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EnerMan

Energy Efficient Manufacturing System Management

D1.2 - EnerMan Pilot Requirements and Use Case Specification

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EnerMan

Short Description
This deliverable provides an overview on the as-is analysis of the EnerMan pilots from end-users and the definition of the requirements posed by the industrial manufacturing approaches to be followed by the pilot partners of the EnerMan framework.

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EXECUTIVE SUMMARY

This deliverable summarises the work that has been carried out as part of Task 1.2. For EnerMan to be able to realise the goals that have been outlined, it is important to define the requirements posed by the industrial manufacturing approaches to be followed by the pilot partners of the EnerMan framework. More specifically, this deliverable aims to identify the current needs on energy consumption within the manufacturing environment focusing on the most energy consuming units that need to be optimized, the personnel practices on assessing energy consumption and its impact on the environment as well as its cost. Additionally, in this deliverable the specificities of each pilot category will be collected, analysed and the appropriate requirement thresholds will be described. The methodology applied in the Task 1.2 is an online survey conducted with all end-users. The appendix of this deliverable features a copy of the final questionnaire. This deliverable ends with concluding remarks and show connections to other EnerMan tasks.

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GLOSSARY OF ACRONYMS

Acronym	Definition
BMS	Building Management System
CCM	Continuous Casting Machine
CHP	Combined Heat and Power
CO	Carbon monoxide
CPS	Cyber Physical System
CSA	Corporate Sustainability Assessment
DES	Discrete Event Simulation
DSS	Decision Support System
EAF	Electric Arc Furnace
EC	Energy Consumption
FTP	Fume Treatment Plant
GHG	Greenhouse Gas
GWP	Global-Warming Potential
IoT	Internet of Things
ISO	International Organization for Standardization
KPI	Key Performance Indicator
KPI	Key Performance Indicator
LF	Ladle Furnace
NO	Nitric oxide
NO_2	Nitrogen dioxide
Pb	Lead
SMC	Standard Meter Cubic
VD	Vacuum Degassing station
Zn	Zinc

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1. INTRODUCTION

To establish a solid approach for the development of an energy-efficient management system in the context of manufacturing, the EnerMan pilot requirements and Use Cases specifications need to be defined. Task 1.2 focused exclusively on the definition of the requirements and specifications posed by the industrial manufacturing approaches to be followed by the pilot partners that are going to deploy the EnerMan framework. Therefore, this task focused on the collection of the current needs of energy consumption within the manufacturing environment focusing the most energy consuming units that need to be optimized, the personnel practices on assessing energy consumption and its impact on the environment as well as its cost. The specifics of each pilot category were recorded and appropriate requirement thresholds were described.

Firstly, the goal of Task 1.2 is to identify the energy sustainability issues that each pilot faces in the manufacturing process, including their impact on the lifecycle cost and the factory value chain. Second of all, the specifications of the use cases that will be used for evaluating the EnerMan framework will be refined and detailed in this task. The requirement analysis of this task was done through conducting an online survey using the EU Survey tool. The survey consists of closed and open questions that were answered by the end-users. The preparation of the survey took place in weekly meetings where the task responsibles defined the scope and the questions of the survey. The end-users and the other partners of the task were involved in the preparation of the survey through the bi-weekly meetings. To make sure that the end-users correctly understood the questionnaire, individual meetings with each end-user was organized to go through the survey. To this end, the following document contains a brief report of the development of the survey questionnaire and the analysis of the responses of the end-users.

The document is organized as follows, Section 2 features the pilots and use cases and check for any updates or additional details that are recently added by the end-users. Section 3 and 4 analyse the end-users responses to the survey and focus on the as-is analysis and the expectations from EnerMan. The deliverable ends with concluding remarks in Section 5. The appendix of the deliverable features a copy of the final questionnaire and the text-mining analysis results.

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2. PILOTS AND USE CASES PRESENTATION

The EnerMan framework will be tested in three different pilot scenarios that consist of eight real-life manufacturing use cases. Different energy intensive manufacturing operations will be involved from the most demanding manufacturing areas, namely:

- Appliances and industrial components manufacturing industry
- Food industry
- Metal manufacturing and processing industry

It is important to start with the presentation of the use cases of the EnerMan Pilots to give a comprehensive overview of the application areas expected from the EnerMan framework. In this section, the Use Cases provided by the end-users will be presented and if any recent updates or refined versions are available, they will be highlighted. The Use Cases are categorized based on the EnerMan pilotsas listed in Table 1 below:

Table 1. Summary of the Use Cases

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

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

2.1.1. *Use Case #1.1: The painting process and bodyshop working area*

The owner of the Use Case 1.1 is CRF and aims at implementing the EnerMan solution in the automotive manufacturing sector.

Motivation: The automotive manufacturing industries are facing new challenges in the multi-faceted context of economy, technology and environment. In the automotive manufacturing area, the painting process has been identified as the most challenging for its energy sustainability (monitoring, prediction and reduction), optimal energy consumption and environmental footprint, as it consumes up to 60% of the total energy of the car production plant [1]. Apart from the painting process, another energy expensive point for the plant is represented by the environmental heating and air conditioning of the industrial building working area. The body shop in the automotive industry is a typical example of the flow shop (or transfer line) where many parts are assembled together in the body shop by various welding operations. The paint shop is the area were the paint is applied on cars.

Deployment of EnerMan solution: CRF plans to implement EnerMan on top of an existing real-time monitoring platform currently installed in the paint shop of FCA's plant for the production of D segment vehicles near Turin (Italy). The goal is to develop a smart Energy Sustainability and Management System that can predict and forecast energy consumption in order to avoid energy drifts and losses. The existing monitoring platform allows monitoring in real-time the consumption of the utilities that drive the painting process and subprocesses, relying on dynamic data acquisition from the field such as temperature/humidity probes and flow rate measurers and data acquisition boards. However, the limits of the current system are related to the difficulty of redesigning and adapting the solution on large scale dimension. Among other limitations there are the lack of predictive models and decision-making recommendations. Furthermore, with the EnerMan solution CRF wants to monitor the operation of the bodyshop environmental air conditioning system by collecting the real-time data of the indoor air temperature of the building working area. The goal would be to compare data with the predictive reference that is given by EnerMan system. Thus CRF will have a better control of building heating. This Use Case consists of two Sub-use Cases, which are detailed here below:

Sub-use Case #1.1.1

Target Process: Automotive manufacturing – Paint shop: In the painting process it is necessary to apply different protective layers to the body of the car in order to give the final aesthetic appearance in terms of colour and clarity. In this process there are several specific subtasks characterized by different utilities and consumption. In the EnerMan project the two subtasks mentioned below will be studied in detail:

Subtask 1: Degreasing Tank of Pre-treatment

The starting process step in which the body car is washed and cleaned into a tank with spray by using hot water before the paint application. Major drivers: Heating for the maintenance of the tank water temperature around 50°C to wash the body car.

Subtask 2: Air Handling Unit of Topcoat Booth

Process step in which the paint is applied to the body car into a booth regulated by specific conditions of temperature and humidity. Major drivers: Heating and cooling the indoor air of the booth to keep regulated condition of temperature and humidity around 24°C and 50% respectively, and ensure the quality of product.

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Sub-use Case #1.1.2

Target Process: Automotive manufacturing – Bodyshop: Environmental heating and air conditioning of the industrial building working area. Heating for maintenance and indoor air temperature of the working area of the building around 18°C to ensure personnel well-being and health. This target process is not breakable into subtasks.

2.1.2. *Use Case #1.2: A testing factory for engines, powertrains and vehicles*

The owner of the Use Case 1.2 is AVL List GmbH and aims at implementing the EnerMan solution in the automotive manufacturing sector.

Motivation: The need for CO_2 reduction and the increasing complexity of new powertrain systems are some of the key challenges faced currently by the automotive industry and for the foreseeable future.

Deployment of EnerMan solution: AVL List GmbH is aiming at using their Tech Centre in Graz/Austria as the execution plant of the EnerMan solution. The existing testing infrastructure, both from hardware and software point of view, can measure real data (such as test conditions such as temperature and humidity), data aggregation and evaluation, simulations and prediction analysis. AVL List GmbH is aiming at bridging the limitations of the existing solution by the use of digitalization (sensors, intelligent algorithms, prediction concepts, etc.) which offers the possibility to lower the environmental footprint of the testing and validation phase in the automotive industry. ThisUse Case consists of two Sub- use Cases:

Sub-use Case #1.2.1

Target Process: Chassis Dyno ambient: A vehicle is tested in a room under ambient conditions of temperature ~25°C and humidity, and under different test cycles. This target process is not breakable into subtasks.

Sub-use Case #1.2.2

Target Process: Chassis Dyno Climate: A vehicle is tested in a room under different temperature conditions which range from -30 °C to +40 °C and humidity, and under different test cycles. The major energy consumption drivers in this use case are technical components such as fan, chiller, cooling coil, heating coil and the humidifier. This target process is breakable into four subtasks which are shown in Table 2 below.

Table 2. breakdown of the target process of sub-use Case #1.2.2

Subtask #	Subtask name	Subtask description	Subtask conditions
1	Ambient Run	Test cycles under ambient conditions	25°C and 45% relative humidity
2	Hot Run	Test cycles under hot conditions	40°C and different humidities
3	Cold Run	Test cycles under cold conditions	-7°C
4	Freeze Start	Start under freezing conditions	-30°C

2.1.3. *Use Case #1.3: An energy-optimized global virtual factory*

The owner of the Use Case 1.3 is IFAG and aims at implementing the EnerMan solution in the semiconductor industry.

Motivation: Semiconductors have been important to automotive innovations in the past decade. However, when it comes to energy sustainability, even though the power consumption of devices has reduced significantly over the years, improvements in the energy used during the chip production

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process have lagged [2]. Energy costs can account for 5 to 30 percent of factory operating expenses, depending on local electricity prices.

Deployment of EnerMan solution: IFAG aims at using the EnerMan solution at its Wafer Fabrication Facilities with the goal of developing an energy-optimized global virtual factory for the semiconductor industry, where ecological parameters are considered strategic decision-making indicators. The current IFAG's global management system will be enhanced by a simulation of the manufacturing network where various energy consumption scenarios can be tested. The current simulation allowed to prove that the flexibility of the manufacturing network of IFAG is an enabler of CO_2 reduction. The existing simulation is representing the two steps of semiconductor manufacturing process, the frontend and backend processes. The simulation is built in Anylogic Software, which is a discrete-event simulation software. The existing solution could be improved by considering ecological parameters such as energy/carbon footprint as important decision-making parameters. Recommendations and improvements regarding the energy consumption are not supported nor predictions for the energy/carbon footprint future scenarios.

Target Process: This target process in this use case will be the manufacturing process of semiconductors at IFAG from an energy consumption viewpoint. In this Use Case we will provide a simulation for the entire production network of Infineon. Only average data of one of the selected sites is used in this survey. In this Use Case we will look at the semiconductor manufacturing processes from an energy consumption point of view. The manufacturing process includes the frontend and the backend processes. The energy consumption in the semiconductor process is very energy intensive with a large contribution to carbon footprint. Therefore, optimization of it is critical. The semiconductor manufacturing is very complex and takes a long time and requires certain conditions to be maintained. Major drivers are energy consumption for machines and energy consumption to maintain cleanroom conditions. This target process is breakable into two subtasks.

Subtask 1: Manufacturing Process by Machines

This process includes the frontend process which includes the wafer fabrication and the sorting of dies which are performed in manufacturing steps such as circuit design, oxidation layering, lithography process and the wafer testing . The backend process is the second process which includes the assembly of the dies to produce the final chips and the final testing. Major drivers of energy consumption is the complexity and the duration of the processes. Since the ENERMAN framework will not impact this part of the process only minor details are provided in this deliverable.

Subtask 2: Maintaining the Cleanroom Conditions

The semiconductor industry requires a vast amount of electricity because it needs to maintain cleanroom conditions in order to manufacture chips, operate heating, ventilation, and air conditioning (HVAC) units and chillers. During the production of wafers, even the smallest particles of dust could destroy the functionality of an entire semiconductor chip. That is why the cleanroom conditions are crucial in the manufacturing process of Infineon Technologies. Cleanrooms are enclosed spaces where contaminants in the air are greatly controlled regarding temperature, humidity, air pressure, airborne particulates, airflow patterns, air motion, lighting, vibration, noise, and living organisms. Moreover, the HVAC units and chillers constitute the cleanroom facility systems along with a process cooling water (PCW) system and an ultra-pure water (UPW) system. These conditions do not only increase the electricity bill of the industry but also pollute the environment by emitting CO_2 and using large volumes of ultra-pure water to avoid the contamination of electronic devices. Major drivers of energy consumption: HVAC units and chillers.

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2.2. Pilot #2: Food industry

2.2.1. *Use Case #2.1: Chocolate processing and manufacturing*

The owner of the Use Case 2.1 is YIOTIS S.A. and aims at implementing the EnerMan solution in the food industry.

Motivation: Food industry is the largest manufacturing sector in the EU. Therefore, an assessment of the energy breakdown for this sector is quite challenging. In the food industry chocolate is one of the most energy-demanding sub-sectors in terms of processing, manufacturing and storing conditions. Due to the delicate properties of chocolate, not many actions can be taken to reduce the energy needs of the process itself.

Deployment of EnerMan solution: YIOTIS aims at implementing the EnerMan solution at its chocolate manufacturing plant with the goal of adopting a more efficient energy-consumption profile through the energy sustainability management framework. Therefore, YIOTIS will deploy and demonstrate the EnerMan solution in a chocolate production line. YIOTIS has upgraded its production by integrating state-of-art processing machines which will be used in the pilot phase. The existing infrastructure comprises of an integrated chocolate line and its supporting utilities. The existing approaches could be enhanced with regards to the lack of data acquisition and energy-consumption awareness.

Target Process: Chocolate processing and manufacturing: Chocolate manufacturing is one of the most energy-demanding sub-sectors in terms of processing, manufacturing and storing conditions of the food industry. Due to the delicate properties of chocolate, not many actions can be taken to reduce the energy needs of the process itself. The aim of the Use Case owner is the energy sustainability management framework which will help to adopt a more efficient energy-consumption profile. This target process is broken down into the following subtasks:

Subtask1: Refining/Conching

Cylindrical double wall heated machines in which all the raw materials are loaded. After loading, the paddles of the machine are activated, and they start rotating. The paddles of the machine start to grind the ingredients using friction. During this process, the granulometry of the mass decreases while the viscosity increases.

Subtask 2: Chiller

Water cooling system that is used for the cooling of the refining/conching machines.

Subtask 3: Storage Tanks

Double wall heated tanks with agitation in which chocolate is stored after the refining/conching and before the tempering and moulding step, in order for the product to develop its liquor flavour. The agitation is slow and keeps the chocolate mass homogeneous.

Subtask 4: Moulding

The chocolate, after the tempering is completed, it is ready to be formed in drops, buttons or flakes by passing through an extruder type head. The pistons of the machine transfer the chocolate by using suction and discharge it passing through a head. After that the formatted chocolate passes through a cooling tunnel chamber for conservation and stabilization.

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2.3. Pilot #3: Metal manufacturing and processing industry

2.3.1. *Use Case #3.1: Autonomous trigeneration facility for aluminium industry*

The owner of the Use Case 3.1 is ASAS and aims at implementing the EnerMan solution in the metal manufacturing and processing industry sectors.

Motivation: Primary aluminium production relies entirely on electrical power. Electrical energy costs represent a sizeable proportion of primary aluminium production expenses. The global demand for aluminium is estimated to increase pushing producers to seek ways to make its production as energy efficient as possible [3]. Therefore, the development of new technologies to produce energy are necessary.

Deployment of EnerMan solution: ASAS aims at employing the EnerMan solution to its trigeneration plants in order to make the system autonomous and able to predict the economic cost of the consumed energy. ASAS is an energy intensive industry mainly in the aluminium industry. In order to recycle the residual energy, trigeneration facilities of ASAS produces electricity, steam and hot water. Hot water and steam are used in the aluminium anodizing facility. ASAS is also active in the day-ahead electricity market, which means that prediction of energy consumption is very essential. In current infrastructure, the management of trigeneration facilities work (powering on/powering off and on-number of engines to be used) is controlled manually. There is not an existing system to control decisions for the trigeneration facility.

Target Process: Trigeneration Plant: Power plant. Major energy consumption drivers in this use case are the oil and steam consumption for electricity generation.

Table 3. Breakdown of the target process of Use Case #3.1

Subtask #	Subtask name	Subtask description	Subtask major energy drivers
1	Coat Water System	The internal combustion engine is cooled by an oil cooling system, and the heated oil is cooled by coat water. Coat water is utilized from waste heat	Mainly water but it is recirculating in a closed system
2	Superheated Water Boiler	Exhaust gas is directed to the hot water boiler with the help of a damper. The waste heat of the exhaust gas is utilized	Mainly water but it is recirculating in a closed system
3	Hot Water Inlet ABS Chiller	It helps in utilizing the waste heat of coat water	Mainly electric water but it is recirculating in a closed system
4	Superheated Water Inlet ABS Chiller	It helps in utilizing the waste heat of the exhaust gas	Mainly electric water but it is recirculating in a closed system

2.3.2. *Use Case #3.2: Titanium and CoCr alloys manufacturing for medical device industry*

The owner of the Use Case 3.2 is DPS and aims at implementing the EnerMan solution in the medical device industry sector.

Motivation: Orthopaedics has been one of the fastest growing sectors in medical device manufacturing [4]. Titanium alloys continue to be one of the most important components used in

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orthopaedic implant devices due to favourable properties. The diversity of orthopaedics manufacturing processes and the machining of the titanium alloy influence energy consumption and create critical challenges, that include the selection of optimum process parameters or the development of effective numerical models for machine tools.

Deployment of EnerMan solution: DPS aims at implementing EnerMan solution in its medical device manufacturing plant with the goal of focusing on assets that enable the manufacture of medical devices. These assets are key for the functioning of the factories and currently consume between 15-20% of the total energy requirements of the factory. The existing solution is currently gathering data related to electrical consumption, pressure, temperature and flow data for the Boiler, Chiller and Compressed Air assets as well as pressure, temperature, and damper positions for AHU assets. The electrical consumption data is collected using Schneider electrical meters from the site's distribution boards. The pressure, temperature, flow and damper position data are collected by physical meters and are hard wired back to JJVCI Building Management System (BMS) for visualisation and monitoring.

However current limitations are: Real-time data acquisition and monitoring, predictive and optimization algorithms developed, tested, and validated and performance improvement according to technological objectives. The comparison will be done based on data with and without the optimization algorithms.

Target Process: The Assets that enable manufacturing of medical devices are included in this study. This includes Air Handling Units (AHU) units, Dust Extraction units, Compressed air units, Boilers and Chilled Water.. Major drivers of the energy consumption are the fact that the load is relatively static, but overall plant production can shift the consumption up and down, as well as other environmental factors.

Table 4. Breakdown of the target process of Use Case #3.2

Subtask #	Subtask name	Subtask description	Subtask major energy drivers
1	Air Handling Units	Regulate and circulate air as part of heating	The outside air temperature, level of production activity
2	Compressed Air Units	Compressed air facilities in the manufacturing plant	compressed air usage - linked to overall plant production - supply pressure.
3	Boilers	Plant boilers	The outside air temperature, occupancy level of overall production activity
4	Chilled Water	Chilled water	The water usage and water temperature
5	Dust Extractors	Dust extraction for process plant	The production output

2.3.3. *Use Case #3.3: Energy consumption in iron and steel manufacturing industry*

The owner of the Use Case 3.3 is STN and aims at implementing the EnerMan solution in the iron and steel manufacturing industry sector.

Motivation: The benefits of energy efficiency are commonly accepted in the steel sector. Beyond cost-saving, the increased productivity and competitiveness associated with improving energy management merit the investment in many cases. Despite this, research continually shows that steel manufacturers are not always choosing to implement energy efficiency measures to the extent that would bring them the highest profit.

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Deployment of EnerMan solution: STN aims at implementing the EnerMan solution in their steel manufacturer plant in Bulgaria. The primary goal is optimizing the energy consumption in the power intensive processes and equipment focusing on the melt shop and filters/pumps station. This can be achieved through modelling and building a digital twin platform, as well as optimizing the operation through sensing-based control, simulations and dynamic machine learning. A close control, monitoring and traceability of the ladles used in the process will allow the prediction of temperature variations and will enable an operation with a lower targeted superheat temperature (lower energy consumption). Limitations consists in the lack of optimization activities that influences product quality (i.e., superheat steel temperature control). Notably, STM need for traceability and condition monitoring of the ladle furnaces in order to optimally control the superheat temperature. In return this will contribute to energy saving and steel quality improvement.

Target Process: Melt shop Plant: melt shop is the plant that melts ferrous scrap and transforms it into long (Blooms or Billets) or flat (Slabs) semi products of desired steel grades. This target process consists of the following subtasks:

Table 5. Breakdown of the target process of Use Case #3.3

Subtask #	Subtask name	Subtask description	Subtask major energy drivers
1	Electric Arc Furnace (EAF)	Electric Arc Furnace is where the scrap melts and converts into liquid steel	The melting of scrap with electrical energy, natural gas, carbon and chemical energy using oxygen
2	Ladle Furnace (LF)	Ladle Furnace is where the liquid steel is transformed to targeted steel grade	The heating of liquid steel through electrical energy
3	Vacuum Degassing station (VD)	Vacuum Degassing Station where degassing of liquid steel take place	The electrical energy for the motors to create the vacuum
4	Continuous Casting Machine (CCM)	Continuous Casting Machine that solidifies the liquid steel into desire flat or long shape semi product	The electrical energy consumed by the motors
5	Fume Treatment Plant (FTP)	Fume Treatment Plant that filter gases from the EAFs and LFs operations	The electrical energy for the motors
6	Natural Gas Preheaters	Natural Gas Preheaters for the vessels of liquid steel (Ladles and Tundishes)	The natural gas consumed for the heating process

2.3.4. *Use Case #3.4: Additive manufacturing for processing metal components.*

The owner of the Use case 3.4 is PE and 3DNT that aims at implementing the EnerMan solution in the metal processing sector.

Motivation: The use of rapid prototyping technologies has increased significantly in recent years [5]. As such, Additive Manufacturing (AM) is projected to exert a profound impact on manufacturing which varies from cost and energy efficiency to development of manufacturing parts.

Deployment of EnerMan solution: PE and 3DNT aims implementing the EnerMan solution at the Advanced Laser Center of Prima Industry with the goal to make AM more sustainable in terms of economics and consumption.The fundamental step is to optimize the process and the systems in order

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to achieve the best solutions for the production. The existing solution has the possibility to provide some information with CPS for monitoring the process and system behaviour. IoT connector is going to be integrated as well in the machine as final structure of IoT architecture, so to collect the information of the machine and process in a unique entry point. In sequent this connector can be linked with external environment so to send information to the cloud or database. A toolbox is able to provide secure transfer of the information. The objectives of such toolbox are:

- Better design or hardware and software adjustments on different sub-systems for more efficient function and use of powder and gas
- Monitoring and control systems for shorter trials & errors procedure and defects reduction during the process. Monitoring of needed laser power, powder and gas can lead to more efficient printing
- Control of manufacturing processes and set-up tasks reconfiguration, optimization of set-up times and production dead-times
- Costs reduction & product life cycle.

Target Process:

Metal print: melting powder via laser radiation. Major drivers of the energy consumption are the laser, laser cooling and platform heating.

Table 6. Breakdown of the target process of Use Case #3.3

Subtask #	Subtask name	Subtask description	Subtask major energy drivers
1	Laser Radiation	Emission of laser radiation	The generation of radiation
2	Laser Cooling	Cooling of the laser	compressor and pump
3	Heating	Platform preheating	The electrical resistors

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3. AS-IS SITUATION ANALYSIS

A survey questionnaire was sent to the 10 end-users involved in the EnerMan project and a series of meetings were organized to guide them through the questions of the survey. The participation of the end-users in these meetings and the answering of the questionnaire reflected strong engagement from the end-users to identify the requirements from the EnerMan solution. Figure 1. The Positions of the End-users Respondents of the Questionnaire shows the positions involved in answering the questionnaire. Most of the answers is coming from process engineers, namely 5 respondents. Involvement of an executive manager in the questionnaire also shows the high commitment by the end-users to the identification of the needs for EnerMan solution. The respondents include also a supply chain engineer, a R&D manager, a operations manager and an automation engineer.

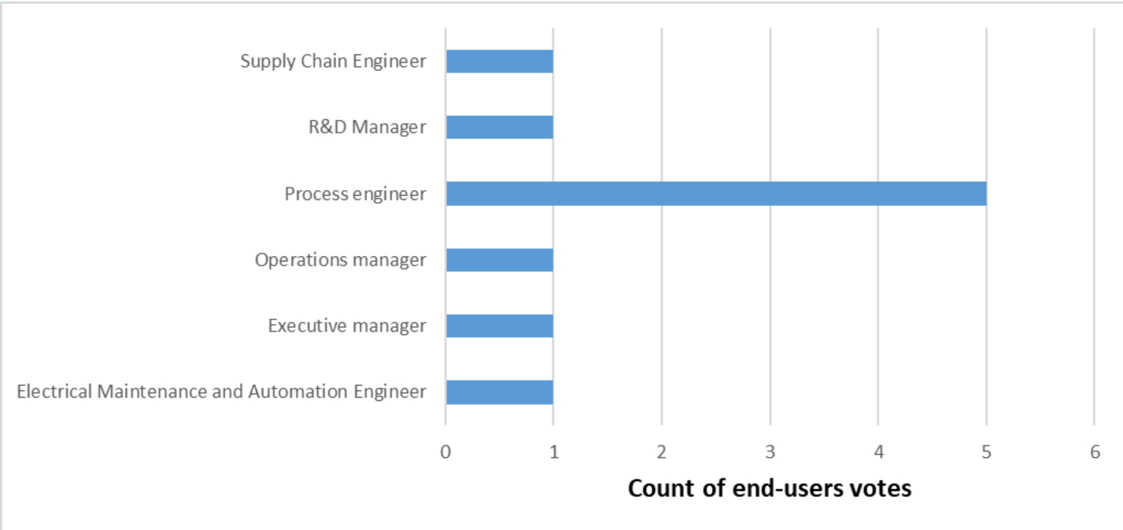

Figure 1. The Positions of the End-users Respondents of the Questionnaire

The section shows the as-is analysis of the questionnaire answers and focus on the energy consumption needs of the EnerMan pilots. Notably, the different energy used by the end-users - such as electricity, water …etc.- are analysed. Secondly, the major drivers of the energy consumption, the energy storage activities and the participation in demand response activities are also presented to indicate the areas of improvements for the end-users. Then, the personnel practices on assessing energy consumption are included in this section. Finally, the environmental impact ad cost-related issues are presented.

3.1. Energy Consumption Needs

In this section the energy consumption needs of the EnerMan pilots are specified. The questionnaire dedicated to this issue detailed questions aiming at discovering all the specificities of the energy needs from the end-users perspective. The end-users were asked to specify the consumption of different forms of energy such as electricity, water, natural gas, ...etc. and how frequently this consumption is measured. The end-users were asked about the sources of purchasing or producing these energy types, average consumption and the presence of power cuts or supply shortages. This section is split into subsections related to each different type of energy used in the target processes or the subtasks.

3.1.1. *Electricity usage*

All the end-users report their usage of electricity at their sites. This reflects the importance of electricity and how its volatility could cause instability for the companies involved in the EnerMan

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project. As a consequence, the optimization of electricity consumption becomes a critical topic for EnerMan project.

Concerning the sourcing of electricity, Figure 2. Sourcing Electricity in the Target Processes and Its Subtasks shows that two end-users buy their electricity from wholesale markets and two end-users buy it from retail market. The majority of the end-users, namely six end-users, get electricity from mixed sources. This could be a mixture of self-production, wholesale market and retail market.

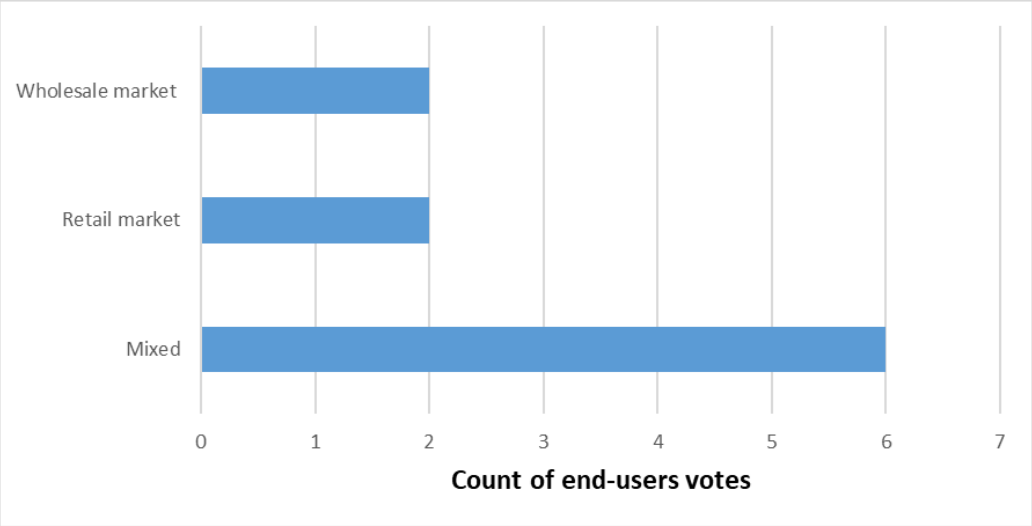

Figure 2. Sourcing Electricity in the Target Processes and Its Subtasks

We observe in Figure 3 that the volatility of the unit cost of electricity is mostly static (6 end-users), since the volatility in some critical sectors could cause major disruptions. One end-user reported rather static prices in longer timescales. On the other hand, two end-users stated that the unit cost of electricity is very volatile in short timescales. One end-user reported that the volatility of the unit cost is rather volatile in longer timescales.

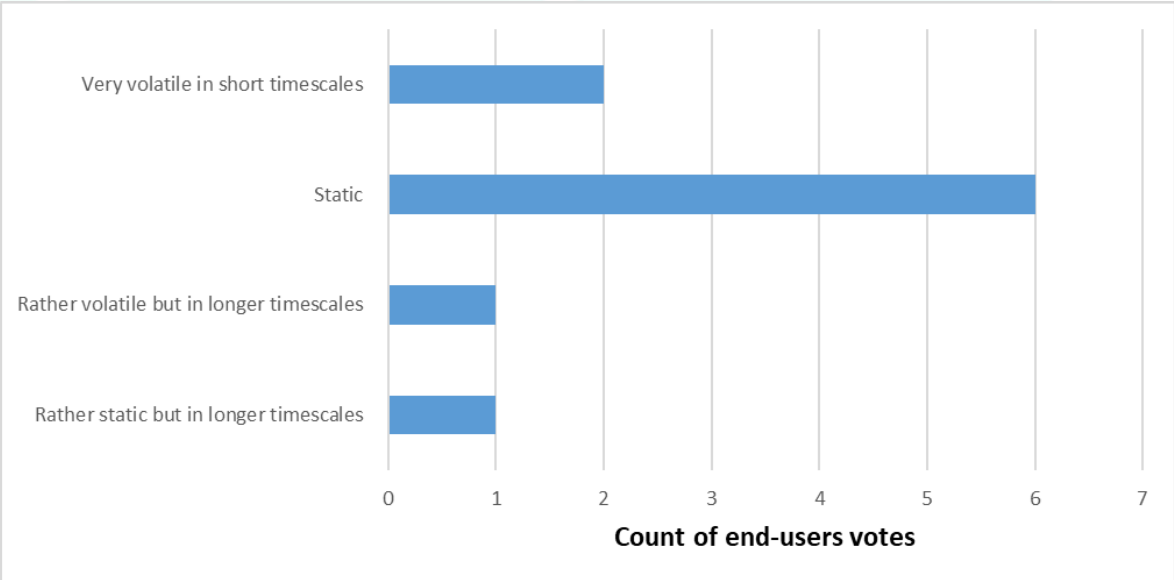

Figure 3. The Volatility of the Electricity Prices

The questionnaire also focused on the electricity power cuts and/or downtime. The aim was to distinguish between the intended power cuts in comparison to the unforeseen power cuts or

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blackouts. With regards to this topic, the end-users reported mainly power cuts and/or downtimes that are rather intentional and dependant on planning aspects or production quantities.

Figure 4. Measurement Frequency of Electricity by End-users show how frequently the end-users obtain the measurement of electricity for the target process. As shown in the figure, the majority of end-users reports measuring the electricity every second (namely 3 end-users). Two end-users report measuring the electricity in their plants every month while one end-user reports quarter-hour and every minute measurements. Regarding the measurement of electricity for the subtasks the frequency does not differ that much from the measurement of the target process. It is worth noting here that some end-users can provide measurements of electricity on a high granularity for subtasks.

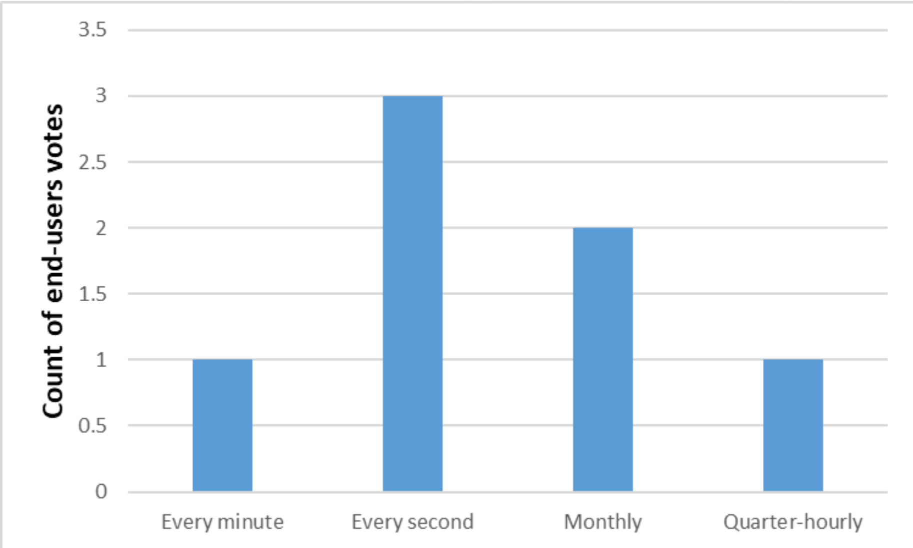

Figure 4. Measurement Frequency of Electricity by End-users

Regarding the average consumption of electricity, this could either be yearly, monthly, or hourly. No consumption data is available on daily basis. As observed from the end-users answers the most common interval reporting energy consumption data is yearly, followed by monthly and hourly data. While daily data is uncommen. This could be clearly seen in Figure 5.

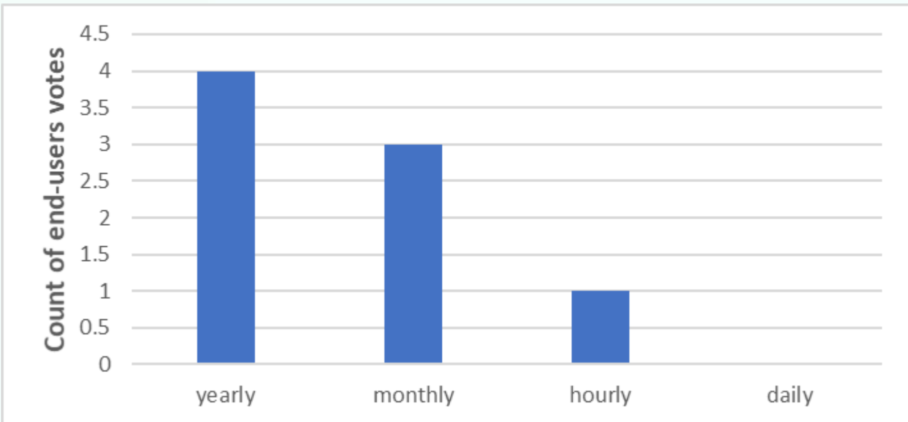

Figure 5. The average electricity consumption reporting interval for the target process

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The end-users's average consumption of electricity per year is in the range of hundreds of GWh per year (for rather energy-intensive industries) to several GWh per year. The consumption of some end-users is available also on smaller timeframes e.g., per day or per hour for the different subtasks.

3.1.2. *Natural Gas usage*

Regarding the usage of the natural gas, Five end-users reported not using natural gas in neither the target process nor the subtasks. On the other hand, five end-users reported using natural gas in the target process and its subtasks, see Figure 6. This reflects the importance of natural gas in the target process and subtasks of the end-users as the second most used source of energy.

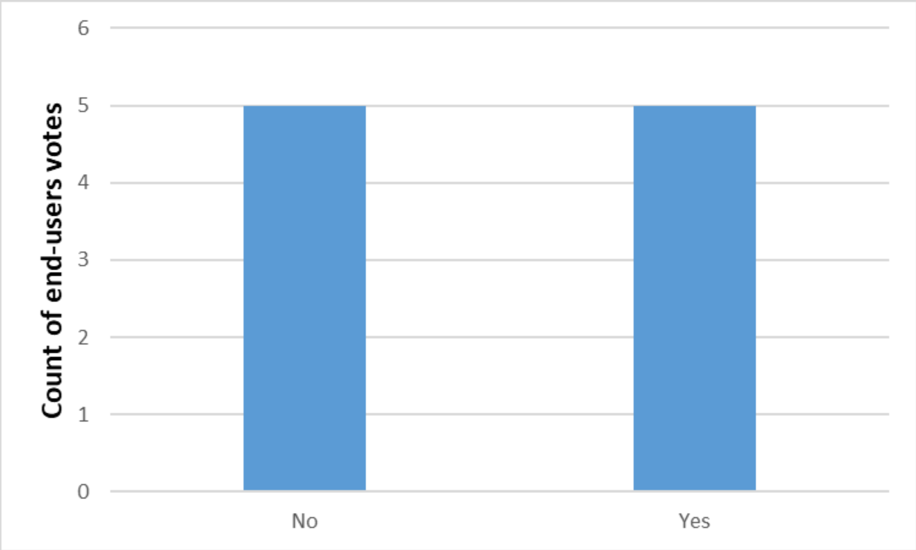

Figure 6. The Usage of Natural Gas

Figure 7 shows the sources of purchasing or production of natural gas. Three end-users source their natural gas from retail markets, while one end-user buy its natural gas from wholesale market and one end-user gets it from mixed source i.e., retail market and wholesale market.

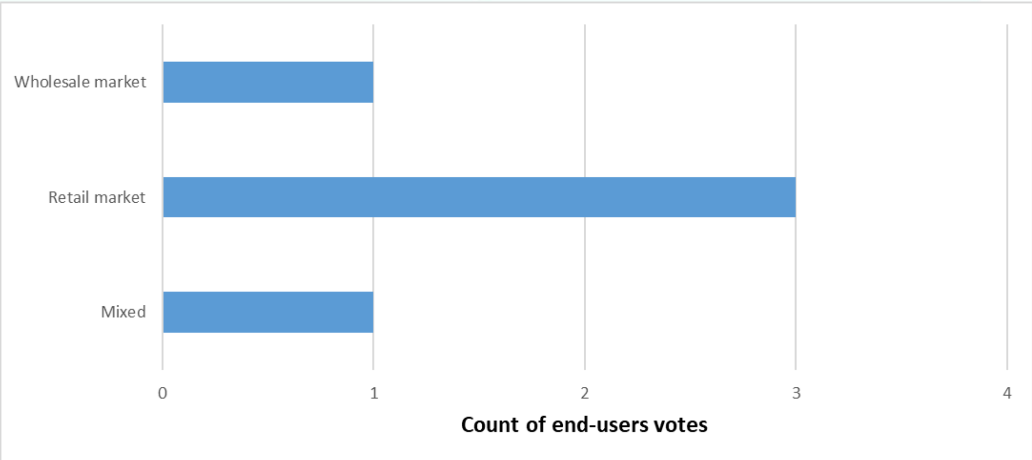

Figure 7. The Sourcing of Usage of Natural Gas

Regarding the volatility of the natural gas cost, most of the end-user show static volatility of the costs, while one end-user stated very volatile in short timescales and another end-user reported a rather volatile in longer timescales, as shown in Figure 8. It is interesting to observe that while the retail market tends to provide natural gas with static prices, the wholesale market provides very volatile

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prices in shorter timescales and the mixed sources of energy provide energy with rather volatile prices in longer timescales.

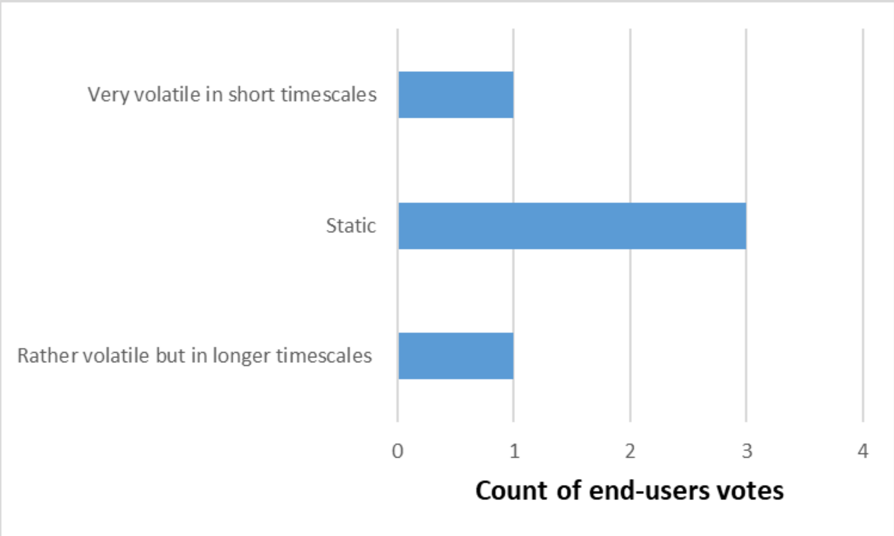

Figure 8. Natural Gas Cost Volatility

Regarding the measurement frequency of natural gas consumption for the target process, three end-users mentioned they measure the consumption of natural gas every-second and one end-user stated monthly measurements, See Figure 9. This holds true also for the subtasks, apart from one end-user which mentioned measuring natural gas consumption for subtask 1 (which is EAF) and subtask 6 (which is the preheaters) every minute and every month, respectively.

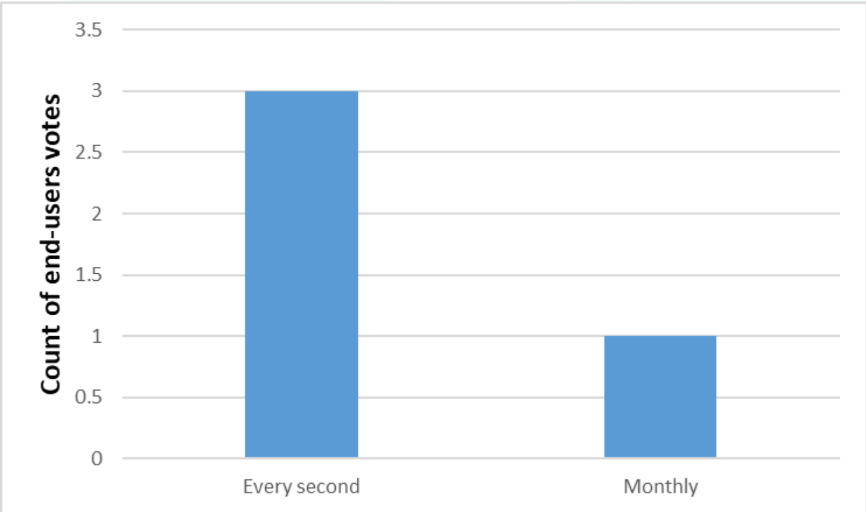

Figure 9. Measurement Frequency of Natural Gas Consumption

Regarding the power cuts and/or downtimes for the natural gas usage, the aim of the questionnaire is to recognize the intentional power cuts (for reasons related to the company's own decision making) in comparison to the unforeseen power cuts (i.e., blackouts or major disruptions to the power supply due to force majeures). The answers of the end-users reveal that both intentional and unforeseen power cuts are rarely occurring. Only one end-user reported a power cut of intentional nature.

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3.1.3. *Water usage*

Regarding the usage of water by the end-users in the target process and the subtasks, four end-users (belonging to automotive, semiconductor and food sectors) reported using water, while six end-users reported not using water for their processes, as shown in Figure 10 below.

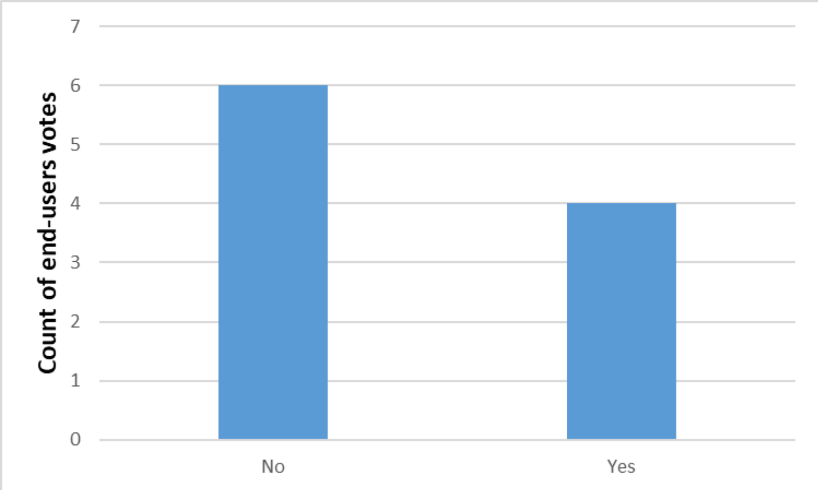

Figure 10. The Usage of Water in Manufacturing Processes by End-users

The prices of water are rather static as reported by the end-users. The measurement frequency of the water used in the manufacturing processes is either per month or per minute according to the answers of three end-users.

Regarding the sourcing of water for the manufacturing processes of the end-users, Figure 11 shows that two of the end-users purchase their water from retail market providers, while one end-user gets their water via self-production and another one getsit through the wholesale markets.

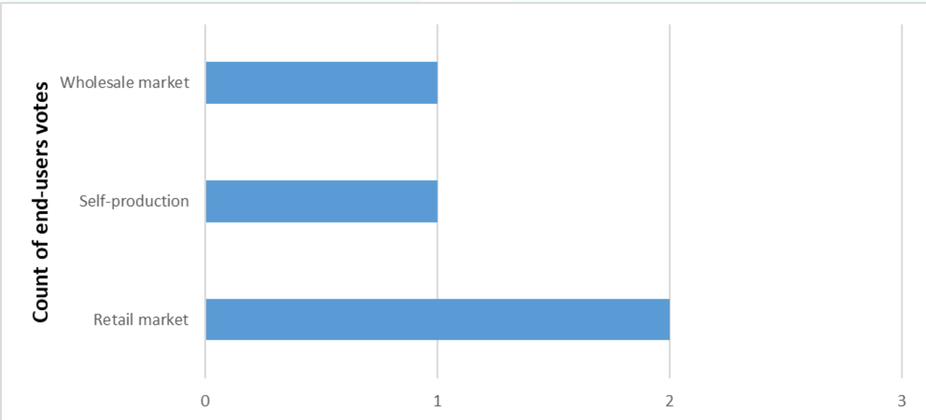

Figure 11. The Sourcing Water for the Target Processes and the Subtasks

Regarding the power cuts and/or downtimes for the water usage, questions are aimed to recognize the intentional water supply interruptions in comparison to unforseen he water supply interruptions. As observed in the answers of the end-users both intentional and unforeseen power cuts are of rare occurrence. Only three end-users reported water supply interruptions of intended nature.

Regarding the average consumption of water in the plants, end-users report big variations of consumption trend that depends on different parameters such as the external temperature and

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winter season. Average consumption of water is mainly reported in used as superheated water or chilled water used for the maintenance of clean rooms in manufacturing sites.

3.1.4. *Other Energy usage*

The analysis of the other energy types used in the manufacturing processes of the end-users shows that four end-users use other type of energy, while six reported not using other energy type, as shown in Figure 7. The most dominant form of alternative energy type used by end-users is district heating as feeder for the heating system. Gas and thermal solar system are also used as a form of energy, as reported by one end-user. The use of carbon in combination with oxygen to produce heating energy is also reported by one of the end-users. For this end-user only the consumption of the carbon is measured and not the energy generated.

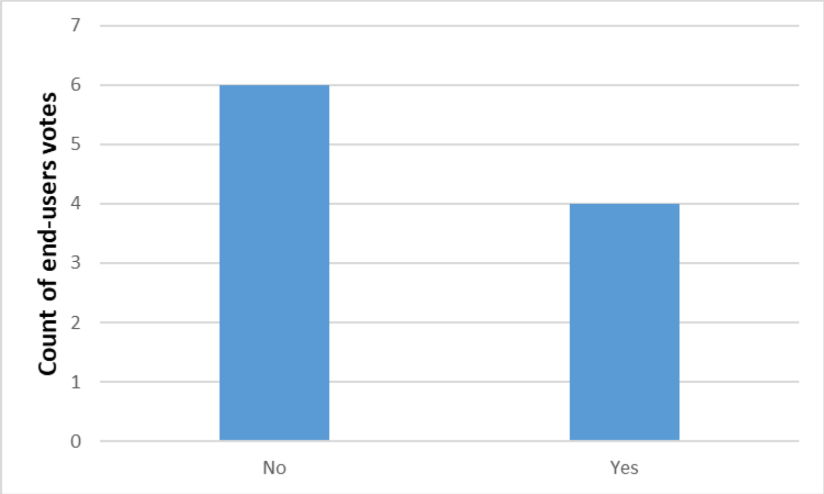

Figure 12. The Usage of Other Types of Energy

Regarding the frequency of measurement of other energy types, the answers vary between measuring it every second in the automotive manufacturing use cases, every month for the semiconductor industry use case and every minute for the use cases from the iron and steel manufacturing.

Regarding the procurement of the other types of energy, the end-users of the EnerMan project gets this form of energy mainly from mixed sources of energy e.g., retail market, self-production and/or wholesale markets, Figure 13. Regarding the volatility of prices of the other energies, end-users reported static volatility, with one end-user reporting rather static but in longer timescales.

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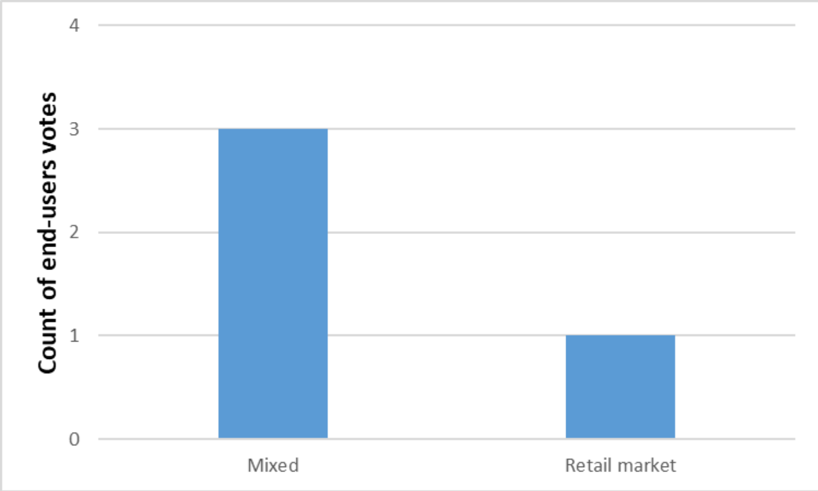

Figure 13. The Sourcing of Other Energy Types

Regarding the power cuts and/or supply interruptions for the other energy usage, the aim is to recognize the intended supply interruptions in comparison to the supply interruptions energy. As a result, both intentional and unforeseen supply interruptions are of rare occurrence. Only one end-user reported other energy supply interruptions of an intended nature related rather to the production planning aspects.

With regards to the current average of the other energy types' of consumption for the target process, this has been provided only by two end-users. The energy consumption in the first end-user is regarding the consumption of district heat and was provided on hourly basis while the second end-user provided data about carbon and oxygen consumption as an additional form of energy.

3.2. Major Drivers of Energy Consumption

In addition to knowing the energy needs of the EnerMan end-users, it is equally important to understand the breakdown of the energy consumption and identify the major drivers of it. This will help to identify the areas for improvements and reduction of energy consumption which is one of the main goals of EnerMan.

It is observed from the answers of the end-users, namely the ones operating in energy-intensive industries, that the maintenance of the cleanroom conditions is a major contributor to the energy consumptions in these sectors. The energy consumed by the maintenance of cleanroom conditions is mainly consumed by fans, chillers, cooling coils, heating coils, humidifiers among others. The cleanroom conditions are needed to maintain favourable environmental for manufacturing of the products, which require the removal of impurities. Furthermore, end-users underlined that the cleanroom conditions have to maintain an indoor air temperature of the working area of the building around 18°C (mainly defined by law) to ensure the personnel healths The cleanroom conditions are also required to ensure the final product quality.

The use-case of the iron and steel industry, being one of the energy intensive industries, shows how oil and steam consumption for electricity generation is a major consumer of energy. The furnaces are among the major contributors to the energy consumption in this industry.

3.3. Energy Storage and Demand Response Activities

Regarding the energy storage activities, the majority of the end-users reported not using any energy storage activities. However, an end-user from the automotive industry reported that heat recovery

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wheels are used for preheating of the air treated by the air handling unit of the topcoat booth. As observed by the answers of the two end-users the heat is a potential source of energy that can be recovered.

Regarding the demand response activities, results are summarized in Figure 14. Eight end-users responded not participating in any kind of demand response activities. One of the end-users, which reported the participations in the demand response activities uses a Combined Heat and Power plant (CHP) for this purpose.

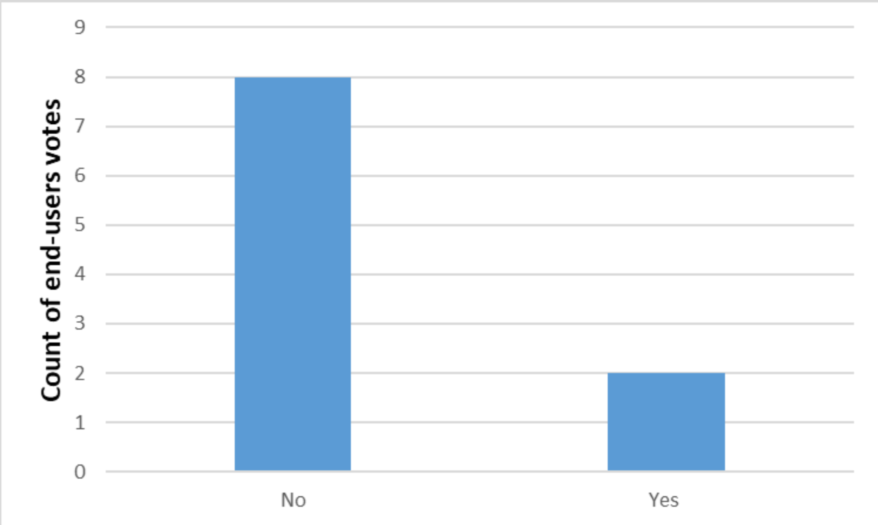

Figure 14. End-Users Participation in Demand Response Activities

3.4. Personnel Practices on Assessing Energy Consumption

This subsection shows the responses of the end-users regarding best practices in the assessment of energy consumption. This includes the number of people involved in the production line, the decision-making process applied in the target process and the duration of target process.

The answers of the end-users regarding the number of personnel in the production line ranged from having several workers to tens of thousands (Figure 14). This reflects the diverse sizes of the workforce of the end-users involved in the EnerMan project.

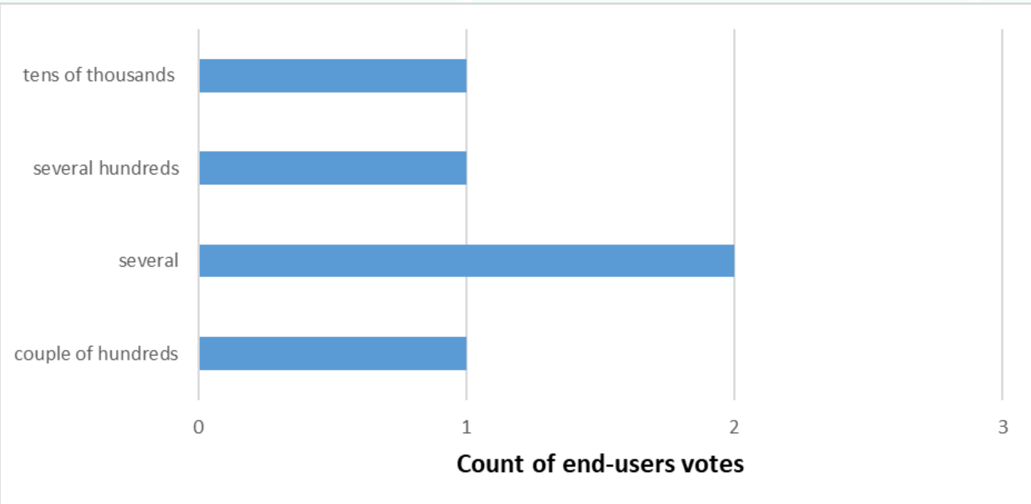

Figure 15. The Number of People Involved in the Production Line

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The questions regarding the nature of the decision-making process applied in the target process and relevant subtasks aim at knowing whether the decision-making is performed automatically or manually, and whether the system in place allows the monitoring of the decision-making or the target process in an automated manner. Two end-users mentioned that the decision process is performed as part of the production management program of the firmby production manager/planners and by using the company methods of production production. One end-user noted the availability of a Building Management System (BMS) that is monitoring all processes, so that the decision making is relatively autonomous. Some of the decisions taken are subject to law and regulations defined by the authorities in the region/area where the end-user is operating. Figure 16 shows the responses of the end-users regarding the type of decision-making process applied.

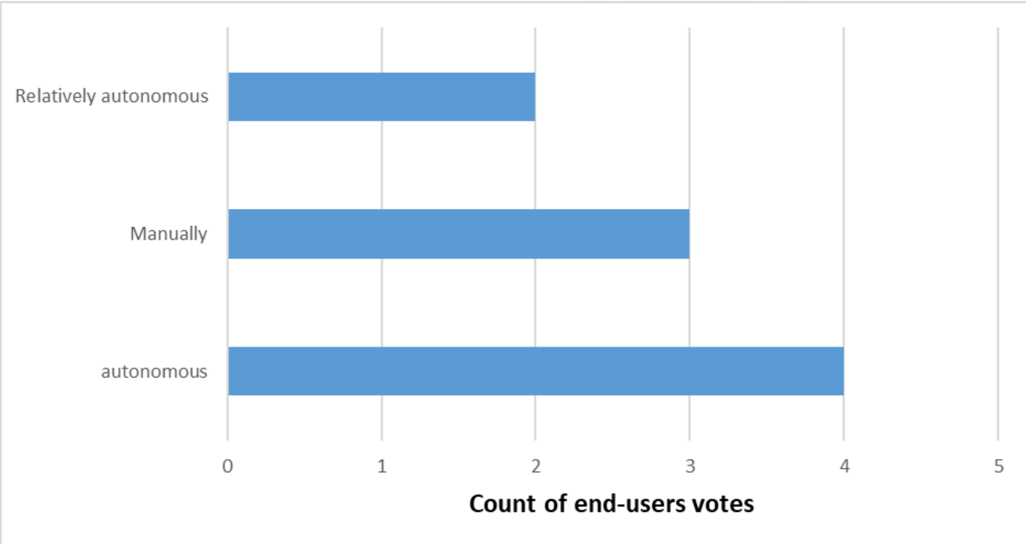

Figure 16. The Type of the Decision-making Process Range from Manual to Fully Autonomous

Regarding the duration of the target process, 50% of the end-users mentioned that the duration of the target process is not relevant or not applicable, and the aim of EnerMan at the improvement of the energy consumption of the target process. The duration of the target process for the end-users who provided an estimation ranges from tens of minutes to tens of hours. The duration, as reported by some end-users, could be completely dependent on the number of tests.

3.5. Social, Environmental, and Economic Related Issues

In this section all the sustainability issues related to the implementation of EnerMan are shown. This includes the social and human related aspects, the environmental aspects and the economic and cost aspects. The section includes also the International standards applied by end-users and cost-related and energy efficiency issues of the target process.

3.5.1. *Environmental-Related Challenges*

Regarding this aspect, six of the end-users reported environmental challenges as shown in the Figure 17 below. The end-users who answer yes elaborated that the most important environmental challenge is the reduction of energy consumption, which in turn will contribute to the reduction of the CO_2 emissions. This could be achieved by reducing drift and losses, notably by using a better supervision of the process and monitoring of the building environmental conditioning with consequent reduction of energy consumption and CO_2 emissions.

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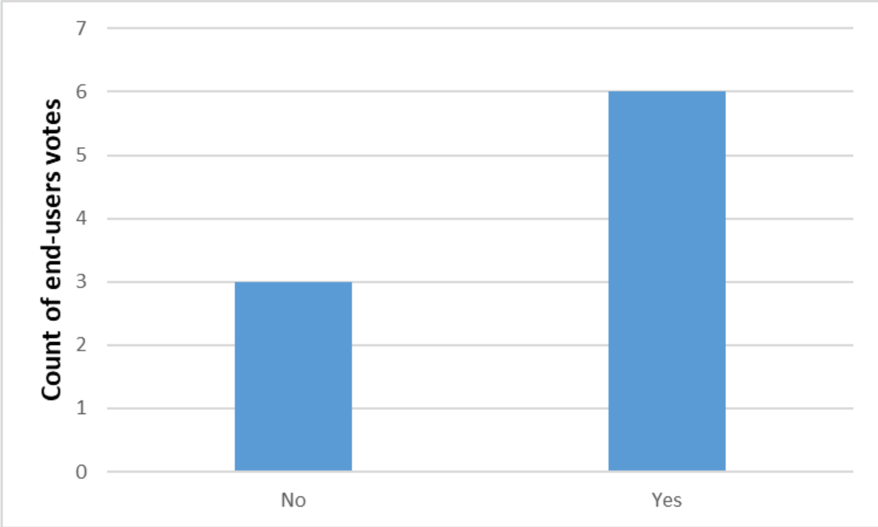

Figure 17. The Environmental Challenges Related to EnerMan Processes

Dust extraction, wastewater and energy efficiency of laser generation are among the environmental challenges reported by the end-users.

3.5.2. *Emissions Related to the Target Process*

This subsection is split into water-related, air-related, land-related, sound-related emissions and other types of emissions.

Water-related Emissions

Two end-users reported having water-related emissions/waste. One end-user reported that the environmental permit of the company regulates the quality characteristics of the water they can return into the surrounding environment. The end-user also measures the consumption of water and the quantity of water returned to the river. These measurements are for the whole factory and not applicable for the case that EnerMan examines. Other end-users also reported adherence to laws defining water discharge and emissions.

Air-related Emissions

This is the most common emissions reported by the end-users. Most air emissions reported by the end-users is related to the emissions of certain pollutants such as CO, CO_2, NO and NO_2 among other pollutants. The use of CO_2 equivalent calculations based on coefficients of conversion are also provided in the answers of the end-users. One end-user is calculating scope 1 and scope 2 emissions according to GHG Protocol [6] available on a plant level not on process level (two end-users reported this process level emissions).

Land-related Emissions

Three end-users reported generating land emissions. The most common land related emissions are are powder or dust and slag. The presence of other solid wastes is also observed but according to one end-user this could be recyclable under the right conditions. Unfortunately, one end-user reported that the EnerMan project will not affect or improve the land wastes.

Sound-related Emissions

The sound related emissions are reported by two end-users. Tolerable level of noise is regulated by environmental permit and for some use cases it is not reported on individual plants level.

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Recycling Material

The recycling material was provided only by one end-user. Hopefully through the implementation of EnerMan solution, end-users could be able to recycle more material and improve the efficiency of the processes. The recyclable material reported by the one and only end-user is in a form of slag, which is recycled for road construction and other infrastructures or for recovery of Zinc (Zn) and Lead (Pb).

3.5.3. *Human-Related Challenges*

Regarding the human-related challenges, Figure 17 shows three end-users responded that there are human related challenges related to EnerMan. The main challenges are the environmental conditions that need to be maintained in the manufacturing facility that need to meet certain regulations. This was observed in the automotive sector, the semiconductor sector and the medical device sector.

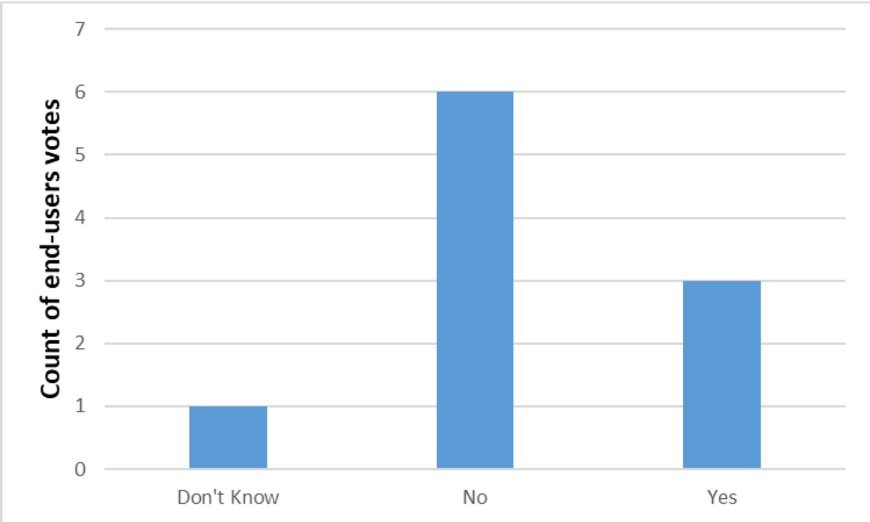

Figure 18. The Human Challenges Related to EnerMan Processes

3.5.4. *International Standards Applied by End-Users*

This question was to assess the application of any international standard for sustainability topics such as environmental, social and economic aspects of the challenges reported in the sections from section 3.5.1 to section 3.5.3 as discussed above. Results are shown in Figure 19.

Regarding the international standards applied, only two end-users reported that they use them in the manufacturing processes. The first one is the semiconductor use case which shows that the energy management system and the calculation of the CO_2 emissions are performed according to the ISO 14000 family of standards. The second Use Case is from the automotive industr,y which reported following the Italian law for their body shop and paint shop use case, namely DLgs 81/08. This latter requires that the employer has to ensure an adequate temperature of the working area related to the type of activity and the worker's physical effort.

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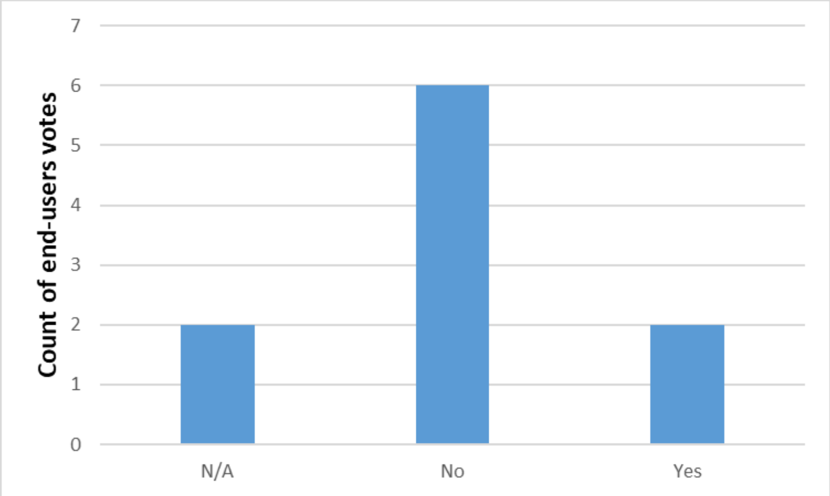

Figure 19. The International Standards Applied in the Manufacturing Processes

3.5.5. *Cost-Related Issues for the Target Process*

Regarding the cost of the target process, most of the end-users reported that the target process cost accounts for less than 25% of the total cost of production. Two end-users reported that the cost is between 25% and 50% of the total cost. One end-user reported that the cost is between 50% and 75% of the total cost. Three end-users reported that the total cost is more than 75% of the total cost. This shows how the cost of the target process varies from being as low as 25% to being more than 75% of the total cost. This makes the cost optimization for target processes highly important to the end-users in the EnerMan project. Figure 20 shows the share of the target process cost with respect to the total cost.

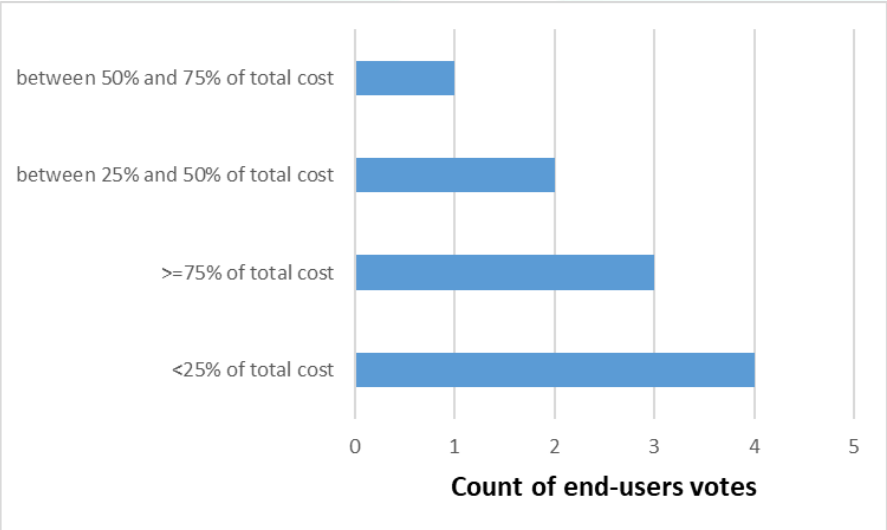

Figure 20. The Percentage of the Cost of The Target Process Compared to the Production Total Cost

Figure 21 shows the magnitude of the cost of the target process in Euros. Where two end-users reported that the target process cost is less than 100K euros, two end-users reported that the cost range between 100k and 500k Euros, one end-user responded that the cost of the target process range between 500k and 1M Euros, while two end-users reported that the cost ranges between 1M and 10M Euros, while two end-users reported that the cost range between 10M and 100M Euros.

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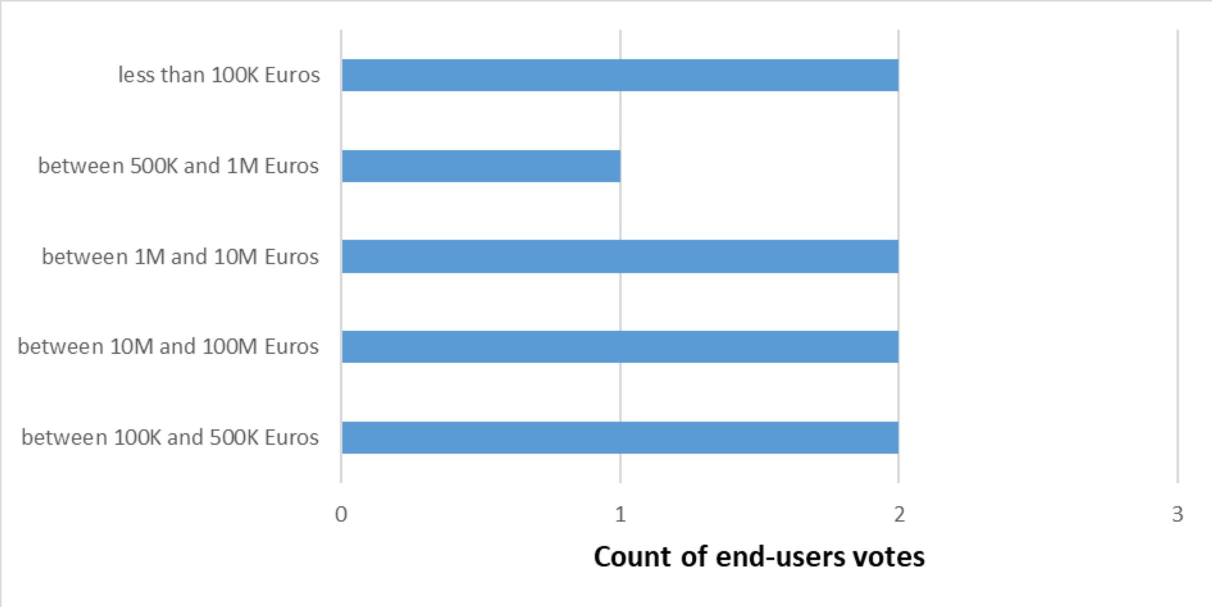

Figure 21. The Magnitude of the Cost of the Target Process in Euros

3.5.6. *The Energy Efficiency of the Target Process*

Regarding the efficiency of the target process, this has been measured in four different KPIs as follows:

kWh/product Unit

This KPI measures the energy efficiency in terms of the numbr of kWh consumed to produce one product. This is the most common KPI for measuring the energy efficiency of the target process. Five end-users responded by providing the energy efficiency in terms of kWh per product. One end-user reported hundreds of Euros per year. One end-user reported adherence to industry standards and their energy efficiency is 53 % less than the average in the industry. One end-user reported that energy efficiency for maintaining certain conditions in the buildings accounts for 2000 kWh per product unit. One end-user provided a range for this KPI accounting for 20kWh / unit to 40kWh / unit. One end-user reported the availability of energy efficiency even on smaller granularity for subtasks which is between 1 kWh to 600 kWh per product unit. One end-user reported to be dependent on the complexity of the product itself and the duration of the production.

Litres of fuel/ product Unit

Only two end-users provided information about the energy-efficiency measured in Litres of fuel per product unit. In these Use Cases the efficiency of the building heating is approximately couple of hundreds of Smc per product unit of natural gas for a certain subtask, and equals approx. less than two Smc per product unit of natural gas.

kWh/personnel-hour

The energy efficiency in terms of kWh per personnel-hour is available only from one end-user who reported that this KPI is available in terms of kWh per unit of revenue, and it accounts for one quarter of kWh hours per unit of revenue.

Others

The other KPIs used in the measurement of the energy efficiency of the target process and subtasks are very diverse and could either be in terms of Liters or cubic meters of fuel per kWh, personal/main/consumables cost/kWh, which reflects the personnel cost and kWh/kWh.

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4. EXPECTATIONS OF ENERMAN: TEXT-MINING ANALYSIS OF OPEN QUESTIONS

In this section, the open questions about the expectations of EnerMan solution are analysed. The section will start by introduction the text-mining analysis technique and present the results of the analysis in the subsequent sub-section.

4.1. Introduction to text-mining analysis

The last part of the questionnaire involved a number of open questions concerning the EnerMan solution related expectations. More specifically the open questions were given to the end-users, to which they could answer by providing their point-of-view. Appendix A includes the questions of the questionnaire.

Given the open format of the answers, a preliminary text-mining analysis was performed to identify qualitative context stemming out of the answers. The main research item from these questions was to see if there are common themes pursued among the end-users and identification of common issues envisioned by them.

For these purposes, a Bag-of-words model approach [7] was followed for feature generation out of the answers given by each end-user. The most common type of features (or characteristics) calculated from the Bag-of-words model is the frequency, namely the number of times a term appears in the text. Julia v1.4 [8] was used for programming a script (a link to the Julia notebook is provided as a footnote[1])

4.2. Results of the text mining analysis

Table 7. Bag-of-Words Results

#	Term	Frequency	#	Term	Frequency
1	energ~	56	**17**	abl~	13
2	consumpt~	47	**18**	base	13
3	air	26	**19**	condit~	13
4	product	26	**20**	run	13
5	data	22	**21**	chang~	12
6	temperatur~	22	**22**	collect	12
7	level	20	**23**	heat	12
8	water	20	**24**	meter	12
9	control	19	**25**	target	12
10	digit~	16	**26**	central	10
11	flow	15	**27**	oper~	10
12	instal~	15	**28**	report	10
13	solut~	15	**29**	chiller	9
14	twin	15	**30**	cost	9
15	manag~	14	**31**	refer	9
16	server	14	**32**	tank	9

[1] https://nextjournal.com/EnerManD12textMining/enerman-d12-text-mining-analysis-for-expectations-related-answers

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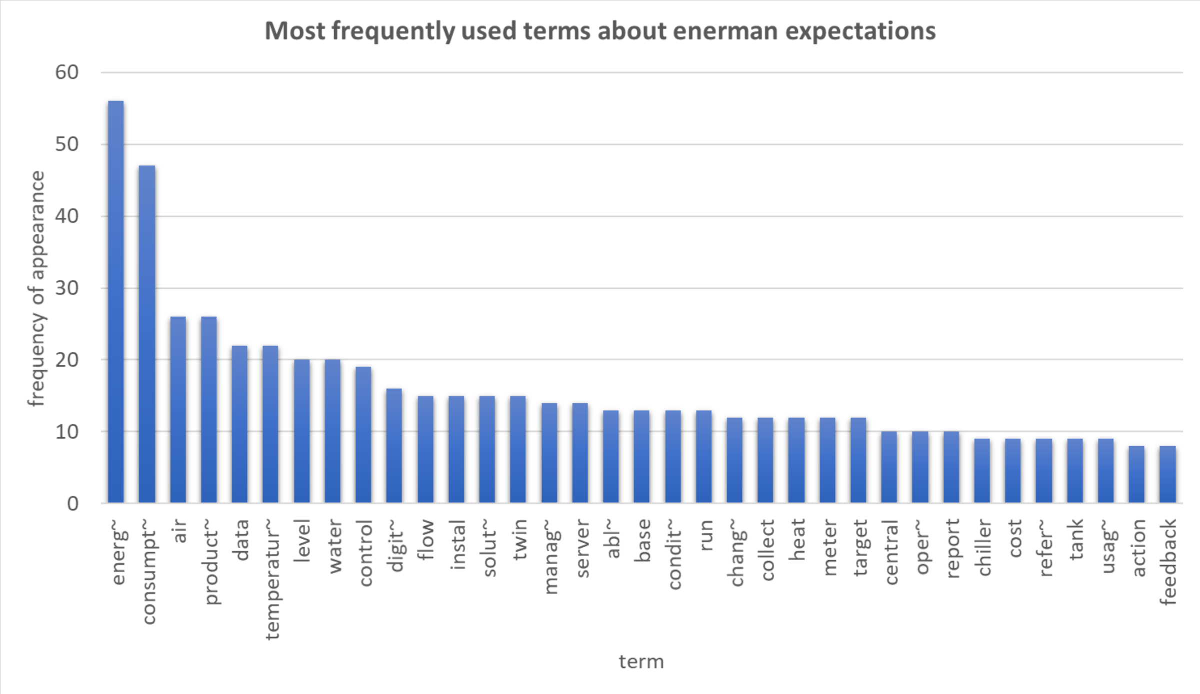

Figure 22. Most Frequently Used Terms from End Users Related to EnerMan Expectations

As we can see from Figure 22, the main terms reflecting the end-users' opinion have to do with manufacturing related issues (e.g., "consumption", "production", "flow"), energy sources (e.g., "energy", "air", "water") and data related characteristics (e.g., "real-time", "data", "digital", "server").

However, in order to get a better view of the end-users perspective, an n-gram analysis was performed to highlight the most commonly used bi-/tri- and quadra-grams (i.e., number of consecutive words found together in a sentence) to extract a meaningful interpretation of common trends. Table 4 in the Appendix shows the results coming from that analysis, as well a short explanation about the overall approach. Terms highlighted with green colour confirm the trends appearing among partners as far the EnerMan application is concerned, with characteristic examples the need for "a central server" and "ML and AI algorithms", while "flow rate measures", "of the building" and "end-node meters" are of high importance as well.

Based on the previous results, we can provide a diagrammatic representation of the context level desired to be achieved by the EnerMan approach, as far as the end-users are concerned. Based on the text-mining analysis, data issues are of outmost importance and are highlighted by the context of the answers provided, followed by manufacturing processes optimization and improvements on existing sources allocation and use.

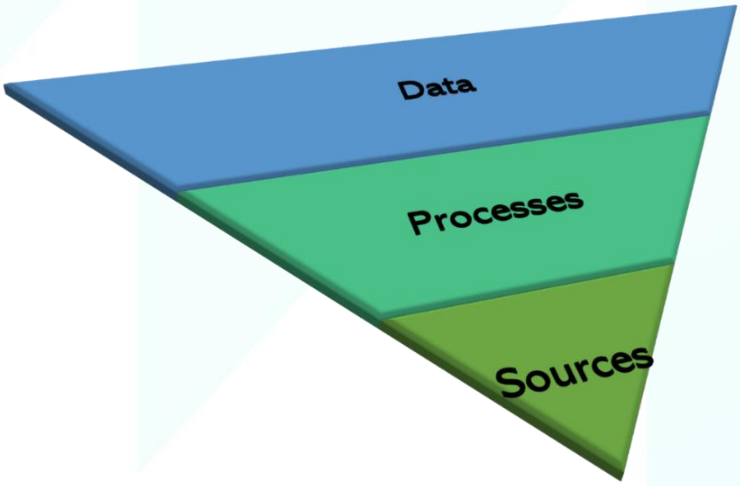

Figure 23. Context-related Expectation Levels regarding EnerMan

This is also aligned with the answers given in the specific question number 5 in Table 1

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related to the KPIs. Table 3 shows a redacted version of the total answers given by the end-users in non-specific order and by removing partner's identifiable information. As we can see data monitoring and measurements issues dominate the answers given in terms of Key Performance Indicators, thus serving as a driver for the upcoming build-up of the EnerMan system.

Table 8. Redacted Answers to Question #5

Redacted sentences from the answers given to Question #5
Real-time energy consumption
Water temperature used for cooling (chiller)
flue gas analysis
natural consumption / kwh
Steam ABS Chiller running performance
engine oil cons / kwh
hot water consumption / kwh
steam consumption / kwh
energy flows
Hot water ABS Chiller running performance
consumption in term of real-time power demand of
Energy Consumption
kWh / per part
Market prices for load shifting
Air usage / kWh - and where is the air being used
COP chillers and COP heater and where is the chilled water / heat being consumed
Waste output
real-time trend of the indoor air temperature of the building working area
Energy consumption of machines and clean room conditions.

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5. CONCLUSION

This deliverable summarised the insights of Task 1.2 which aimed at defining the requirements posed by the industrial manufacturing approaches to be followed by the pilot partners of the EnerMan framework. Notably, there are 3 Pilots which consists of 10 Use Cases in the EnerMan project aiming at implementing the EnerMan solution in 7 different industries and sectors. This deliverable presented the specificities of use cases in detailed manner describing the different target processes and the subtasks and the overall aim and expectations from the implementation of the EnerMan solution. The end-users answers were collected using a questionnaire which was answered by diverse roles inside the end-users organizations. The deliverable identified the current needs by the end-users in terms of energy consumption within the manufacturing environment as described in Section 3.1. The deliverable focused as well on the most energy consuming units that need to be optimized, the personnel practices on assessing energy consumption and its impact on the environment as well as its cost as described Section 3.3 and Section 3.5. These important elements will help to identify the energy sustainability issues that each pilot faces in the manufacturing process including their impact on the lifecycle cost and the factory value chain. The deliverable depicted some of the requirement thresholds reported by the end-users which are either dependent on regulators or on production planning aspects. A further update will be provided in deliverable 1.3.

Regarding the energy needs, the most used source of energy is electricity which mainly comes to the end-users from mixed sources (i.e., retail market, wholesale market, and self-production) with unit prices that are rather static. The majority of the end-users measure its consumption every second. The natural gas is the second most used source of energy. End-users gets natural gas mainly from retail market with prices that are mainly static. The natural gas consumption is also measured frequently by end-users in second granularities. Water and other sources of energy comes third in terms of the most-used energy resources. End-users get water mainly from retail markets and its price is mostly static and its consumption is measured every minute. Regarding the power cuts and the supply interruptions of the energy sources, the interruptions is mainly due to intended actions dependant on the production planning or the production quantities, while the unforeseen power interruptions such as blackouts are not reported by any end-user.

The majority of the end-users mentioned that the cleanroom conditions are the major driver of the energy consumptions in the manufacturing process. This includes the maintenance of certain heating and cooling conditions that are favourable for the manfacturing of products and the health and well-being of workers in the factories. The end-users aim through the implementation of EnerMan solution at optimizing the energy consumption and achieving an energy-efficient manufacturing process. For achieving this, end-users showed their expectations, as described in Section 4, and the analysis of the expectation using text mining shows the importance of energy consumption and the digital twin solutions as ways to achieve energy-efficiency in production environment.

It is clear that Task 1.2 is relevant for all other tasks of the EnerMan project. However there is direct linkage to Task 1.3 since the definition of the requirements and energy needs will help in the work on EnerMan Platform architecture, system specifications and awareness. Task 1.2 is also important for the progress on the subsequent EnerMan work packages such as WP4, WP5 and WP6.

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APPENDIX A: BLANK QUESTIONNAIRE

ENERMAN Internal Questionnaire on Sustainable Industrial Manufacturing

1 Section A: Partner Info

1.1 Please indicate the name of your organisation

1.2 Please describe your job/position in the organisation

- Executive manager
- Plant manager
- Process engineer
- Operations manager
- Field worker
- Other

1.3 Please specify job/position

2 Section B: Current Status

2.39 Please briefly describe the target process

	Name	Description	Major drivers of energy consumption
Target Process			

2.39 Can the process be broken down into subtasks?

- Yes
- No
- Don´t know

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2.40 Please briefly describe the main subtasks of the target process

	Name	Description	Name of preceding subtask (s) (if any)	Name of subsequent subtask (s) (if any)	Major drivers of energy consumption
Subtask 1					
Subtask 2					
Subtask 3					
Subtask 4					
Subtask 5					
Subtask 6					
Subtask 7					

2.40 Do you use electricity as energy type in the target process or any subtask?

- Yes
- No
- Don´t know

2.5 You mentioned that you consume electricity in the manufacturing process. Please provide the current average electricity consumption for the target process or any relevant subtask.

	Yearly	Monthly	Daily	Hourly
Target Process				
Subtask 1				
Subtask 2				
Subtask 3				
Subtask 4				
Subtask 5				
Subtask 6				
Subtask 7				

2.6 You mentioned earlier that you consume electricity in the manufacturing process. Please indicate how frequent electricity consumption measurements are available (if at all) for the target process or any relevant subtas.

	Every second	Every minute	Quarter-hourly	Hourly	Daily	Weekly	Monthly	Not available	Don't Know
Target Process	○	○	○	○	○	○	○	○	○
Subtask 1	○	○	○	○	○	○	○	○	○
Subtask 2	○	○	○	○	○	○	○	○	○
Subtask 3	○	○	○	○	○	○	○	○	○
Subtask 4	○	○	○	○	○	○	○	○	○
Subtask 5	○	○	○	○	○	○	○	○	○
Subtask 6	○	○	○	○	○	○	○	○	○
Subtask 7	○	○	○	○	○	○	○	○	○

2.7 You mentioned earlier that you consume electricity in the manufacturing process. Please specify the average number of Power Cuts and/or Downtime Duration for the most appropriate time period.

	Average Number of Power Cuts	Average Downtime Duration	Most usual reason(s)
Per hour			
Per day			
Per week			
Per month			

2.8 You mentioned earlier that you consume electricity in the manufacturing process. Please indicate how do you source electricity.

	Retail market (e.g., electricity supplier)	Wholesale market (e.g., power purchase agreement with an electricity producer, bids for electricity in the intraday market)	Self-production using stochastic renewable technologies (solar, wind, hydro, etc)	Self-production using raw material (natural gas, coal, etc.)	Other
Target Process	☐	☐	☐	☐	☐
Subtask 1	☐	☐	☐	☐	☐
Subtask 2	☐	☐	☐	☐	☐
Subtask 3	☐	☐	☐	☐	☐
Subtask 4	☐	☐	☐	☐	☐
Subtask 5	☐	☐	☐	☐	☐
Subtask 6	☐	☐	☐	☐	☐
Subtask 7	☐	☐	☐	☐	☐

2.9 You mentioned earlier that you consume electricity in the manufacturing process. Please indicate. How volatile is your electricity unit cost?

- Very volatile and spontaneous (e.g., prices are determined in intraday electricity market and may significantly vary, etc)
- Very volatile in short timescales (e.g., prices may significantly vary during peak and off-peak periods2)
- Very volatile but in longer timescales (e.g., prices may significantly vary on a weekly/monthly basis) Rather volatile and spontaneous (e.g., prices are determined in intraday electricity market and prices may slightly vary)
- Rather volatile in short timescales (e.g., prices may slightly vary during peak and off-peak periods)
- Rather volatile but in longer timescales (e.g., prices may slightly vary on a weekly/monthly basis)
- Rather static and spontaneous (e.g., prices are determined in intraday electricity market; yet prices exhibit low variation)
- Rather static in short timescales (e.g., prices usually don't vary during peak and off-peak periods)
- Rather static but in longer timescales (e.g., prices usually don't vary on a weekly/monthly basis)
- Static (e.g., prices are defined via long-term)
- Don't know

2.10 Do you use natural gas/ air as energy source in the target process or any subtask?

- Yes
- No
- Don´t Know

2.11 You mentioned that you consume natural gas/air in the manufacturing process. Please provide the current average gas/air consumption for the target process or any relevant subtask.

	Yearly	Monthly	Daily	Hourly
Target Process				
Subtask 1				
Subtask 2				
Subtask 3				
Subtask 4				
Subtask 5				
Subtask 6				
Subtask 7				

2.12 You mentioned earlier that you consume natural gas/air in the manufacturing process. Please indicate how frequent gas/air consumption measurements are available (if at all) for the target process or any relevant subtasks.

	Every second	Every minute	Quarter-hourly	Hourly	Daily	Weekly	Monthly	Not available	Don't Know
Target Process	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 1	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 2	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 3	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 4	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 5	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 6	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 7	◯	◯	◯	◯	◯	◯	◯	◯	◯

2.13 You mentioned earlier that you consume natural gas/air in the manufacturing process. Please specify the average number of Power Cuts and/or Downtime Duration for the most appropriate time period.

	Average Number of Power Cuts	Average Downtime Duration	Most usual reason(s)
Per hour			
Per day			
Per week			
Per month			

2.14 You mentioned earlier that you consume natural gas/air in the manufacturing process. Please indicate how you source this energy.

	Retail market (e.g., gas supplier)	Wholesale market (e.g., power purchase agreement, bids in wholesale market)	Other
Target Process	☐	☐	☐
Subtask 1	☐	☐	☐
Subtask 2	☐	☐	☐
Subtask 3	☐	☐	☐
Subtask 4	☐	☐	☐
Subtask 5	☐	☐	☐
Subtask 6	☐	☐	☐
Subtask 7	☐	☐	☐

2.15 You mentioned earlier that you consume natural gas/air in the manufacturing process. Please indicate. How volatile is your energy unit cost?

- ○ Very volatile and spontaneous (e.g., prices are determined in intraday wholesale market and may significantly vary, etc)
- ○ Very volatile in short timescales (e.g., prices may significantly vary during peak and off-peak periods)
- ○ Very volatile but in longer timescales (e.g., prices may significantly vary on a weekly/monthly basis)
- ○ Rather volatile and spontaneous (e.g., prices are determined in intraday wholesale market and prices may slightly vary)
- ○ Rather volatile in short timescales (e.g., prices may slightly vary during peak and off-peak periods)
- ○ Rather volatile but in longer timescales (e.g., prices may slightly vary on a weekly/monthly basis) Rather static and spontaneous (e.g., prices are
- ○ determined in intraday wholesale market; yet prices exhibit low variation)

- Rather static in short timescales (e.g., prices usually don’t vary during peak and off-peak periods)
- Rather static but in longer timescales (e.g., prices usually don’t vary on a weekly/monthly basis)
- Static (e.g., prices are defined via long-term) Don’t know
-

2.16 Do you use water as energy source in the target process or any subtask

- Yes
- No
- Don´t Know

2.17 You mentioned that water is an energy source of the manufacturing process. Please provide the current average water consumption for the target process or any relevant subtask.

	Yearly	Monthly	Daily	Hourly
Target Process				
Subtask 1				
Subtask 2				
Subtask 3				
Subtask 4				
Subtask 5				
Subtask 6				
Subtask 7				

2.18 You mentioned earlier that water is an energy source of the manufacturing process. Please indicate how frequent water consumption measurements are available (if at all) for the target process or any relevant subtask.

	Every second	Every minute	Quarter-hourly	Hourly	Daily	Weekly	Monthly	Not available	Don't Know
Target Process	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 1	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 2	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 3	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 4	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 5	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 6	◯	◯	◯	◯	◯	◯	◯	◯	◯
Subtask 7	◯	◯	◯	◯	◯	◯	◯	◯	◯

2.19 You mentioned earlier that water is an energy source of the manufacturing process. Please specify the average number of Power Cuts and/or Downtime Duration for the most appropriate time period.

	Average Number of Power Cuts	Average Downtime Duration	Most usual reason(s)
Per hour			
Per day			
Per week			
Per month			

2.20 You mentioned earlier that water is an energy source of the manufacturing process. Please indicate how do you source this type of energy.

	Retail market (e. g., district heating/cooling supplier)	Wholesale market	Self-production using stochastic renewable technologies (solar, wind, hydro, etc)	Self-production using electricity, natural gas, coal, etc.	Other
Target Process	☐	☐	☐	☐	☐
Subtask 1	☐	☐	☐	☐	☐
Subtask 2	☐	☐	☐	☐	☐
Subtask 3	☐	☐	☐	☐	☐
Subtask 4	☐	☐	☐	☐	☐
Subtask 5	☐	☐	☐	☐	☐
Subtask 6	☐	☐	☐	☐	☐
Subtask 7	☐	☐	☐	☐	☐

2.21 You mentioned earlier that water is an energy source of the manufacturing process. Please indicate. How volatile is your unit cost?

○ Very volatile and spontaneous (e.g., prices are determined in intraday wholesale market and may significantly vary, etc)

- Very volatile in short timescales (e.g., prices may significantly vary during peak and off-peak periods)
- Very volatile but in longer timescales (e.g., prices may significantly vary on a weekly/monthly basis)
- Rather volatile and spontanteous (e.g., prices are determined in intraday wholesale market and prices may slightly vary)
- Rather volatile in short timescales (e.g., prices may slightly vary during peak and off-peak periods)
- Rather volatile but in longer timescales (e.g., prices may slightly vary on a weekly/monthly basis) Rather static and spontanteous (e.g., prices are
- determined in intraday wholesale market; yet prices exhibit low variation)
- Rather static in short timescales (e.g., prices usually don’t vary during peak and off-peak periods)
- Rather static but in longer timscales (e.g., prices usually don’t vary on a weekly/monthly basis)
- Static (e.g., prices are defined via long-term contracts)
- Don’t know

2.22 Do you use any other energy source during the manufacturing process?

- Yes
- No
- Don´t Know

2.23 You mentioned above that you use an energy source other than electricity, gas/air and water. Please elaborate.

2.24 You mentioned that you consume additional energy sources in the manufacturing process. Please provide the current average consumption for this particular energy type in the target process or any relevant subtask.

	Yearly	Monthly	Daily	Hourly
Target Process				
Subtask 1				
Subtask 2				
Subtask 3				
Subtask 4				
Subtask 5				
Subtask 6				
Subtask 7				

2.25 You mentioned that you consume additional energy sources in the manufacturing process. Please indicate how frequent consumption measurements for this energy type are available (if at all) for the target process or any relevant subtask.

	Every second	Every minute	Quarter-hourly	Hourly	Daily	Weekly	Monthly	Not available	Don't Know
Target Process	○	○	○	○	○	○	○	○	○
Subtask 1	○	○	○	○	○	○	○	○	○
Subtask 2	○	○	○	○	○	○	○	○	○
Subtask 3	○	○	○	○	○	○	○	○	○
Subtask 4	○	○	○	○	○	○	○	○	○
Subtask 5	○	○	○	○	○	○	○	○	○
Subtask 6	○	○	○	○	○	○	○	○	○
Subtask 7	○	○	○	○	○	○	○	○	○

2.26 You mentioned earlier that you consume additional energy sources in the manufacturing process. Please specify the average number of supply interruptions and/or Downtime Duration for the most appropriate time period.

	Average Number of Supply Interruptions	Average Downtime Duration	Most usual reason(s)
Per hour			
Per day			
Per week			
Per month			

2.27 You mentioned that you consume additional energy sources in the manufacturing process. Please indicate how do you source this type of energy.

	Retail market	Wholesale market	Self-production using stochastic renewable technologies (solar, wind, hydro, etc)	Self-production using electricity, natural gas, coal, etc.	Other
Target Process	☐	☐	☐	☐	☐
Subtask 1	☐	☐	☐	☐	☐
Subtask 2	☐	☐	☐	☐	☐
Subtask 3	☐	☐	☐	☐	☐
Subtask 4	☐	☐	☐	☐	☐
Subtask 5	☐	☐	☐	☐	☐
Subtask 6	☐	☐	☐	☐	☐
Subtask 7	☐	☐	☐	☐	☐

2.28 You mentioned that you consume additional energy sources in the manufacturing process. Please indicate. How volatile is your unit cost?

- Very volatile and spontaneous (e.g., prices are determined in intraday wholesale market and may significantly vary, etc)
- Very volatile in short timescales (e.g., prices may significantly vary during peak and off-peak periods)
- Very volatile but in longer timescales (e.g., prices may significantly vary on a weekly/monthly basis)
- Rather volatile and spontaneous (e.g., prices are determined in intraday wholesale market and prices may slightly vary)
- Rather volatile in short timescales (e.g., prices may slightly vary during peak and off-peak periods)
- Rather volatile but in longer timescales (e.g., prices may slightly vary on a weekly/monthly basis)
- Rather static and spontaneous (e.g., prices are determined in intraday wholesale market; yet prices exhibit low variation)
- Rather static in short timescales (e.g., prices usually don't vary during peak and off-peak periods)
- Rather static but in longer timescales (e.g., prices usually don't vary on a weekly/monthly basis)
- Static (e.g., prices are defined via long-term)
- Don't know

2.29 Are there any activities (e.g., preheating) or infrastructure (e.g., battery system) that can “store” energy (or delay, expedite consumption)?

	Storage type
Target Process	
Subtask 1	
Subtask 2	
Subtask 3	
Subtask 4	
Subtask 5	
Subtask 6	
Subtask 7	

2.30 Do you participate in Demand Response (or Interruptible Load) activities, in which you are compensated for adjusting your power consumption in case of electricity grid instability, failures, etc?

- Yes
- No
- Don´t Know

2.31 Please specify

2.32 What is the currently assessed environmental footprint of the target process? Is this measurable and how?

	Amount (and/or type) of environmental footprint
Water-related emissions (e.g. Total Suspended Solids, Total Organic Carbon)	
Air-related Emissions (e.g. CO2-eq)	
Land-related emissions (e.g. Waste liters)	
Sound-related emissions (e.g. in dB)	
Recycling Material including those that are recycled by other industries (e.g. Kg)	

2.33 Are there any environmental challenges related to the target manufacturing process(es) and/or subtasks of ENERMAN?

- Yes
- No
- Not Relevant
- Don't Know

2.34 Please elaborate

2.35 Are there any human-related challenges (e.g. hazards, aging workforce) related to the target process, that you wish to address?

- Yes
- No
- Not Relevant
- Don't Know

2.36 Please elaborate

2.37 Are there any international standards applied or any gap in the international standards to cover this (e. g., ISO 14040/44 for life cycle analysis)

- Yes
- No
- Not Relevant
- Don't Know

2.38 Please elaborate

2.39 What is the current overall production cost of the target process?

- >=75% of total cost between 50%
- and 75% of total cost between 25%
- and 50% of total cost
- <25% of total cost

2.40 What is the magnitude of the current overall production cost?

- more than 500 M Euros between
- 100M and 500M Euros between
- 10M and 100M Euros between
- 1M and 10M Euros between
- 500K and 1M Euros between
- 100K and 500K Euros less than
- 100K Euros

2.41 What is the current energy efficiency of the target process and/or subtasks?

Please fill in all relevant KPIs

	Energy efficiency KPI
KWh/product unit	
Liters of fuel/ product unit	
KWh/personnel-hour	
Other (please specify)	

2.42 What is the decision-making process that is currently followed in the target process and/or subtasks?

2.43 What kind of decisions or actions can you take for the target process and/or subtasks?

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2.44 How much time does it take for the target process to be completed before applying the ENERMAN solution?

2.45 How many people are currently involved in the production line?

3 Section 3: Expectations from ENERMAN

3.1 How do you envision the ENERMAN solution fit to your current manufacturing process (e.g. in terms of time-management, decision-support system, data availability, resources management)? Do you target a specific process or metric to be addressed?

3.2 How ENERMAN is expected to interact with those processes?

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3.3 Are there any environmental challenges related to the manufacturing process to which ENERMAN will be applied, that you wish to address?

- Yes
- No
- Not applicable
- Don't Know

3.4 Please provide a description

3.5 What KPIs should be monitored in real-time?

3.6 What raports should be automatically generated?

3.7 Which part (if not the whole) of the process are you most interested in “digitally twin-ing" it?

3.8 What dynamic parameters of the target process are important to be acquired and monitored from the field in order to “digitally twin-ing" it? (e.g. set-point temperatures and humidity, water flow rate in heater exchanger, air flow rate in fan, etc.)

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3.9 Which part (if not the whole) of the process are you most interested in getting earlier warning /notifications and intelligent information/decisions about it?

3.10 What are your expectations as far as the digital twin approach is concerned?

3.11 In which part of the process (if not in the whole process) do you intend to use the ENERMAN Intelligent Decision Support System (IDSS)?

3.12 Where will you install (if required) the ENERMAN solution?

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3.13 Regarding the previous question, how interruptive do you think this will be in the usual manufacturing process (e.g., are there any user adoption issues foreseen)?

3.14 Will someone from the team be assigned to use solely the ENERMAN solution?

3.15 What is your time saving estimations/expectations as far as human-driven processes are concerned?

3.16 How do you intend to (re-)assign the personnel that might not be needed in case of a full setup and expected installation/running of the ENERMAN solution?

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APPENDIX B: N-GRAM REPRESENTATION OF THE TEXT MINING ANALYSIS RESULTS

bigram	count	Log Likelihood	3gram	count	frequency	4gram	count	frequency
of the	78	230.7206681	in order to	13	0.351351351	of the target processes	5	0.135135135
should be	26	166.5385862	be able to	9	0.243243243	process in order to	4	0.108108108
EnerMan solution	14	134.2989556	of the target	8	0.216216216	should be able to	4	0.108108108
central server	10	121.5994228	of the process	7	0.189189189	No No Answer energy	4	0.108108108
in order	13	107.1364106	the target processes	7	0.189189189	ML and AI algorithms	4	0.108108108
digital twins	8	93.51045046	should be installed	6	0.162162162	should be installed in	4	0.108108108
energy consumption	17	91.33639048	the central server	6	0.162162162	on a central server	4	0.108108108
order to	13	89.84082096	the EnerMan solution	6	0.162162162	Bodyshop environmental air conditioning	3	0.081081081
able to	13	89.84082096	it should be	6	0.162162162	environmental air conditioning system	3	0.081081081
No Answer	7	77.76521748	be installed in	6	0.162162162	to minimize energy consumption	3	0.081081081
flow rate	6	75.66086265	EnerMan solution should	6	0.162162162	of the target process	3	0.081081081
target processes	7	63.615794	of the production	5	0.135135135	acquired from the field	3	0.081081081
based on	7	63.20992252	the temperature and	5	0.135135135	dynamic parameters that are	3	0.081081081
AI algorithms	4	62.65131198	of the system	5	0.135135135	parameters that are important	3	0.081081081
from the	20	59.01259668	No Answer energy	5	0.135135135	that are important to	3	0.081081081
digital twin	5	56.99132581	resulting from the	5	0.135135135	are important to be	3	0.081081081
be able	9	56.77686705	consumption of the	5	0.135135135	important to be acquired	3	0.081081081
installed in	8	55.28594873	from the field	5	0.135135135	to be acquired from	3	0.081081081
end users	4	55.01314196	No No Answer	4	0.108108108	be acquired from the	3	0.081081081
be installed	8	54.54396203	data from the	4	0.108108108	and flow rate measures	3	0.081081081
feedback actions	4	51.56095709	installation of the	4	0.108108108	to be able to	3	0.081081081

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bigram	count	Log Likelihood	3gram	count	frequency	4gram	count	frequency
use case	5	50.81119992	of the building	4	0.108108108	and finally the signals	3	0.081081081
In fact	4	50.2860036	at the moment	4	0.108108108	e.g ON/OFF status of	3	0.081081081
hot water	5	50.0893905	the end-node meters	4	0.108108108	the operation of the	3	0.081081081
ON/OFF status	3	48.71214756	should be able	4	0.108108108	about the operation of	3	0.081081081
Handling Unit	3	48.71214756	should not affect	4	0.108108108	signals about the operation	3	0.081081081
carbon footprint	3	48.71214756	the energy consumption	4	0.108108108	the signals about the	3	0.081081081
resulting from	5	48.69494328	air conditioning system	4	0.108108108	finally the signals about	3	0.081081081
end-node meters	4	47.37497194	parameters that are	4	0.108108108	rate measures of the	3	0.081081081
will be	9	46.73759429	the target process	4	0.108108108	energy consumption of the	3	0.081081081
the target	11	46.47287505	in all our	4	0.108108108	flow rate measures of	3	0.081081081
decision-support system	5	45.68158408	application of EnerMan	4	0.108108108	temperature and flow rate	3	0.081081081
in the	26	44.89047252	server should be	4	0.108108108	the temperature and flow	3	0.081081081
base loads	3	44.2134664	on the utilities	4	0.108108108	are represent by the	3	0.081081081
decision support	3	44.2134664	utilities of the	4	0.108108108	field related to the	3	0.081081081
topcoat booth	3	44.2134664	energy consumption of	4	0.108108108	the field related to	3	0.081081081
to be	17	43.64567579	process in order	4	0.108108108	from the field related	3	0.081081081
energy flows	5	42.38795516	involved in the	4	0.108108108	ON/OFF status of the	3	0.081081081
e.g ON/OFF	3	41.98203089	the digital twins	4	0.108108108	resulting from the usage	3	0.081081081
signals about	3	41.98203089	on a central	4	0.108108108	and where is the	3	0.081081081
data from	7	41.37791731	the type of	4	0.108108108	Unit of topcoat booth	3	0.081081081
that are	8	40.46624226	a central server	4	0.108108108	Handling Unit of topcoat	3	0.081081081
rate measures	3	40.39438139	our use case	4	0.108108108	Air Handling Unit of	3	0.081081081
interact with	4	40.32651484	EnerMan system should	4	0.108108108	with the EnerMan solution	3	0.081081081
conditioning system	5	40.29438045	installed in the	4	0.108108108	from the usage of	3	0.081081081
help us	3	39.71532549	The EnerMan solution	4	0.108108108			

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bigram	count	Log Likelihood	3gram	count	frequency	4gram	count	frequency
not affect	4	39.65905399	that should be	4	0.108108108			
field related	3	39.15143409	ML and AI	4	0.108108108			

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