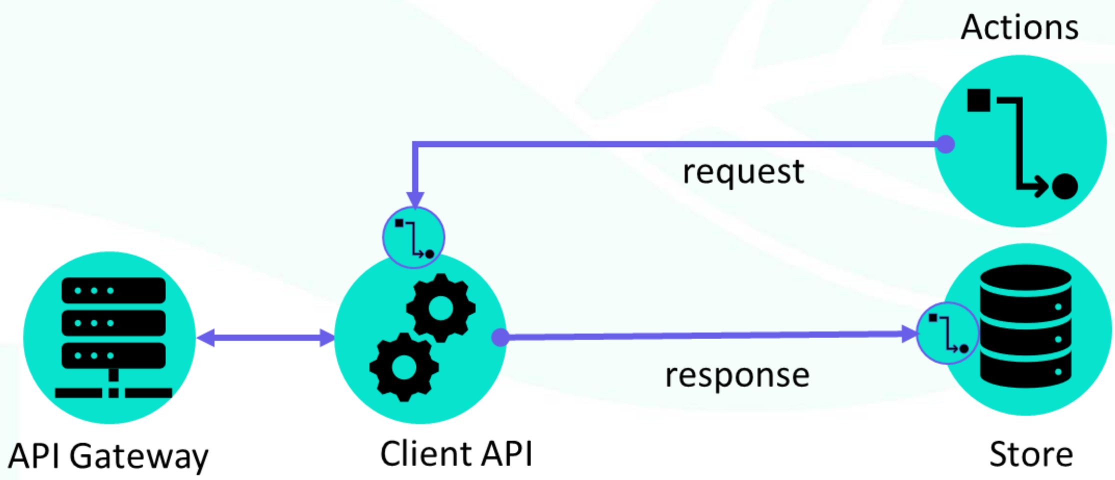

Figure 7 Zoomed in view of the API-related functionalities

The API and Store elements in the schema hold all the related information to the use-cases. The configuration holds static definitions and configurations (e.g. constants) used throughout the entire application. A schema describes a specific data structure for EnerMan objects (where there are defined based on each Component needs). A basic API client handles external requests, responses, and errors. The developed APIs can also provide information about the request state (e.g. loading).This will allow the technical partners the opportunity to deploy the technicalities under generic schemas for the EnerMan application which will be stored within the schemas directory. The overall configuration, deployment and launching can be facilitated by Docker.

A pub/sub can be used with many different goals in mind. It can loosely couple the EnerMan modules from various API clients for instance. This ensures one uniform way to use API calls across the application, regardless of the API clients the end users are using. The pub/sub can have different purposes as well. When the EnerMan monitoring module has an 'auto sign out' feature based on inactivity, the pub/sub can easily be used to reset the timer on different actions. Or it can be used to synchronous concurrent API calls at the moment it is needed to refresh the authentication first. İt can also be used to synchronize events across the data fusion bus without persisting data in a local storage.

5.2. ARCHITECTURE OF A MODULE

Business logic is used to define a module and how it is separated from complex UI components. The structure of a module is reflected in the models, actions and pages/components directories. Most times, the application routing points towards a specific module. The routing of the module itself determines which model it loads, i.e. a single page is linked to a single model. A page is what a user sees and comprises out of UI components and actions. Actions combine ways to get capture interaction and get information out of our module or application state. The EnerMan users trigger actions when they interact with the WP related components, depending on the complexity of the problem they try to solve.

When the application routing points towards a specific module, the module determines how the routing should continue. The module routing determines which page should be shown. A page comprises a lot of UI components, which is what the user will get to see on the screen. A page in this context does not differ from a UI component. It is a big UI component but, other modules can interact with components (and actions), but not with pages. The only way how pages from different modules can interact with each other is with nested routing. This means that the module routing should be put inside a page from a different module. Components interact with the application layer through

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actions. These actions can come in different formats. They can be plain JavaScript functions, Redux related functions or React Hooks. Small utility functions may be deemed specific for a module (e.g., in case of WP2, WP3 and WP4 modules). In that case, these can be put in the actions' directory, or technical partners can create a dedicated utils directory for a module. One advanced pattern that can be used between components is the use of a pub/sub (Publisher/Subscriber). With this pattern, it is not possible to share components, but data can be shared. Figure 8 below shows how this works.

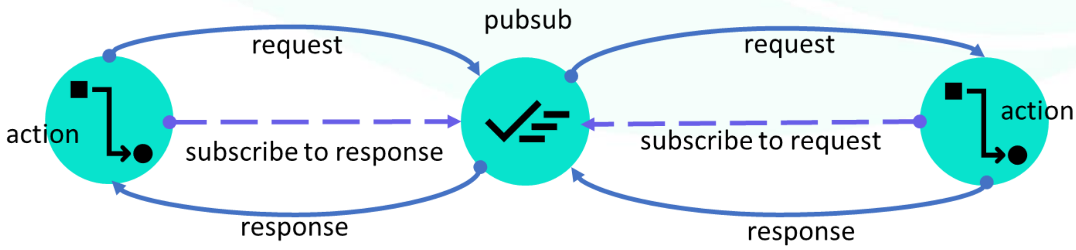

Figure 8 Zoomed in view of the API-related functionalities

5.3. UI COMPONENT ANATOMY

One last detail level is about the architecture of a UI component (Figure 9). The front-end is the first point of entry for the EnerMan users. Like the application layer, we can have static code (e.g. constants or schema definitions) that is only relevant for the specific module. In that case, the related code is put in the config or schema directories. Query and mutation definitions can be also applied more easily by creating a directory with a similar purpose. While working with an application store for this module, use of files can be used to describe how to access data in the store. An index file for the app directory, shall be also used to describe all the components, actions and constants accessible for others.

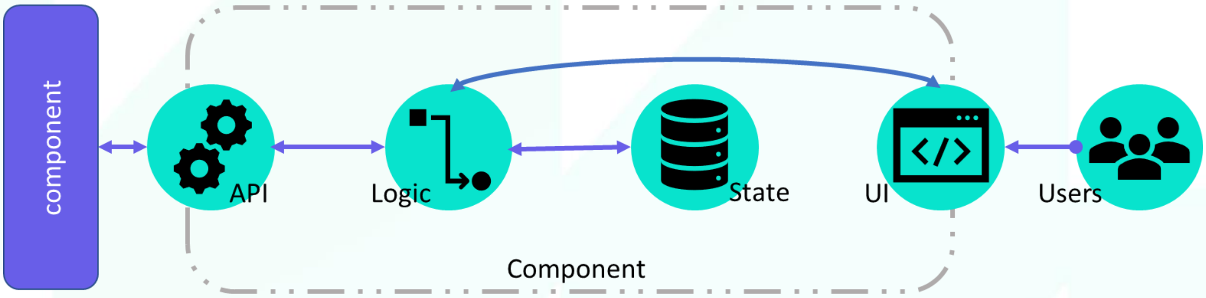

Figure 9 UI Component

5.3.1. *API*

Interfaces are a way to describe how the technical partners would want the end users to use and interact with the components. The UI is a good example of an interface, as it describes what both sides are expected to see and what is allowed for interaction. The API of the components, better known as props or properties in most frameworks, is the interface for developers. There are some different API types that can be defined for other developers.

- *Configuration*: interfaces that allow developers to determine how a UI component should look and act. These are often static values that do not change based on user interaction.
- *Data*: data often reside higher in the component tree. These interfaces allow data to be present and used in a component. These flows are uni-directional.
- *Actions*: sometimes changes are needed to be invoked higher in the component tree. This requires callback functions to pass through the API.

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5.3.2. *State*

State is a mutable object that dictates the behavior and UI of a component. It is often combined with data received through the API. The addition of a state to a component makes it sometimes easy to introduce bugs. The data and action properties are part of the 'data-flow'.

5.3.3. *Actions*

Actions link everything together. They are functions harboring small pieces logic. User interaction triggers actions. Triggered actions can use data from the state and properties in their execution. Actions can come in many forms, e.g., actions defined inside the component as a separate function or actions defined outside the component and used in many components. Good examples are the actions within a module of the scalable architecture.

5.3.4. *UI*

The UI describes what the EnerMan users are expected to interact with. These interactions, such as clicking on a button or loading a model, trigger actions. It results from the rendering of the UI component. State changes or changing properties trigger the rendering.

5.4. MODULE COMMUNICATION

Not every module needs to have all the directories and files as described. Some modules, for instance, do not need pages, as they only comprise components and actions. An indicative example is a 'files' module. This module can combine components and actions for viewing and uploading files. Another example is a drag-and-drop area for files that uploads the result to a blob storage. This could be a reusable component. Yet, the actual uploading of files depends on the service that can be used for it. By combining the UI component and the actual action to upload a file, a small contained module is created. The moment these components are combined with business logic, they are converted into the EnerMan modules.

In terms of transferability and extensibility, other modules can be used as the components or actions from the files module, by using the index file of a module, which describes which components, actions, and constants are accessible for other components. Therefore, by using a file drop-zone or the upload action from the files module, can create an exposure to other modules. For example, if we use a user drop-down, we can create an action that provides to all the users access to different modules. This in turn needs to create a specific drop-down in all other modules, therefore to have a generic drop-down component. When something changes around users, a change can happen at a component or an action level, thus allowing to deploy, if needed, a micro front-end route.

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6. CONCLUSION

In this document we have presented a preliminary version of the technical specifications, the data requirements and the end-to-end architecture that will be used for the EnerMan framework.

This document, which is part of WP1, incorporates information from the core technical WPs of the EnerMan project. In fact, in the tables provided above, contents from WP2, 3 and 4 have been included, making this document transversal to the project. Possible risks and related countermeasures were also assessed to prevent these risks from materializing and potentially compromising project results. The contents of this document complement the information provided in previous deliverables (and more specifically D1.2 which included the perspective and detailed analysis of the use cases by the use case owners). D1.3 is also a part of the first Milestone in the EnerMan project (MS1: Project's baseline: system architecture, dissemination & exploitation plans; quality and project management).

In addition to the technical contents on the various technologies applicable to the various use cases, it has been presented in depth how the architecture of the framework on which the EnerMan project will focus will be structured. This initial version of the architecture is very important because with this description it is possible to make the functioning of the framework more understandable. Given the modular approach of the EnerMan end-to-end architecture, the technical WP components can be deployed, adjusted, and modified in a maintainable, reliable and scalable manner. Moreover, this approach allows quicker software and hardware modifications, if deemed necessary. Therefore, we achieve both fitting to the specific needs of each use case while maintaining the generic and extensible character of the EnerMan framework.

As far as next steps are concerned, the fine-tuning of the use cases will be performed in the next period of the project, leading to the setup and first run of the use cases, where the EnerMan framework will be deployed and tested. During the development of the project, there may be changes to better adapt the architecture of the framework to the specific needs of the case studies. Everything that will be subject to changes will then be included in the final version of the next deliverable (D1.4) which is expected by the end of the second year of the project and will include the finalised version of the EnerMan end-to-end architecture

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7. APPENDIX

The distributed questionnaire was designed in the Survey Planet platform (https://app.surveyplanet.com/). The full set of questions is hereinafter provided in Table 10.

Table 10 Questionnaire for T1.3 purposes

TITLE	QUESTION	TYPE
Q1	What type of dataset do you have that can be shared among the EnerMan consortium?	Multiple Choice
Q2	When is the starting date of recording for the available dataset?	Date / Time
Q3	When is the last recorded date of the available dataset?	Date / Time
Q4	Is there a reference file for the dataset (e.g., web address, repository link)?	Multiple Choice
Q5	Are there any data restrictions applied to the existing dataset?	Multiple Choice
Q6	Could you please provide the following for your dataset:	Form
Q7	What is the data file structure?	Multiple Choice
Q8	Are they raw data (not pre-processed)?	Multiple Choice
Q9	What method/type of pre-processing are you willing to use (should it be required)?	Multiple Choice
Q10	What is the rate of measurements for the recorded data collection?	Multiple Choice
Q11	Could you please indicate the scaling level of the data?	Multiple Choice
Q12	Could you please provide the data format and layout (i.e., description of header/data records, sample records)	Essay
Q13	Which of the following data labels exist in the dataset?	Multiple Choice
Q14	What are the input parameters of the dataset that you would like to get optimized in your use case?	Form
Q15	How will the data be made accessible?	Multiple Choice
Q16	Could you please provide a brief text description of the instrument (e.g., name of the device, link) and how it collects data? Please note that this question refers to the overall data acquisition system and not a specific sensor	Essay
Q17	Could you please provide an estimation on how often each device produces data and how many devices of each type to expect (this is expected so as to have an idea on the amount of data to be handled from the various framework components):	Essay
Q18	Could you please provide any configuration, communication protocol and interfaces (APIs) being used in the devices?	Essay
Q19	Could you please describe the data collection process (e.g. description of measurements and derived parameters and/or processing techniques used)?	Essay
Q20	Could you please provide the following details for the data acquisition system software (if any)?	Form

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TITLE	QUESTION	TYPE
Q21	Are there any mechanical simulator software to existing machine components and/or states that can be used for prediction purposes?	Multiple Choice
Q22	Are there any non-electronic data that need to be depicted related to non-recorded data (e.g., -minor- processes happening on-the-floor that are not measured)	Multiple Choice
Q23	Are you GDPR compliant?	Multiple Choice
Q24	What provisions are in place for data security (including data recovery, secure storage and transfer of sensitive data)?	Essay
Q25	Is the data safely stored in certified repositories for long term preservation and curation?	Multiple Choice
Q26	Where will the datasets be stored or are already stored?	Essay
Q27	Are the data to be produced and/or used in the project useable by third parties, in particular after the end of the project?	Multiple Choice
Q28	How long is it intended for the data to remain re-usable (in terms of months after the project)?	Scale

The following pages show the distribution of answers to selected questions, mainly those who can be publicly displayed due to the dissemination level of the deliverable.

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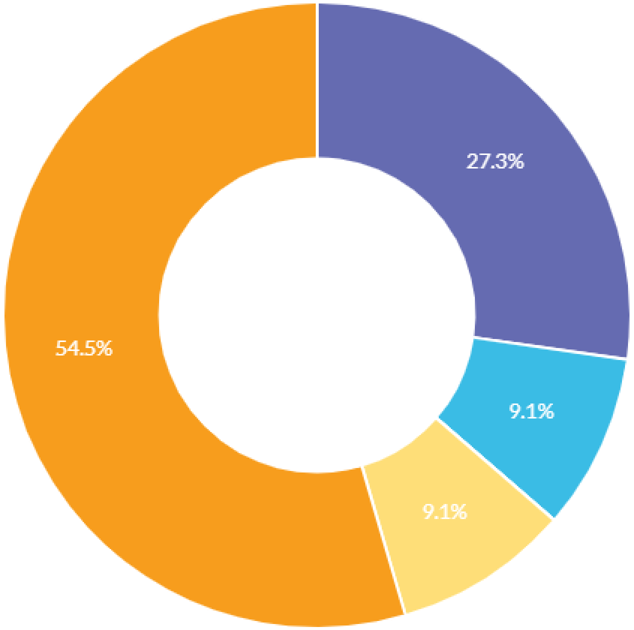
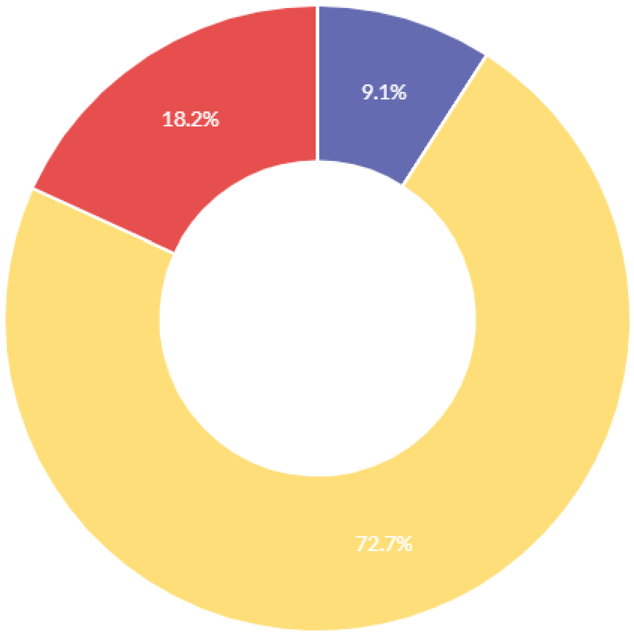
Q5 Are there any data restrictions applied to the existing dataset?
Multiple Choice



Choice	Total
password protected data	3
personal information inclusion	1
licensing scheme applied	0
not aware	1
no	6

Figure 10 Answers to Q5.

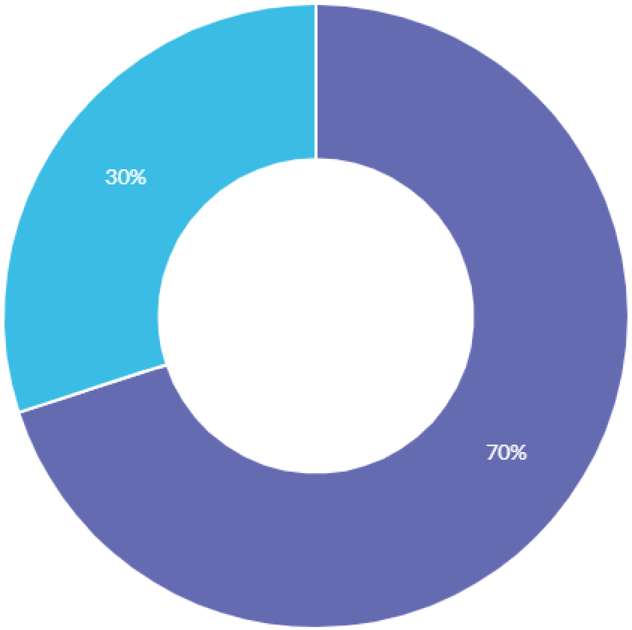
Q7 What is the data file structure?
Multiple Choice



Choice	Total
column delimited ASCII	1
NetCDF	0
comma delimited values (CDV)	0
comma separated values (CSV)	8
hierarchical data format (HDF)	0
Other (please provide a description or the file extension)	2

Figure 11 Answers to Q7.

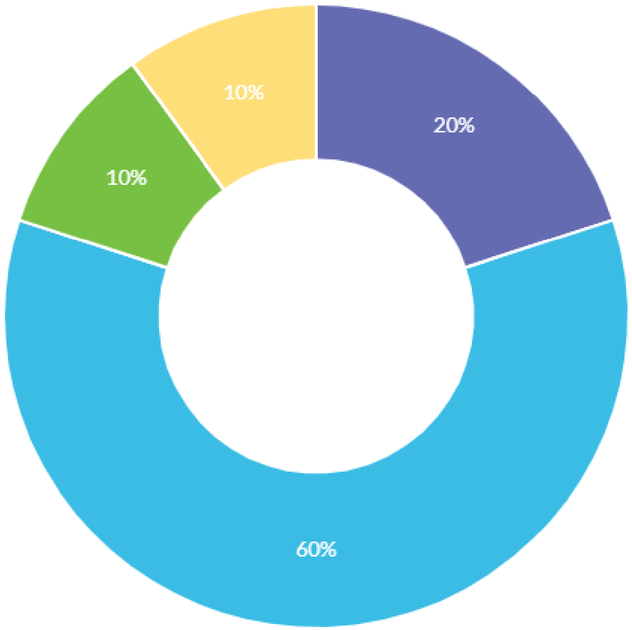
Q8 Are they raw data (not pre-processed)?
Multiple Choice



Choice	Total
No	7
Yes	3

Figure 12 Answers to Q8.

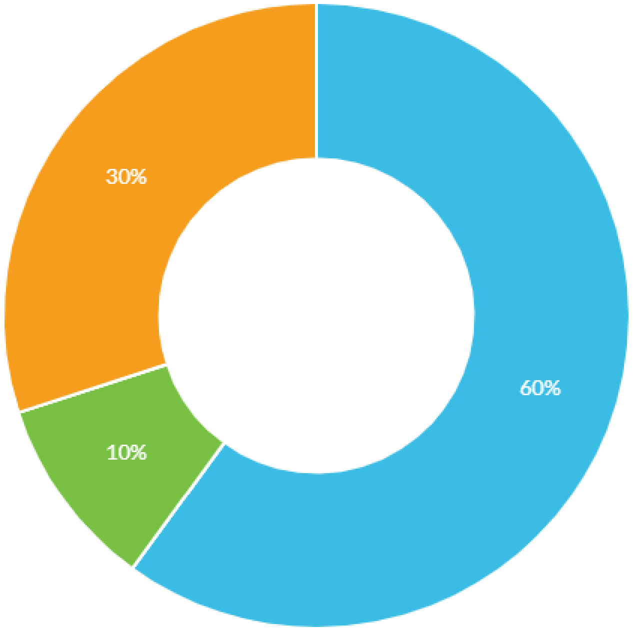
Q10 What is the rate of measurements for the recorded data collection?
Multiple Choice



Choice	Total
per second	2
per minute	6
per hour	1
per day	1
continuous	0

Figure 13 Answers to Q10.

Q11 Could you please indicate the scaling level of the data?
Multiple Choice

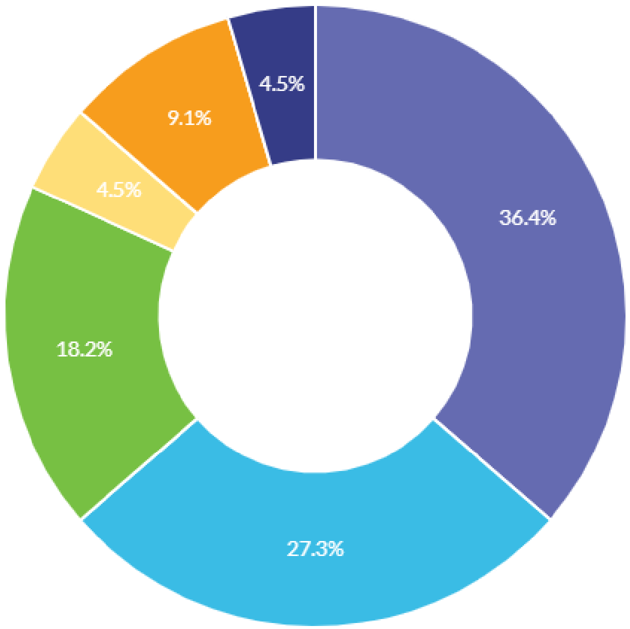


Choice	Total
Nominal (i.e. non-numeric categories)	0
Ordinal (i.e. numeric categories)	6
Interval (i.e. data grouped in categories with order and equal distances)	1
Ratio (i.e. percentages)	0
Combination of the above (please elaborate):	3

Figure 14 Answers to Q11.

Q13 Which of the following data labels exist in the dataset?

Multiple Choice



Choice	Total
units	8
sampling intervals	6
frequency range	4
flags (e.g. error codes)	1
missing values	2
functional status	0
Other (please elaborate)	1

Figure 15 Answers to Q13.

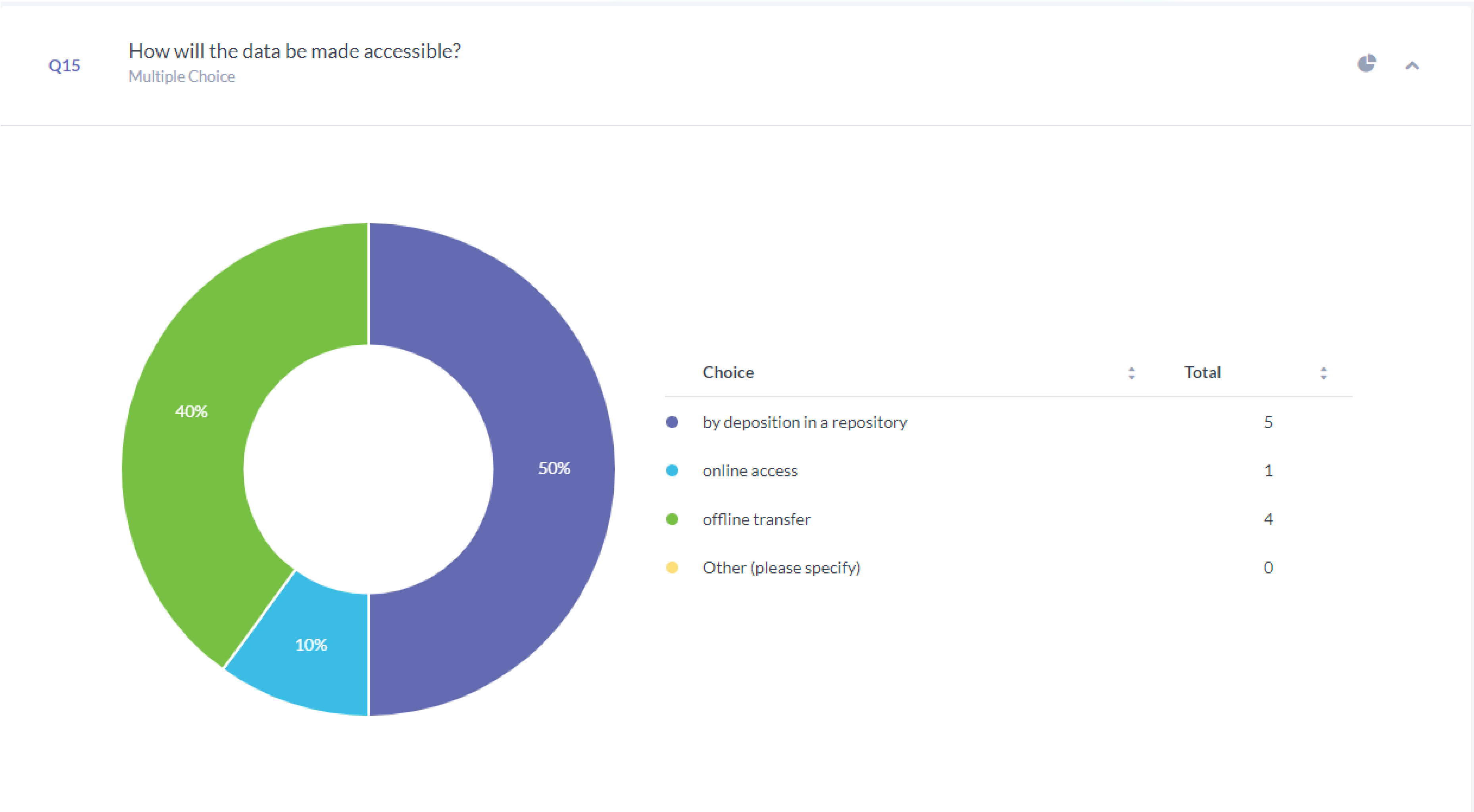
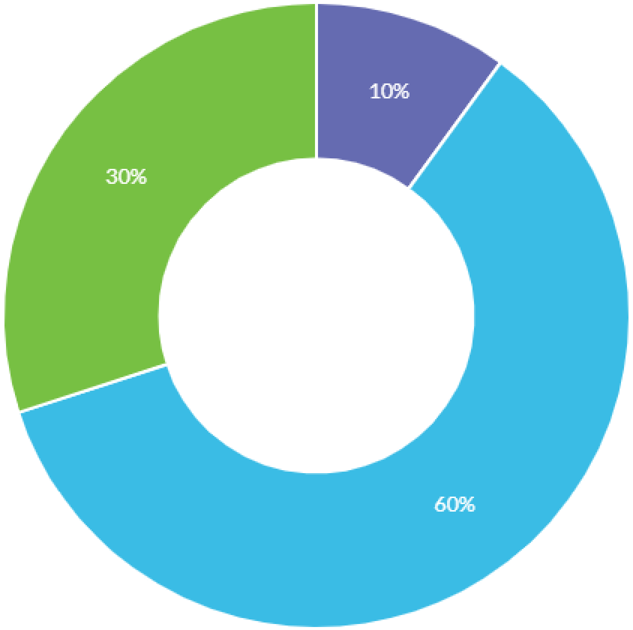


Figure 16 Answers to Q15.

Q23 Are you GDPR compliant?
Multiple Choice

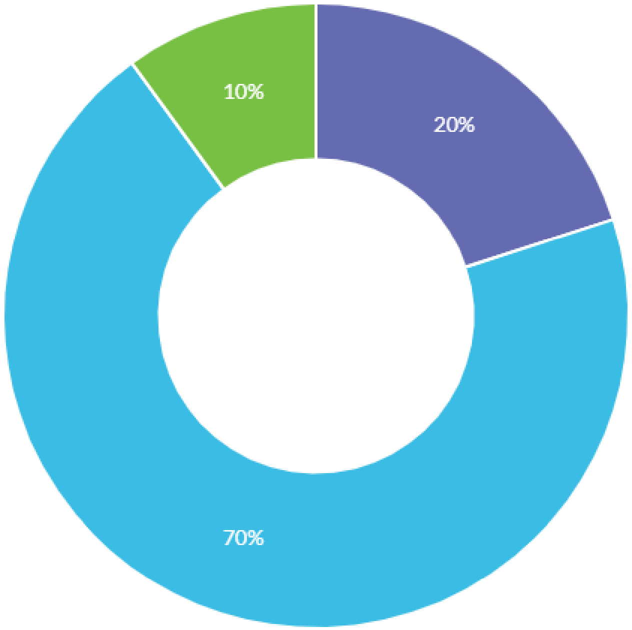


Choice	Total
No	1
Yes	6
Not aware	3

Figure 17 Answers to Q23.

Q25 Is the data safely stored in certified repositories for long term preservation and curation?

Multiple Choice



Choice	Total
No	2
Yes	7
Not Aware	1

Figure 18 Answers to Q25.

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