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Autonomous self powered miniaturized intelligent sensor for environmental sensing and asset tracking in smart IoT environments

AMANDA

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Deliverable

D1.3 Voice-of-the Customer completed

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List of definitions & abbreviations

Abbreviation	Definition
ADC	Analog to Digital Converter
ASSC	Autonomous Smart Sensing Card
BLE	Bluetooth Low Energy. Now known as Bluetooth Smart
DCS	Distributed Control System
FMCG	Fast Moving Consumer Goods
GSM	Global System for Mobile communications
IIoT	Industrial Internet of Things
IoT	Internet of Things
IP	Intellectual Property
LED	Light Emitting Diode
LoRa	Long Range
LPWAN	Low-Power Wide-Area Network
MCU	Microcontroller Unit
MID	Molded Interconnect Devices
MPPT	Maximum Power Point Tracking
NFC	Near Field Communication
OT	Operational Technology
PCB	Printed Circuit Board
PMIC	Power Management Integrated Circuit
POE	Power Over Ethernet
PV	Photovoltaic
RF	Radiofrequency
RTC	Real Time Clock
USB	Universal Serial Bus
VOC	Volatile Organic Compound

Executive Summary

This report is part of **WP1 - System Specifications, Requirements and Use Cases** of the AMANDA project. The aim of WP1 is to provide an overall framework for the project, to ensure a common reference point regarding the system requirements that arise from use analysis and to provide overall considerations and guidelines with respect to the solutions introduced. Deliverable D1.3 presents the initial end-user requirements and specifications as part of **Task 1.2: System requirements and needs**, the result of a thorough discussion with end users (including Penta) and investigation of different scientific and commercial resources. The recent advances in the research and development of the technologies used in the AMANDA ASSC (including PV Energy Harvesters, Sensors, Battery, MCUs and wireless communication components) will either improve existing applications, or enable new applications and use cases. Finally, this document proposes a list of recommendations to give further directions for the AMANDA project.

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1 Introduction

1.1 Purpose, Context and Scope of this Deliverable

This Deliverable presents initial requirements and specifications for technologies related to the AMANDA ASSC, focusing on complete use case scenarios. Use cases encompass various applications such as building automation, smart cities, industrial IoT and wearables. Moreover, a list of recommendations is proposed to give further directions for the AMANDA work as part of **Task 1.2: System requirements and needs**. Task T1.2 has a focus on cutting edge technologies developed within the scope of this project and on the way these technologies can meet the requirements of specific use cases identified amongst end users.

This document is structured as follows: Section 2 describes the Voice of the Customer methodology and outcome. In Section 3, detailed use cases (classified in key application areas) are presented, with a focus on qualitative and quantitative requirements. In Section 4, a list of functional and non-functional requirements is given. In Section 5, the core ASSC platform that will be developed in the duration of the AMANDA project is described. Section 6 outlines the different versions of the AMANDA ASSC. Section 7 proposes recommendations to give further directions for the project. Finally, in Section 8, the conclusions of this Deliverable are drawn and further work is discussed.

2 Voice of the Customer

2.1.1 Methodology

AMANDA is a research and innovation project that aims to develop and validate a cost-attractive next generation ASSC. It relies on technological innovations that will be implemented in various forms of human activity. The multi-sensing ASSC should be directly applicable with concrete use cases and trigger new opportunities to improve living and working conditions within the scientific and industrial community.

Determining the end users' needs and wishes is usually a useful and coherent way to show the direction of research and to express the need for innovation. The end users provide directions for development and research. To identify the needs of stakeholders, the following multi-step procedure was used.

First, the stakeholders were identified, based on their involvement with sensing applications; either as members of the scientific community, business partners or end users. Among the users contacted, included industrial partners, local governments as well as the academic community.

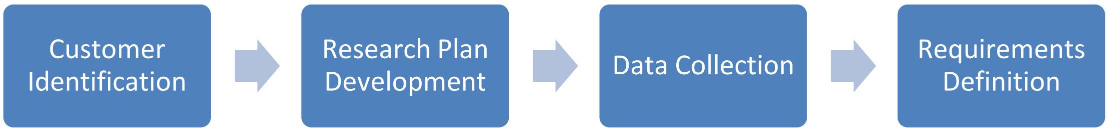

Figure 1 Voice of the Customer methodology

Then, a research plan for the Voice of the Customer was developed. This included the introduction of the research method, the development of the research procedure and the identification of the questions to be asked. Before answering specific questions, the end users were made familiar with the key concept and objectives of the AMANDA project. Moreover, the potential technical features of the AMANDA ASSC were presented. Some of the basic questions to potential customers included the following:

- What are some typical use cases?
- How is any sensor system you have deployed currently powered?
- What type of data transmission is currently used?
- Are there any improvements that you wish to implement to a current solution?
- Which sensors would you consider as the most important for your application?
- What is a sensor functionality that you would like to target?
- What would be the frequency of measurements required for your application?
- In the case of wireless data transmission, what would be the ideal range?
- What is the type of lighting condition in the deployment area?
- Do you need to record the data on the card?

The next step involved the collection of the customer needs and their categorization into groups with common characteristics. For the data collection, different methods were used; surveys and interviews were conducted, focus groups were organized where stakeholders were gathered and asked to share their needs related to the project and phone interviews were arranged. Some questionnaires were also sent electronically to selected end users from the consortium customer database. In order to reach a broader audience, the digital database of the Chamber of Economy of Croatia was also consulted by Penta. A total of more than 50

participants from 15 companies and research centres have been contacted. An analysis of a part of the data is given in Section 2.1.2 below.
Finally, the needs and issues of the stakeholders were translated into user and business requirements. Users' needs and requirements were covered for different use cases, both indoors and outdoors. In most scenarios, autonomy and small size are key features for the users, including the ability to have many sensors within a small footprint. End users should have the possibility to upgrade existing applications with the AMANDA ASSC, incorporating or retrofitting it into their system. The AMANDA multi-sensing card should enable the development of a range of new, widely available and applicable services and applications, based on its sensing and wireless capabilities. The result of this step is presented in Section 4.
A summary of the methodology followed as part of this Deliverable is depicted in Figure 1.

2.1.2 Analytics

The answers from all participants have been split into several applications, including building automation, smart cities, smart agriculture, wearables and industrial IoT.
Building automation and wearable device use cases are based on answers collected amongst experts from the field within IMEC organisation, including business developers aware of the market trends and customer's needs. Smart cities and IIoT use cases were defined based on specific questionnaires submitted by Penta and CERTH and following the methodology described earlier. Other types of applications have been identified through direct discussion with end users and via discussions at industry conferences, workshops and tradeshows.
The questionnaire requested initially for contact details such as name, email and area of expertise. Basic analytics regarding the IIoT group of participants is shown herein since this group gathered the largest number of responses.

2.1.2.1 Participants

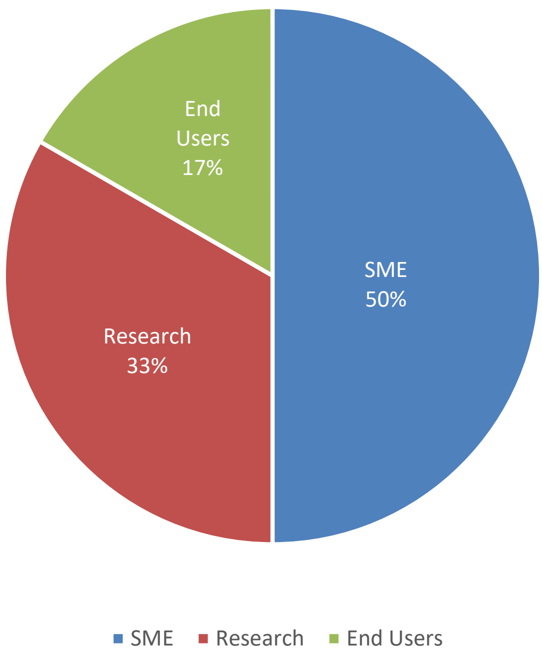

Figure 2 Questionnaire participants

Figure 2 provides an overview of the participating stakeholders to this query. As it becomes evident the questionnaire managed to cover diverse backgrounds and point of views that contribute to an extended overview of the industry needs for the IoT sector.

2.1.2.2 Are you currently using any sensor platform/IoT solution?

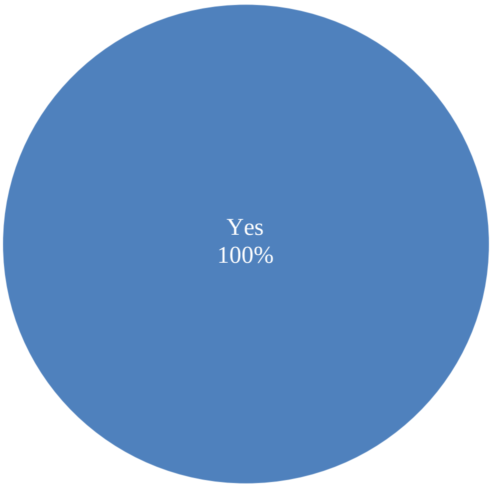

Figure 3 Adoption of IoT solutions

Figure 3 presents how many of the participating companies are already using IIoT solutions which constitutes that there is a high demand from companies for such solutions that will help them improve their products or services.

2.1.2.3 How is your sensor system powered currently?

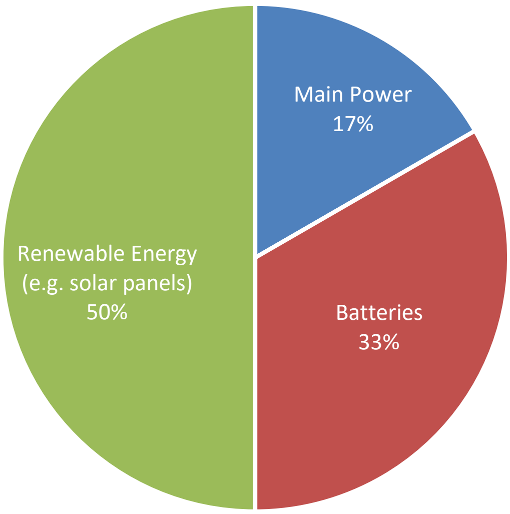

Figure 4 IoT power management

Additionally, the survey included a question regarding power management for existing solutions, as shown in Figure 4. Most of the companies prefer renewable energy sources for their IoT solutions.

2.1.2.4 What type of data transmission is used?

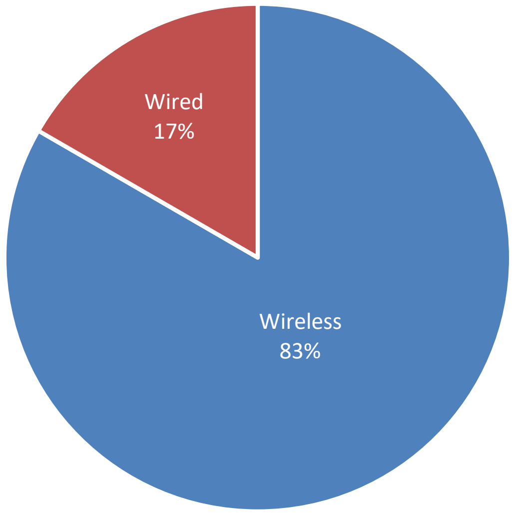

Figure 5 Types of data transmission

Moreover, the survey included a question regarding the way the gathered data is distributed within their company's systems, as shown in Figure 5. Most of the companies required for a wireless data in order to provide mobility to their solutions.

2.1.2.5 What are the desired sensors for your target application?

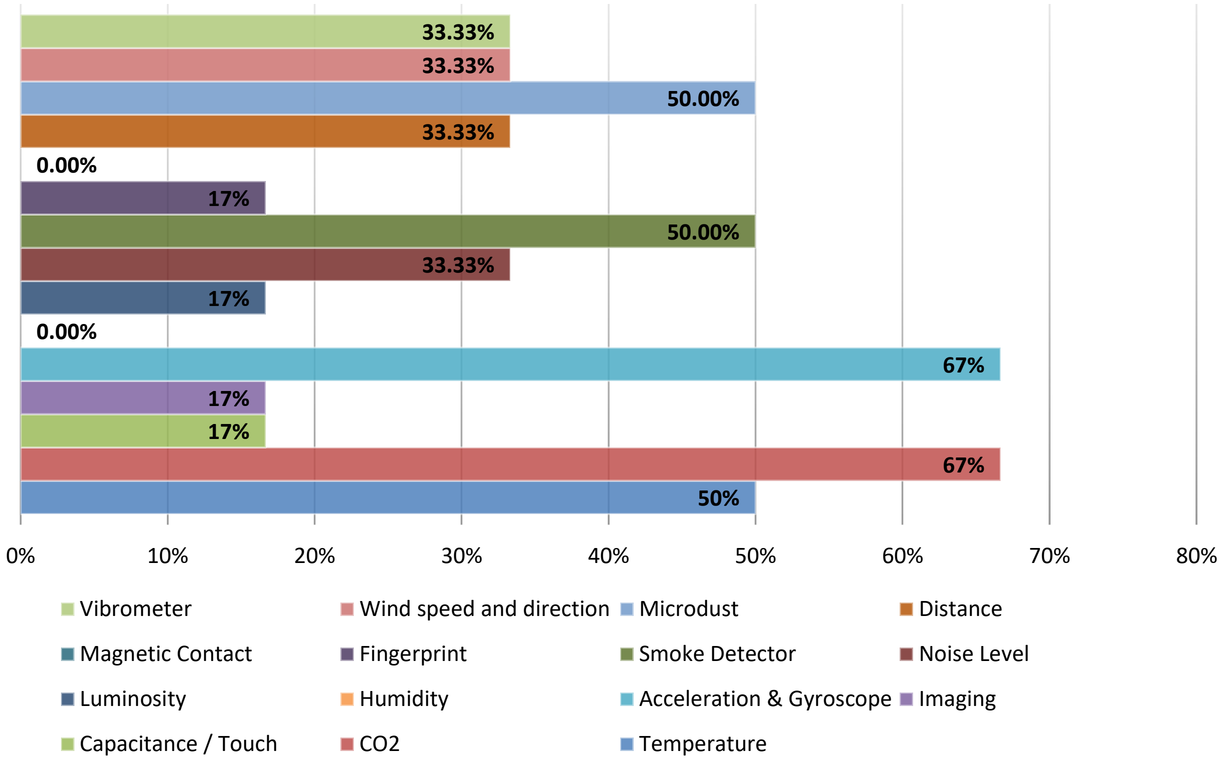

Figure 6 Desired sensors

Then, there was an open question regarding the improvement the stakeholders would like to implement to their current systems and a question regarding specific sensors they would desire this system to include. The needs in sensors can be seen in Figure 6, and include CO_2, acceleration, temperature, smoke detection and microdust sensors.

2.1.2.6 What would be some additional desired hardware options?

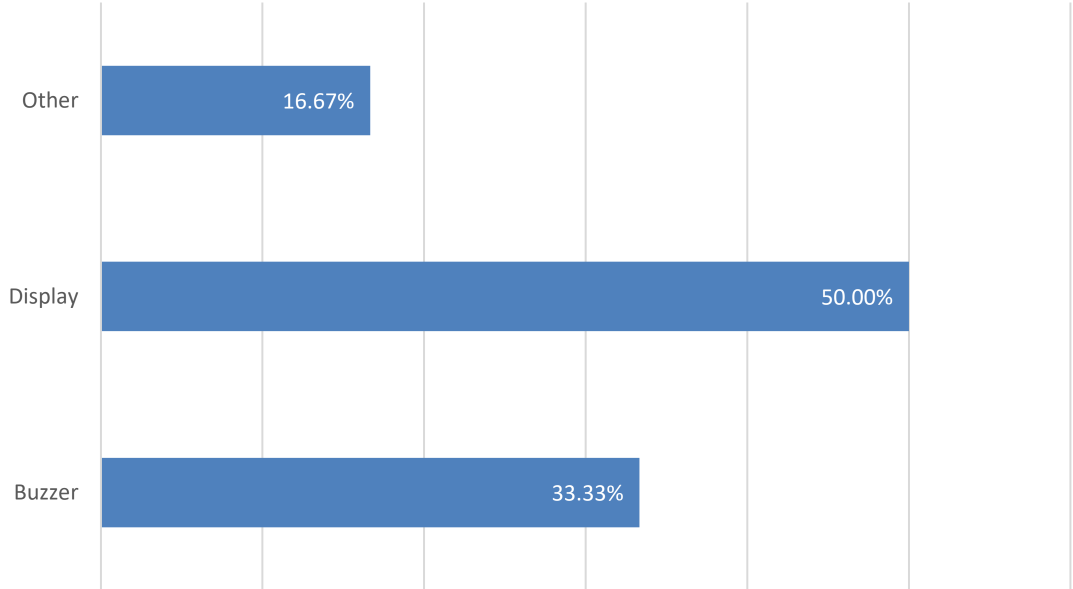

Figure 7 Desired hardware options

The next query was about the hardware that the stakeholders wished the system to include. Those hardware and sensor needs become obvious in Figure 6 and Figure 7, information that is exploited for the ASSC's system and architecture design.

2.1.2.7 Is power autonomy or "place and forget" capability necessary for this solution?

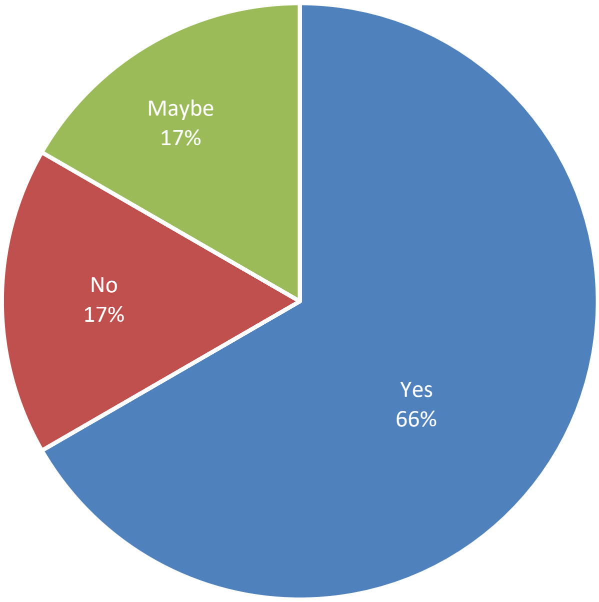

Figure 8 Power autonomy needs

Apart from the aforementioned queries, the survey included some questions regarding the details of any specific use case or function the applicant companies might want to include, as well as the frequency of their needed measurements, the ASSC's installation location (as it is shown, the ideal wireless data transmission range (if needed), the system's battery autonomy (in hours) in dark conditions, as shown in Figure 8, whether there are size constraints regarding a similar platform and what the expected lifetime of such a device would be from their perspective.

2.1.2.8 Does the installation space have access to light? If so, what type of light?

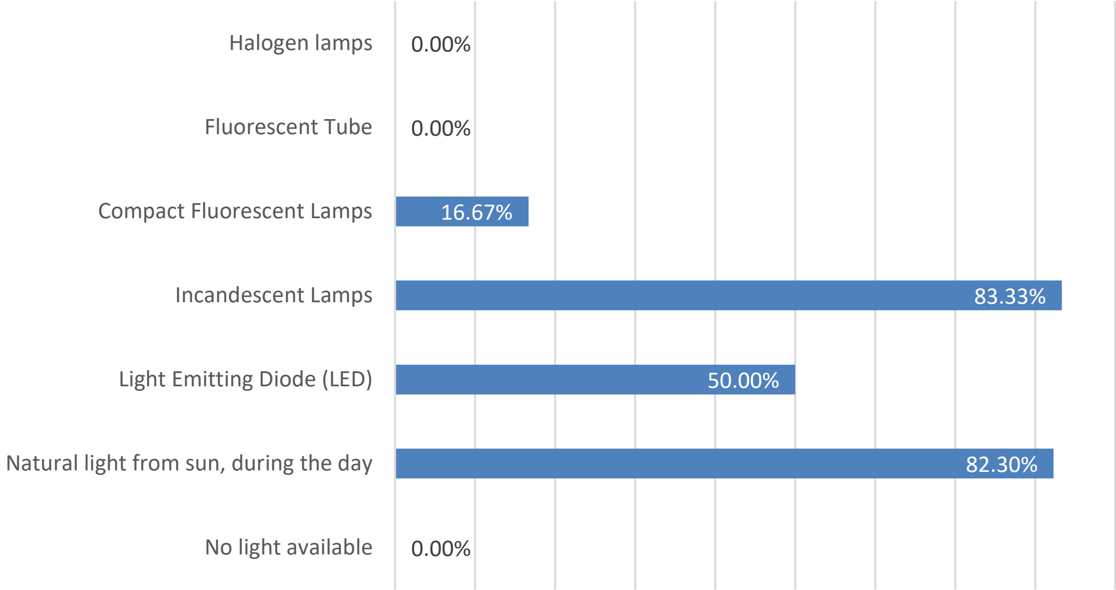

Figure 9 Light emission conditions of the workplace

Furthermore, an overview of the light conditions surrounding the ASSC's environment was gathered, as shown in Figure 9, to ensure the full functional potential of the energy harvester that will be used in the AMANDA implementation.

2.1.2.9 Is retrofitting with your existing solution an important criterion to implement this platform?

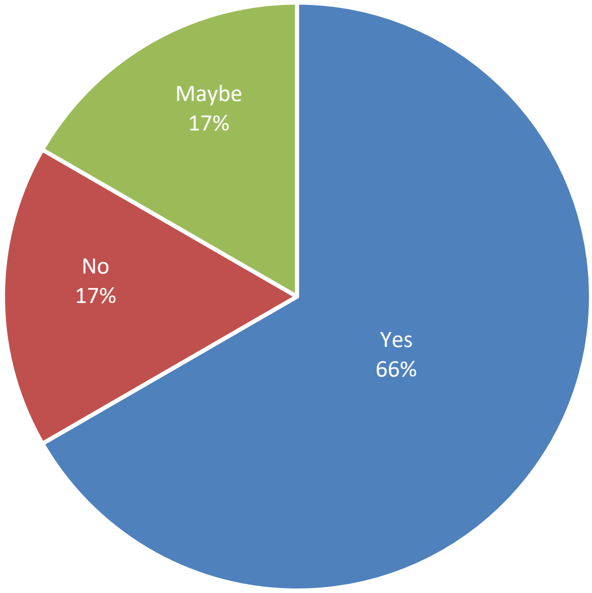

Figure 10 Need for retrofitting of new solutions to the existing

Additional questions were included that could provide better insight on the details provided from the stakeholders and would decipher the exact interfacing needs of the Industry, as presented in Figure 10, and the AMANDA ASSC's role as an IIoT solution.

2.1.2.10 How critical/useful would AMANDA ASSC be for your company?

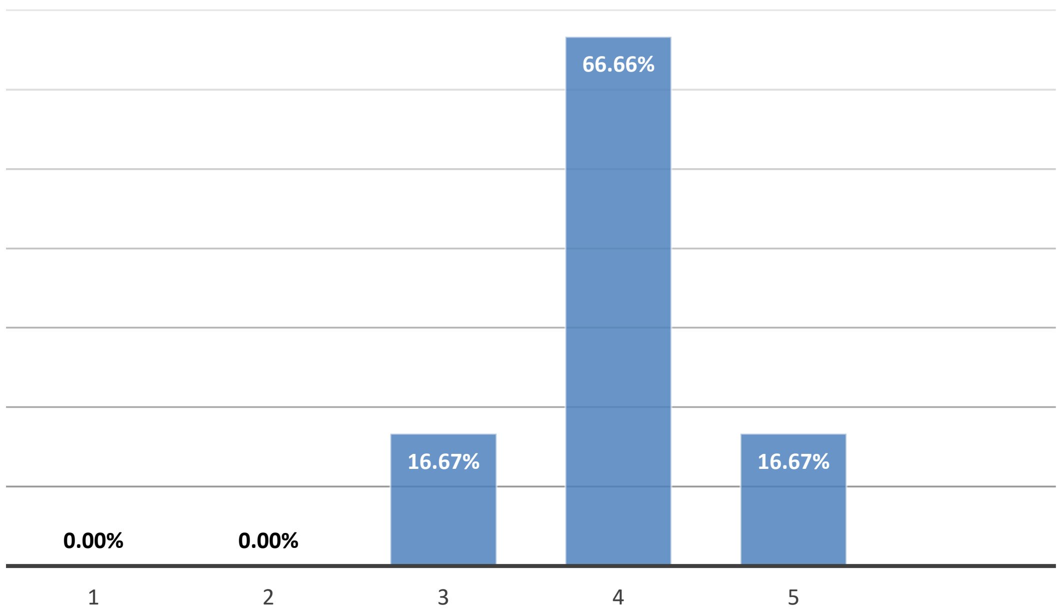

Figure 11 Usefulness/urgency of AMANDA ASSC for the industry

Lastly, with the intention to ensure the capacity for the AMANDA ASSC to be considered a reliable IIoT solution; a question regarding the usefulness, and how critical a platform that would include the previously requested capabilities would be for the Industry and is shown in Figure 11. All the aforementioned replies from the stakeholders were gathered, analysed and clustered in order to compose the use cases that are detailed in the rest of this document.
The users were asked about the suitability of the four sensors developed during AMANDA for their use case. Table 1 below presents the results in key application areas. Some of these use cases, detailed in Section 3, will require additional off-the-shelf sensors and fitting enclosures. The three options are: the sensor is useful for the use case (), the sensor is potentially useful for the use case (), the sensor is not useful for the use case (). The use cases investigated as part of the AMANDA project and detailed in Section 3 are highlighted in bold in both Table 1 and Table 2.

Application (A)	Use cases (UC)	**Sensors**			
		CO_2	Imaging	Temperature	Touch
A1: Building automation	UC0: Open/close window or door				
	UC1: Environmental room indicator				
	UC2: Automated room controller				
	UC3: Adaptive room controller				
A2: Smart cities	UC4: Parking slot occupancy				
A1: Building automation A2: Smart cities	UC5: Weather Station				
A1: Building automation A2: Smart cities	UC6: Air quality station				
A2: Smart cities *A4: Wearables*	UC7: Personal identification card with toxic gas detector				
A2: Smart cities	UC8: FMCG tracking and monitoring for food delivery)				
A1: Building automation A2: Smart cities	UC9: People counting/occupancy				

A2: Smart cities	UC10: Asset tracking (outdoor)				
	UC11: Data Mapping (on movable asset e.g. bus)				
	UC12: Event trigger/feedback collection				
A2: Smart Cities A4: Wearables	UC13: Payment device (smart card)				
A2: Smart Cities A5: Industrial	UC14: Fire detection				
A3: Smart agriculture	UC15: Cattle tracking				
	UC16: Smart irrigation				
A4: Wearables	UC17: Behaviour monitoring				
A5: Industrial	UC18: Cargo transportation conditions				
	UC19: Asset tracking (indoor)				
	UC20: Worker comfort level monitoring				
	UC21: Workplace information delivery				
A4: Wearables A5: Industrial	UC22: Fall/change detection/Intruder alarm				
Other applications	UC23: Health and condition monitoring				
	UC24: Aircraft cabin interior monitoring				
	UC25: Automotive sensing and cabin interior monitoring				
All	UC26: General data logging				

Table 1 End user requirements

Moreover, the end users were asked about the required type of wireless connection, as shown in Table 2:

Use cases (UC)	RF Chip alternatives
UC0: Open/close window or door	BLE, LoRa, Nb-IoT
UC1: Environmental room indicator	BLE, WiFi, Zigbee
UC2: Automated room controller	BLE, WiFi, Zigbee
UC3: Adaptive room controller	BLE, WiFi, Zigbee
UC4: Parking slot occupancy	LoRa, Nb-IoT
UC5: Weather Station	BLE, LoRa, Nb-IoT
UC6: Air quality station	BLE, LoRa, Nb-IoT
UC7: Personal identification card with toxic gas detector	BLE, LoRa, Nb-IoT
UC8: FMCG tracking and monitoring for food delivery)	Lora, Nb-IoT, Sigfox
UC9: People counting/occupancy	BLE, LoRa, Nb-IoT
UC10: Asset tracking (outdoor)	LoRa, Nb-IoT, Sigfox
UC11: Data Mapping (on movable asset e.g. bus)	LoRa, Nb-IoT
UC12: Event trigger/feedback collection	BLE, LoRa, Nb-IoT
UC13: Payment device (smart card)	Nb-IoT
UC14: Fire detection	LoRa, Nb-IoT, Sigfox
UC15: Cattle tracking	LoRa, Nb-IoT, Sigfox
UC16: Smart irrigation	LoRa, Nb-IoT, Sigfox
UC17: Behaviour monitoring	BLE
UC18: Cargo transportation conditions	Lora, Nb-IoT, Sigfox
UC19: Asset tracking (indoor)	BLE, LoRa
UC20: Worker comfort level monitoring	BLE, LoRa
UC21: Workplace information delivery	Lora, Nb-IoT, Sigfox
UC22: Fall/change detection/Intruder alarm	BLE, LoRa, Nb-IoT
UC23: Health and condition monitoring	BLE, Nb-IoT
UC24: Aircraft cabin interior monitoring	BLE

UC25: Automotive sensing and cabin interior monitoring	BLE, Nb-IoT
UC26: General data logging	Any

Table 2 RF chip alternatives

Based on the feedback from end users, the AMANDA Partners have created some conceptual solutions for the ASSC architecture, detailed in Deliverable 1.2.
From the Voice of the Customer, it is clear that a rapidly growing awareness of air quality and health-related issues is creating some enthusiasm for intensive research and development of solutions that will satisfy the primary and advanced standards of health and safety, whilst ensuring energy and cost savings.
The outcome of the AMANDA ASSC will be tested and implemented in the most feasible application areas among the ones identified in this document. Further work will try to explore and develop an ASSC platform that will largely meet the needs of end users. Since different sensors and RF connectivity will be required depending on the application, several designs of the ASSC will have to be considered. The next Section describes possible applications and corresponding technical requirements.

3 Use cases scenarios

This Section presents the specific use cases and end-user requirements for each application. Functional and non-functional requirements of these selected use cases are then derived in Section 4. The ASSC will include different sensors developed by the AMANDA Partners as part of the project, including temperature, touch, CO_2 and imaging sensors, the photovoltaic energy harvester, solid-state battery, power management (PMIC) and the main system MCU. The ASSC will also include additional off-the-shelf components and peripherals that will be optimized and integrated as part of the AMANDA project. This includes additional sensors required by the use cases, RF chipsets and feedback components, such as displays, indicators and buzzers, a memory module (FRAM), and timers (RTC). The required device functionality is discussed for each use case, followed by a qualitative analysis, including the type of sensors and other components as well as a quantitative analysis of its power consumption, footprint and cost.

3.1 Building automation

3.1.1 Key end-user requirements

Future building automation systems will be based on multi-functional sensors that form a control system which continuously interprets observed information, as received from the direct environment and from the Internet. Relying on the combined data of sensors, this control system will make decisions to automatically adjust building parameters, its device settings or to alert the stakeholders of the system. Commercial systems today already have advanced functionality but are still far from such perceptive sensing system. Today's existing building automation functions control lighting, heating, ventilation, shutters, sun blinds, windows, doors and more. This is typically done from a central place indoors, with an interface such as a touchscreen, a tablet or a smartphone.

There is a transition from wired to wireless sensing. The previously wired thermostat concept with temperature, humidity and CO_2 sensors placed in every room is evolving towards standalone devices which users can place in their home or building. These devices presently include wireless connectivity to a building control system or to services located in the cloud.

Several types of network technologies and wireless communication protocols are appearing in homes and buildings, including WiFi, BLE Thread and Zigbee.

The end-user requirements for building automation applications can be split into two different themes:

- Intelligent energy management (cost saving)
- Personal comfort and health (experience)

Building automation systems that focus on comfort and health do take additional parameters into account, including relative humidity and CO_2 concentration. Combined with temperature information, these parameters can determine the comfort level that a person experiences within the building. Well-known examples include dry air which can be sensitive for the eyes and skin of people or very humid air which feels heavy and tiresome for breathing. The last decade there was an increase concern towards the concentration of CO_2, with excessive levels causing discomfort, dizziness and negatively impacting the performance of people. In particular, persons in school classrooms and professional meeting rooms may suffer from too high CO_2 levels. Legislations are in place in many countries aiming to keep the typical CO_2 levels below 1000ppm. However, in practice there are no regular checks and building ventilation and automation systems are not fully prepared for providing an optimized air quality in every situation. The future building automation systems are expected to operate dynamically; high-rate ventilation where the air quality is poor and reduced ventilation when there is no need (unoccupied rooms for example) in order to save cost and energy. This can only be realized when accurate sensor data is available in real time.

The sensing device functionality for the building automation application of the AMANDA ASSC will be focused on temperature, relative humidity and CO_2 levels. Examples of additional parameters that could provide extra functionality are the amount of light in lux or the sound pressure in dB.

3.1.2 Specific use cases (UC)

The way towards a fully automated building can be described through a few intermediate use cases.

3.1.2.1 Environmental room indicator (UC1)

A first use case includes the provision of feedback to building occupants about the environmental parameters measured by sensors installed in the room. In the case where the air quality is not optimal, a user can receive an alert via a red blinking LED on the card or via a text message on their mobile phone. Such an indicator can provide direct feedback to building occupants about the air quality, but a direct action must be performed by them, for example by setting the ventilation to a higher flow rate or opening the windows. A similar approach can be followed for feeding back information on light level conditions or sound levels (noise).

3.1.2.2 Automated room control (UC2)

The automated room use case describes a reactive system that acts upon the actual sensor reading from each individual room. The system uses data from the sensors on the ASSC. That information is sent to the control system where decisions are made to adapt the set point for the various actuation options of the specific room. Ventilation-rate, sunshields, air-humidifiers, window open control systems and other components can be involved in order to maintain an optimum environment for the user. As a result, the cost of heating and cooling can also be reduced since the temperature of each room can be set to the lowest point when it is not in use.

3.1.2.3 Predictive and adaptive building environmental control (UC3)

A smart building approach combines input or information from several sources; from the sensors located within a building, from the Internet (e.g. room booking system) or weather predictions and from historical usage trends (e.g. occupancy of the rooms over time, UC10). This approach makes use of a central control system where inputs are processed by algorithms that can provide optimal environmental conditions to the building users at all times and minimum cost. One example would be the redirection of the ventilation flow from offices towards a meeting room in case the offices are not occupied and the people are gathered in the meeting room.

3.1.3 Qualitative analysis

For building automation, the AMANDA ASSC will preferably be located close to the building users, in order to collect relevant sensor data. For commercial buildings this may be in offices or other workspaces such as meeting rooms or the canteen. For private homes, this may be in the living room, the kitchen or the bathroom.

For this application, the most relevant sensors include temperature, relative humidity and CO_2. These 3 parameters cover both intelligent energy management and personal comfort and health scenarios.

The energy management is based upon heating and cooling, where temperature and humidity levels are controlled by the air conditioning system. An intelligent energy management system should minimize the heating and cooling costs while maintaining the temperature and relative humidity within a required range.

Personal comfort is determined by the combination of temperature, relative humidity and CO_2 levels. In the case of high CO_2 levels (e.g. above 1000 ppm), the air quality is perceived as poor and may cause a tiredness feeling, headaches and concentration loss, ultimately resulting in a significant drop in performance. Therefore, not only the temperature and relative humidity should be controlled, but also the ventilation air flow in order to renew the air such that the CO_2 levels remain below 1000ppm.

Light and sound pressure sensors can provide additional functionality about ambient light and noise levels respectively.

Several indoor communication protocols may be used for wireless communication of the sensor data (WiFi, BLE, or Zigbee). In some cases, the sensors may be static and power can be provided by wires (mains, USB or POE). Using indoor energy harvesting devices can provide installation flexibility and energy autonomy to these systems and reduce installation costs (wired systems) or system maintenance altogether (battery replacements).

3.1.4 Quantitative analysis

The building automation application requires a relatively low sample rate: since environmental changes are slow, a 30-seconds interval should be sufficient. Furthermore, the sample rate could even be lowered when the rooms in a building are not occupied (for example, an individual office at night). Therefore, from a power-saving perspective, it would be advantageous to power down the sensors between the measurement and RF transmission cycles.

The footprint requirements of the device will be determined by practical and aesthetic aspects. The latter depends mostly of the end users' requirements. For a working environment, such as an office, it is often acceptable for rugged devices to be visible. For residential use, the design, colour and form factor of devices can play an important role towards the end user acceptance. A residential home end user is expected to be more critical on the look and appearance of an environmental monitoring device.

In building automation, the devices are foreseen to be located at well illuminated places, such as desks, cabinets or near a window or to be wall-mounted like conventional thermostats.

According to the information available in Deliverable D1.2, Table 3 below summarizes the components required to meet the building automation use cases. This has been taken into account for the design of the ASSC indoor version, as detailed in Section 5.

Sensor type	Power consumption					Dimensions
	Quiescent current (lowest sleep mode/OFF)	Quiescent current (standby mode)	Wake-up current	Active current	Peak current	
Audio	Sleep: 3µA max. 10µA	No standby, either sleep or operation	n/a	600µA	n/a	3.35 x 3 x 1mm
CO_2/Smoke Detector	4µA/switch off externally	2mA	20mA	Average:20mA	Peak:30mA	5 x 10 x 1mm
Humidity	n/a	Sleep mode 0.15µA	n/a	RH, P, T: 3.7µA @ 1Hz		2 x 2 x 0.75mm
Capacitive	50nA	50nA 720nA (oscillator enabled for periodic measurement)	n/a	Average: 770nA at 2 measurements / sec 1.5uA at 32 measurements / second	11µA	1.52 x 1.03 x 0.64mm
Light	Power down: 0.3-0.4µA	-	n/a	Active: 1.8-3.7µA	n/a	2 x 2 x 0.65mm
Temperature	15nA max. 20nA	15nA max. 20nA	n/a	Average: 80nA	Peak: 75µA	1.39 x 0.93 x 0.84mm
PV	-	-	-	-	-	10 x 10 x 1.5mm
Battery	10nA		-	-	-	25.5 x 10 x 0.7mm
MCU	280nA	850nA (RTC + 8kB SRAM retention)	n/a	29µA/MHz	n/a	10 x 10 x 1.2mm
PMIC	200nA		n/a	n/a	n/a	5 x 5 x 1mm

FRAM	9µA	n/a	n/a	0.8mA (Max@10 MHz)	n/a	2 x 3 x 0.7mm
BLE	Deep Sleep, IO Wake–up, 25nA	With 32KHz running and data retention 100nA	-	Peak Tx: 4.6mA (3V. 0dBm) Peak Rx: 3.0mA (3V)	-	6.4 x 6.4 x 1mm

Table 3 Power consumption and footprints of the components for building automation

It is often difficult to determine the highest acceptable price for a product on the market. There are many ways to estimate it. One straightforward way is to observe the price of competitive products already on the market, and then adjust the price of the new product accordingly. Products with the functionality described earlier in this Deliverable do not currently exist on the market. It is therefore impossible to estimate an acceptable price point in this way. However, it is possible to do a comparison with similar groups of products, such as the Philips Hue starter kit. It is used for house lighting management and automation. The current price for the Philips Hue starter kit is 160 euro per kit. A single node included in the kit costs around 50 euro. We expect a similar price range in building automation is likely to be acceptable for the AMANDA ASSC.

3.2 Smart cities

Smart cities are betting their future on digital networked technology that is utilized to redesign aspects of everyday life and to address urgent problems. Of the many tasks that need to be realized in smart cities, this Section is focused on:

- The need to create smart mobility and efficient traffic systems
- The environment that promotes the sustainability and development of green energy
- Improving the quality of life, increasing safety and reducing all types of risks
- Better and faster citizen information

Smart cities are a challenging project for local governments as well as for providers of digital network technologies. The AMANDA ASSC concept is a valuable contribution to the advancement of digital networked technologies for smart cities.

3.2.1 Key end-user requirements

In smart cities, managing traffic organization and flow rate in a cost-effective way. Maintaining good air quality and living conditions on the other hand is a key challenge that modern cities are facing. In this context, developing a quick and efficient detection of free parking spaces could be beneficial. Today, a whole range of applications is available to users in order to determine an available parking slot. There are also many systems that can assist in the flow of traffic and for parking. These include public display systems that inform on the number of free parking spaces or applications on smartphones leading the user towards the nearest parking lot.

PENTA as an end user, has a rich and long-standing experience in public transportation, from parking charge to ticket sales in public transportation. It is the project leader of the Spark-Sense project funded by the EU which aims to develop a parking slot reservation system. For the whole system to function and be effective, it is important to keep track of the current

occupancy of a given parking space. Magnetic sensors are commonly installed at each parking space for this purpose. To a lesser extent, ultrasonic sensors are also used.
The car parking detector market (parking lots) has a great market potential. A city with about 50,000 inhabitants would require about 3,000 sensors to detect cars presence in all parking lots. The estimated lifetime of each sensor is 3-5 years, mainly limited by its battery lifetime.
PENTA conducted a survey on potential end users of the AMANDA ASSC, including questions as defined in the questionnaire presented in the Annex. In addition to the questionnaires, PENTA also conducted interviews with local government officials and industry partners. The local government has shown interest not only in needs in the field of transport, but also in air quality monitoring and noise control. It is also important to be able to track main pollutants, such as CO and VOC: cities can have a legal obligation to measure pollution and to regularly report it to the public. The possibility of low-cost and mobile sensors for measuring pollution gives the ability to create air quality maps in individual parts of a city. In many cities, there is also an increasing problem of noise pollution. The desire of local authorities is to reduce noise in certain areas and to improve living and working conditions. An adaptive multi-sensing platform such the AMANDA ASSC has the potential to meet the majority of local government needs.
Industrial partners have also shown interest in the area of public protection and surveillance. An identification card that could detect the presence of toxic gases or a shortage of oxygen in the air would significantly enhance the safety of people working in hazardous environments.
The following part of this Section expresses the needs of end users, based on PENTA's experience, together with the conducted surveys and interviews.

3.2.2 Specific use cases

End users have clearly expressed interest in determining the way innovative technologies developed within the AMANDA project will address challenges from existing applications and how they may trigger additional use cases. The wish of every end user is to get a product that will be reliable and will also increase the quality of the business process while being financially acceptable. The challenge of the AMANDA project is to meet the maximum needs of a variety of end users.
End-user requirements have been studied for the following use cases, as presented in Table 4 below:

Use Case (UC)	Functionality
UC4: Parking slot occupancy	Detect a car arriving to a parking spot. Detect the departure of the car from the parking spot. In closed garages, data is collected on temperature, humidity, increased concentrations of toxic gases, light intensity
UC5: Weather station UC6: Air quality station	Collect data on temperature, humidity, air pressure, humidity, UV index, and concentrations of toxic gases in the air.
UC7: Personal identification card with toxic gas detector	Collect data on temperature, humidity, air pressure, noise, and concentrations of toxic gases
UC8: FMCG tracking and monitoring for food delivery	Collect data on temperature, humidity and transport time

Table 4 End user requirements and use cases

The use cases of Table 4 are further described below.

3.2.2.1 Parking slot occupancy (UC4)

Determining occupancy of parking spots is a prerequisite for efficient and timely management of traffic in cities. The detection scenario of a car presence in the parking lot is the following: A car arrives to a parking lot. Sensors detect the arrival of the car and send this information via a wireless network (for example LoRa) to a central station. The car leaves the parking spot. Sensors detect its departure and transmit relevant information. The presence of the car is detected in the open and in closed spaces (indoor or underground) with the use of the following sensors:

- Magnetic sensor: measures the Earth's magnetic field. The system measures the change in the magnetic field and thus detects the presence of a car or its departure from a parking space
- Ultrasonic sensor: the sensor detects an object that has entered in the ultrasound wave field
- Light sensor: detects changes in light when a vehicle is parked
- Temperature and humidity sensor: collects data on temperature and humidity in the environment
- CO_2 sensor: detects an increased carbon dioxide concentration and informs about the possible occurrence of fire

In practice, all of these sensors will achieve below 100% success rate due to limited accuracy. However, having an array of sensors for redundancy within a single parking space will significantly increase the likelihood of detecting the presence of a car in a parking space. This can be a significant advantage of the AMANDA ASSC over existing solutions.

3.2.2.2 Weather (UC5) and air quality (UC6) station

Aside from autonomy, one of the greatest advantages of the AMANDA ASSC will be its small volume and low weight. These features will allow the ASSC to be mounted on any moving object, providing a mobile weather and air quality station. Such an option can be used to get instant information from multiple locations in a very short time or from places that are difficult to access or completely unavailable to people. The ASSC can be easily installed on all mobile vehicles such as radio-controlled vehicles (buses, car, and bikes) or the increasingly popular and fast-growing drones. Air Quality in Europe is defined by the Common Air Quality Index (CAQ). According to the CAQ norm [1], the following pollutants are measured:

NO_2, PM10, PM2.5, SO_2, CO, O_3

Research should continue towards development of adequate sensors for air quality. Although it is generally out of scope of the AMANDA project at the present phase, some of these air-quality sensors may be added to the AMANDA platform at a later stage if found to be compatible with the power and size requirements of the AMANDA ASSC.

The scenario for weather and air quality: The data from sensors is collected in predefined time periods and transmitted via a wireless network (usually long range such as LoRa or Nb-IoT) to a centralized monitoring system. The required sensors for this application include:

- Temperature, humidity sensor, air pressure sensor to collect environmental data
- Noise: Information on surrounding noise level is collected, possibility to detect a set threshold
- CO_2 sensor: detects an increased concentration of carbon dioxide and informs about the possible occurrence of a fire, such as Combustion by-products
- VOC sensor: information on an increased amount of pollutants is collected

There are countless variants of static weather and air quality stations available on the market, however autonomous mobile variants were not found. The ASSC may fill that gap.

3.2.2.3 Personal identification card with toxic gas detector (UC7)

Every year, thousands of workers are under the direct and indirect impact of toxic gases. There is a strong interest to integrate a card that can simultaneous provide identification information on the presence of harmful gases. In many cases, it is sufficient to detect the reduced oxygen content in the air.
The corresponding scenario is described herein:
The ASSC is placed in a harsh working environment. Measurements are made at pre-programmed intervals. Measurement data is sent wirelessly to the monitoring system and a few data points can be stored locally on the card for redundancy. In the event of a gas event or a reduction in the presence of oxygen in the air, a buzzer is activated as a warning. After completing the operation, the ASCC switches off until the next event.
Possible sensors:

- Temperature, humidity sensor, air pressure sensor: collect environmental data
- Noise: Information on surrounding noise level is collected (possibility to detect a set threshold)
- CO_2 sensor: detect an increased concentration of carbon dioxide and inform about the possible occurrence of a fire
- VOC sensor: information on an increased concentration of potentially harmful gases
- LED diode: light indicator
- Buzzer: alarm sound
- Capacitive sensor: manual switch on/off of the system

3.2.2.4 FMCG tracking and monitoring for food delivery (UC8)

Home delivery currently accounts for 1% of total food turnover [2]. It is assumed that the US market value of food delivery to residential addresses is approximately 10 billion dollars [2], [3]. Fast-growing companies such as UberEATS or Deliveroo represent an increasing part of the food delivery market. In most cases, the customers would like to have information on the temperature at which the food was delivered including transport time [4]. This option provides the seller and customers with additional (and hopefully reassuring) information about the conditions of delivery. New standards in the quality of home food delivery are being specified.
A typical home food delivery scenario is described below: A customer orders food items. Once the items are ready, they are usually packed in food boxes and put in special delivery bags or parcels that include the ASSC. The temperature and humidity data as well as the delivery time are collected. The delivery driver displays data from the ASSC, for example through an e-ink display, on the average temperature, humidity and delivery time. The ASSC could also switch to a payment device as part of the account. Required sensors for this scenario:

- Temperature, humidity sensor: collects information about the temperature and humidity of the air inside the delivery bag or parcel
- Capacitive sensor: switch on/off
- E-ink display: optional for displaying sensor and delivery data

3.2.3 Qualitative analysis

Summing up the information from the previous Sections, Table 5 lists the recommended sensors for each use case:

Sensor	Parking slot occupancy (UC4)	Weather and air quality control (UC5,6)	ID Card and gases detector (UC7)	Food delivery (UC8)
Temperature	✓	✓	✓	✓

Humidity	✓	✓	✓	✓
Air Pressure	-	✓	✓	✓
Capacitive	-	✓	✓	✓
CO_2	✓	✓	✓	✓
VOC	✓	✓	✓	-
Magnetic field	✓	-	-	-
Noise sensor	-	✓	-	-
Ultrasonic sensor	✓	-	-	-
Light sensor	✓	✓	-	-
Led	-	✓	✓	✓
Buzzer	-	-	✓	✓
e-ink display	-	-	✓	✓

Table 5 Sensors for the intended use case

The proposed RF connectivity options for each of these use cases are shown in Table 6 below:

Use case	RF
Parking slot occupancy	LoRa, Nb-IoT
Weather and air quality control	BLE, LoRa, Nb-IoT
ID Card and gas detector	BLE, LoRa, Nb-IoT
Home food delivery	BLE, LoRa, Nb-IoT

Table 6 RF connection for the use cases

3.2.4 Quantitative analysis

By analysing customer surveys and through discussions with end users, it was clear that the ASSC could provide benefits such as card autonomy, small dimensions and multi-sensor capability. Table 7 below shows the end user's needs analysis according to each use case.

	Parking slot occupancy (UC4)	Weather and air quality control (UC5,6)	ID Card and gasses detector (UC7)	Home food delivery (UC8)
Distance from gateway	max 300m	max 2km	max 300m	-
Measurement interval	15 sec	4 / hour	3 min	Delivery time
Wireless data transmission frequency	30 sec for alive ping 2-3 / hour (average car	4 / hour	2 min for alive ping -after a certain occurrence, 2-3 / day	End of delivery/few time a day

	change on parking spot)			
Light condition	day/night time, indoor 40-200 lux	day/night time	Industrial light condition	Home or office light condition
Operating hours for ASSC	0-24	0-24	Max 8 hours	Delivery time
Existing sensor market price	100€	50-1000€	100-800€	-

Table 7 End user requirements for smart cities

The measurement interval and RF transmission frequency will depend on variations between consecutive measurements. If there is no significant difference between consecutive measurements (or within tolerance limits), there is no need to transfer the data to the wireless into the cloud. This is likely to be the case for the parking slot occupancy, ID card and gas detection, and home food delivery use cases. In some instances, such as the parking slot occupancy, an alive ping needs to be transmitted at certain intervals. An alive ping request represents the easiest way to determine if a host/client, in this specific case a sensor is connected to the network and available. By sending a reply, the sensor unit can confirm that it is available for use. Also, in cases where multiple ASSCs exist in a single place, it is not necessary to send an alive ping or such a ping could be sent at much larger intervals. In some cases, like an ID card and gas detection, or home food delivery, the ASSC should also have the ability to store data in local memory.

3.3 Smart agriculture

3.3.1 Key end-user requirements

With the continuous expansion of urban spaces and the increase of world population, there is a strong need for optimization of available agriculture lands. In order for this optimization to occur and for large scale deployment of solutions, there are several requirements to need to be addressed.

Size is a critical factor in smart agriculture, be it for devices that are directly attached to cattle, or devices in the ground for monitoring purposes. Solutions developed as part of the AMANDA project will address this need for cattle monitoring, where size and weight are critical as the farm animals will carry the device permanently. They will also address irrigation applications, where a small size factor is critical to place devices in various locations in the fields.

It is not uncommon that a farmer cannot see his cattle for extended periods of time, in some cases the cattle being located in a remote area, hence the need for remote monitoring. Geofencing and movement monitoring are examples of what farmers need to monitor the well-being of their herds.

For irrigation, the monitoring of soil humidity is vital in order to avoid waste of water, especially considering the scarcity of water in many parts of the world. By watering the exact amount of water needed to the fields, healthy crops are grown with minimum resources, saving on cost and reducing the impact to the environment. Temperature monitoring is also crucial to enable an educated decision about the crops. Weather variations and the risk of freezing weather (for example during spring time), have significant economic repercussions if the necessary procedures or precautions are not taken at the right moment.

Market and end user requirements are for a small, light, and autonomous solution that is easy to install and will not require regular maintenance which is the biggest cost over the lifetime of the device itself. Indeed, in smart agriculture with outdoor environment, there is an abundance of light even during winter and energy harvesting is privileged for a sustainable, maintenance free, and economical solution.

3.3.2 Specific use cases

Several applications are possible, and solutions are in demand today with the wider IoT deployment and pressure on results and profitability of land and farms.
Cattle tracking and monitoring (UC15): it is a use case where the position and grazing patterns of the cattle can be monitored, with the ability to set alarms if individual animals are not moving or fenced boundaries have been breached. Each tracker would have an accelerometer, a GPS transceiver and a communication module. Additional temperature sensors to monitor the well-being of animals can also be considered. This would imperatively need a robust, small, and light outer casing that will resist the high temperatures the cattle are exposed to, as well as the harsh interactions between the animals in some cases.
Smart irrigation (UC16): it comprises of environment monitoring: temperature, humidity, and lux meter, and may be communicated by different means depending on the possibilities and restrictions of the farm land.

3.3.3 Qualitative analysis

Several components are necessary in a smart agriculture device, including

- Temperature sensor from Microdul (cattle tracking and monitoring, irrigation)
- Humidity off the shelf sensor (irrigation)
- Light off the shelf sensor (irrigation)
- Accelerometer from ZHAW (cattle tracking and monitoring)
- PMIC from EPEAS
- Light harvesting PV cells from Lightricity
- Storage element from Ilika
- Off-the-shelf LPWAN RF module (LoRa)

The selected sensors need to be low power, and the idea is to use photovoltaic cells from Lightricity to harvest the light energy from the environment and store it in Ilika rechargeable storage element. The efficient power management of this energy unit is performed by EPEAS PMIC. The autonomous nature of the device is a must-have to avoid heavy maintenance costs and potential quality issues associated with the manipulation of the device. The integration of this ultra-thin device will be provided by CERTH.

3.3.4 Quantitative analysis

The power budget is the determining factor of the feasibility of a device to be autonomous. This implies that it needs to consume the least possible and harvest as much energy as possible. A small device (like cattle trackers), constrains the size of the PV cell and therefore, an ultra-low device power consumption as well as high efficiencies of PV cell and PMIC become even more important. The amount of energy that can be harvested depends on the amount of energy available at the source. It is critical to analyse the power consumption of the device and adapt the parameters accordingly. Table 8 provides information about typical illumination levels and energy required for data acquisition and transmission. Table 9 provides information about energy consumption and required area for components, for both the cattle tracking and irrigation use cases.

Specific use case	Average illumination level (lux)	Average power for data acquisition (µW)	Measurement interval range required (s)	Energy/wireless transmission (mJ)	Transmission interval (s)

Cattle tracking and monitoring (UC15)	3000 - 10000	8.5	60	200	600
Irrigation (UC16)	3000 - 10000	8	60	200	3600

Table 8 Typical illumination available and energy levels required for each use case

Sensor type	**Power consumption**					**Dimensions**
	Quiescent current (lowest sleep mode/OFF)	**Quiescent current (standby mode)**	**Wake-up current**	**Active current**	**Peak current**	
Accelerometer	Power down: 0.5µA	No standby, either power down or operation	n/a	Normal: 2µA@1Hz Normal: 11µA@50Hz	Low power: 6µA@50Hz	3 x 3 x 1mm
Humidity	n/a	Sleep mode 0.15µA	n/a	Average 2.1µA @ 1Hz	Peak: 12mA for VoC	2 x 2 x 0.75mm
Light	Power down: 0.3-0.4µA	-	n/a	Active: 1.8-3.7µA	n/a	2 x 2 x 0.65mm
Temperature	15nA max. 20nA	15nA max. 20nA	n/a	Average: 80nA	Peak: 75µA	1.39 x 0.93 x 0.84mm
PV	-	-	-	-	-	10 x 10 x 1.5mm
Battery	-	-	-	-	-	25.5 x 10 x 0.7mm
MCU	280nA	850nA (RTC + 8kB SRAM retention)	n/a	29µA/MHz	n/a	10 x 10 x 1.2mm

PMIC	200nA	n/a	n/a	n/a	n/a	10 x 10 x 1mm (including passive components)
LoRa	1.18µA	-	-	Active Tx current (SF12, +13dBm, 3.3V) > 33mA	-	4.1 x 4.1 x 1mm

Table 9 Power consumption and footprints of the components for smart agriculture

The smart agriculture market segment is relatively sensitive to the unit price of monitoring devices with target prices ranging from 30 to 100 euros for tracking and irrigation monitoring devices.

3.4 Wearables

3.4.1 Key end-user requirements

The outcome from the AMANDA project could be used to establish the relationship between environmental conditions (both indoors and outdoors) and personal habits. In particular, the ASSC could be used to investigate the well-being of people or livestock. Wearable devices can unobtrusively collect information about environmental parameters relevant to comfort of the investigated subject. The ASSC can be uniquely assigned to a person or animal. It can then collect both environmental and behavioural information which are directly related to the subject exposure. The data can subsequently be analysed to establish the congruence between habits and environmental exposures. For example, if a subject is exposed to sub-optimal environmental conditions, it may exhibit some health damaging behaviour. Repeated physical discomfort can create serious health problems in the long term.

In order to capture environmental or behavioural events, the measurement data should be acquired for a significant amount of time. Longer term experiments require methods where the ASSC will have enough power to operate. Consequently, low-power electronics as well as efficient power management and energy storage methods are paramount. In order to provide electrical energy to the measurement system, in a way that does not actively involve the subjects, energy harvesting methods should be applied. Light energy harvesting is one which is the most promising for this application. If night-time is excluded, people or animals do not usually experience long periods of complete darkness.

Several indoor parameters can be tracked to determine environmental exposure. One of the indoor air pollutants is carbon dioxide [5]. At low concentrations, gaseous carbon dioxide appears to have little toxicological effect. At higher concentrations, it leads to an increased respiratory rate, tachycardia, cardiac arrhythmias and impaired consciousness. Concentrations above 10% may cause convulsions, coma and death [6].

Also prolonged staying in environment where parameters like suboptimal temperature and humidity can increase rate of chronic fatigue.

Prolonged exposure to very bright or very dim light can lead to sight distorts. Constant exposure to different wavelengths and intensities of light promoted by light pollution may produce retinal degeneration as a consequence of photoreceptor or retinal pigment epithelium cells death [7]. Light intensity (typically in lux) can be measured by an ambient light sensor.

An exposure to elevated sound level has also negative consequences on people's health. The sound has an important role in both physical and psychological injuries, and it also affects

individuals' performance and productivity [8]. This parameter can be measured by microphones.
Finally, another non-environmental but important parameter is the physical activity level of an individual. It can be measured by an accelerometer. Prolonged sitting or lack of movements can lead to severe health issues [9]. Having the possibility to track physical activity provides extra input for gathering information about a user's habits.
Equally important is the information gathered from indoor location systems. The location brings context to the measurement data. A tracking can be done with help of radio technology. The ASSC could send information to a receiver radio system that would collect both identification and signal strength, and translating this information into an estimated location of the subject, both indoors and outdoors.
The ASSC could also provide access control to restricted indoor areas by sending encrypted identification signals to the system.
In order to increase functionality and provide additional interactions with the users, capacitive touch buttons can be added to record specific touch events or send access requests.

3.4.2 Specific use cases

3.4.2.1 Behaviour monitoring (UC17): autonomous intrusive card for identification, indoor conditions and habits monitoring

Nowadays, access to sensitive parts of professional spaces is restricted. In order to grant access to such areas or resources, employees can be given NFC ID tags. These tags are passive electronic devices which can identify the owner. The idea of professional ID cards is already wildly deployed. The AMANDA project could provide a technology that would enhance the capability of such cards by providing active and longer-range RF connectivity features.
The card could also provide quantitative information about environmental exposure (e.g. indoor conditions) of the test subject by adding technology which can sense parameters in an intrusive way:

- CO_2 concentration
- Temperature
- Humidity
- Light intensity
- Sound pressure
- Estimated indoor position (short-range radio)
- Acceleration
- Interaction with the user through the use of capacitive buttons

The AMANDA card can measure acceleration. The data can give insights about the test subject physical activity. The data, collected over long time, can be analysed and behavioural habits of the test subject can be found. People have a unique way of walking. The gait features can be used as a biomarker that can provide measurable features for the identification of a subject.
Buttons on the card can be used as feedback from individuals. They allow for a subjective event labelling e.g. when the subject feels tired should press the button. That information can lead to the identification of the environmental conditions which caused the event. The advice, about the optimization of a work schedule, can be granted to the user based on measurements and analysis. This could lead to higher efficiency of work and in the long-term to an increased quality of life.

3.4.3 Qualitative analysis

An ASSC for indoor conditions and habits monitoring would require multiple sensors. In order not to disturb the user under test, the device needs to be miniaturized and yet still be able to collect, store and transmit environmental parameters. The components used for the ASSC assembly could include sensors such as:

- IMEC's CO_2 sensor
- Microdul's temperature sensor and touch sensor
- Off-the-shelf humidity sensor e.g. BME680
- Ambient light sensor e.g. OPT3001
- MEMS microphone e.g. SPH0645LM4H-B
- Accelerometer e.g. LIS3DHTR

A short-range radio technology such as BLE (e.g. RSL10-SIP) could provide ultra-low power wireless data transfer. On top of this, indication of the indoor location as well as automated identification capability can be developed. In the situation that test subject is out of the radio range, the limited amount of data could be stored into the card memory (e.g. MB85RS64TU) and sent to the gateway when in range.

The subject should not be concerned about the maintenance of the card which should therefore be completely autonomous. The main challenge in this case is to provide sufficient electrical energy to the system in active mode. This can be achieved by light energy harvesting using photovoltaic cells provided by Lightricity. Harvested energy should be stored in high energy and power density storage components, e.g. with low profile and high capacity. Cutting-edge solid-state technology for storage is provided by Ilika. The card system also needs extremely efficient PMU (Power Management Unit) and low power micro-controller, both components being developed by EPEAS. To integrate that many components in such a limited volume, ultra-fine line PCB technology is likely to be required. The integration of the ASSC components will be provided by CERTH.

There is one more aspect of the system; the ASSC will contain BLE radio transmitter and Ethernet driver. The device will send data to a cloud data centre. From there, data will only be accessible to authorized developers. In the cloud server, data can be subsequently processed by data fusion algorithms and visualized is such a way that it gives direct feedback to the subjects about their environmental exposure and correlated habits. This task will be performed by PENTA using off-the-shelf IT getaway devices (e.g. NTO-DVC-BLE-GW4) and cloud services. IMEC can provide relevant cloud algorithms in order to extract relevant information from the multi-sensor measurements database.

3.4.4 Quantitative analysis

The system is meant to be autonomous, thus it will rely on harvested energy when ambient light is available. Devices cannot work in a sustainable way if there is not enough energy available and system functionality should be matched with available energy. That is why PMU has a very important role in this device, since it should provide indication of available energy at any given time. Based on this information, embedded algorithms within the microcontroller could make decisions on which peripherals can be enabled. In such self-powered systems, measurement intervals do not have to be equal since algorithms are able to reconstruct data. However, these measurements may happen so rarely that it could be impossible to reconstruct the missing values. That is why it is important to use the best available energy harvesting technology to provide sufficient energy to the system and optimize its power consumption.

In Deliverable D1.2, a set of the most suitable components was created and explained. In Table 10 below, the required components for the wearable use case have been listed.

Sensor type (UC17)	Power consumption					Dimensions
	Quiescent current (lowest sleep mode/OFF)	Quiescent current (standby mode)	Wake-up current	Active current	Peak current	
Accelerometer	Power down: 0.5µA	No standby, either power down or operation	n/a	Normal: 2µA@1Hz Normal: 11µA@50Hz	Low power: 6µA@50Hz	3 x 3 x 1mm
Audio	Sleep: 3µA max. 10µA	No standby, either sleep or operation	n/a	600µA	n/a	3.35 x 3 x 1mm
CO_2/Smoke detector	4µA/switch off externally	2mA	20mA	Average: 20mA	Peak:30mA	5 x 10 x 1mm
Humidity	n/a	Sleep mode 0.15µA	n/a	Average VoC: 12mA@1Hz VoC: 0.9mA @ 1/3Hz VoC: 0.1 mA@1/300 Hz RH, P, T: 3.7µA @ 1Hz	Peak: 12mA for VoC	2 x 2 x 0.75mm
Capacitive	50nA	50nA 720nA (oscillator enabled for periodic measurement)	n/a	Average: 770nA at 2 measurements / second 1.5µA at 32 measurements / second	11µA	1.52 x 1.03 x 0.64mm

Light	Power down: 0.3-0.4µA	-	n/a	Active: 1.8-3.7µA	n/a	2 x 2 x 0.65mm
Tempera-ture	15nA max. 20nA	15nA max. 20nA	n/a	Average: 80nA	Peak: 75µA	1.39 x 0.93 x 0.84mm
PV	-	-	-	-	-	10 x 10 x 1.5mm
Battery	-	-	-	-	-	25.5 x 10 x 0.7mm
MCU	280nA	850nA (RTC + 8kB SRAM reten-tion)	n/a	29µA/MHz	n/a	10 x 10 x 1.2mm
PMIC	200nA	n/a	n/a	n/a	n/a	5 x 5 x 1mm
FRAM	9µA	n/a	n/a	0.8mA (Max@10 MHz)	n/a	2 x 3 x 0.7mm
BLE	Deep Sleep, IO Wake–up, 25nA	With 32KHz running and data reten-tion 100nA	-	Peak Tx: 4.6mA (3V. 0dBm) Peak Rx: 3.0mA (3V)	-	6.4 x 6.4 x 1mm

Table 10 Power consumption and footprints of the components for the wearable card

A similar type of product would be the Samsung smartwatch. This product is a wearable watch with additional features including heart rate, blood pressure or body temperature monitoring. The current market price of the Samsung smartwatch is 220-350 euro. Similar price range is expected to be suitable for the mass production of a wearable version of the AMANDA ASSC.

3.5 Industrial IoT

IoT devices are nonstandard computing devices that connect wirelessly to a network and have the ability to transmit data. The IoT sector involves the extension of internet connectivity be-yond standard devices, such as desktops, laptops and others to any range of traditionally non-smart or non-internet-enabled physical devices and everyday objects. Embedded with tech-

nology, these devices can communicate and interact over the internet, and they can be remotely monitored and controlled. The use of such devices has upgraded the industry and is, essentially, the evolution of a DCS that allows for a higher degree of automation by using cloud computing to refine and optimize the process controls. More specifically, industrial IoT or IIoT applications are connected to sensors found in a common network, instruments and other devices that communicate with computers' industrial applications, as well as, production and energy management. This connectivity allows for collection, exchange and analysis of data.
While connectivity and data acquisition are imperative for IIoT, they are not the end goals, but rather the foundation to facilitate improvements in productivity and efficiency as well as other economic benefits for the industry. The advantages of the frameworks and systems that the IIoT refers to, is that they can operate semi-independently or with very minimal human intervention. Such systems will increasingly be able to respond in an intelligent way and even change their course of action based on the information received through the feedback loops established within the framework. An element of the Internet of Things that also refers to specific activities and to the initial stages of the IIoT is the machine-to-machine communication (M2M). The idea behind M2M is to reduce human intervention as much as possible so that the highest level of automation could be achieved. The IIoT in this sense can be considered a movement towards 'smart machines' where the accuracy levels of the operations involved in the respective systems are heightened to a level that cannot be achieved through a human intervention.
The AMANDA Partners have been working in a variety of relevant projects in the IIoT area. While keeping the same philosophy of IoT operation, with various smart devices accessing the network and performing simple and complex tasks, Industrial IoT is targeted more in making the manufacturing process profitable. Examples are cost reduction due to optimized asset and inventory management (hence, lower inventory carrying costs and search times), or making the working spaces safer, since paired with wearable devices, IIoT allows monitoring workers' health state and detecting risky activities that can lead to injuries. In order to better define what Industrial IoT is, a few examples of devices are presented below that were developed by CERTH/ITI in order to solve a variety of problems in industrial processes:

- Vibration measuring devices that were installed in heavy industrial machines and collect vibration data. With a corresponding platform, nominal and problematic operation profiles were created and as a result, the system can alert the appropriate user in case of abnormalities or even predict need for maintenance. This device was developed as part of the COMPOSITION project (funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 723145)
- Fill level monitoring devices that were installed in big recycle bins to keep track of the amount of collected material. Through a corresponding platform, the responsible user can access the measured data as well as get alarms on when a specific bin needs to be emptied. The platform was also developed as part of the COMPOSITION project.
- Working space quality monitoring devices that were installed in companies' offices to ensure that critical parameters such as temperature and humidity are constantly monitored for the H2020 SatisFactory project (funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 636302).

As mentioned above, different questionnaires were created by CERTH and Penta for the purpose of this document. The objective was to gather the end user requirements from all the available industrial stakeholders, such as end users, product providers, suppliers and developers that have previously collaborated with anyone involved in the consortium. The industries were targeted by their interest in new ways to improve their business with the integration of new technologies. In order to provide a better overview of the questionnaire's main focus, some details are listed in the following Section.

3.5.1 Key end-user requirements

The industrial IoT sector has already proven its versatility with deployments going live in various enterprises, such as Airbus and Siemens, that do not only incorporate IoT devices for their products but also to the tools their workers use in the manufacturing process, showing off dozens of different use cases.

It is important to note that IoT use cases will continue to expand in the coming years. That said, a compilation of the most requested industrial IoT use cases, from the aforementioned questionnaire, is presented.

One of the biggest challenges that industrial companies have when evaluating industrial IoT is finding “use cases” or scenarios where IoT can be used to improve operations. IoT devices are expected to bring value to an organization in one of the following ways [10]:

- Reduce cost
- Increase revenue
- Increase customer satisfaction
- Reduce risk and improve compliance

The aim of the following analysis is to provide an overview of the requirements for the design and implementation of the different versions of the ASSC. There are three main objectives that are addressed with this questionnaire and are given below:

- Learn more about the currently used sensor platforms / data acquisition systems in the industrial sector and identify any potential gaps for improvement and expansion
- Present the main characteristics of the AMANDA ASSC as well as the variety of available sensors and hardware options that could be integrated.
- Based on the available hardware mentioned previously, identify which individual sensors would a company need and their intended usage. The identification of different end user needs or even use cases to address them materialized due to this data.

The requirements were defined to describe how the system works and what it should do, based on the gathered information. There are several benefits that arose. The first one is to reduce the development effort, since the definition of rigorous requirements before the design can reduce later redesign, recoding, and retesting. Moreover, the requirements can be considered as an agreement between the potential customers and the supplier about the product (to be developed), for instance, facilitating the business model and marketing. Furthermore, a detailed description of the requirements can accurately estimate costs and time planning. Finally, the requirements can set the evaluation and validation criteria to obtain a quality product.

The end-user requirements were combined from the questionnaire answers and were clustered in the use cases and ASSC functionalities that are presented in Table 11. The use cases will be detailed in the following Sections.

Use Cases (UC)	ASSC Functionality
UC18: Cargo transportation conditions	Collect information about temperature, CO_2/Smoke levels, noise levels and travel distance from a set point to ensure proper conditions and safety for the cargo and its means of transportation.
UC19: Indoor asset tracking	Keep track of a company’s high value assets and their condition
UC20: Worker comfort level monitoring	Ensure comfort levels for the employees to increase their efficiency and motivation

UC21: Workplace information delivery	Keep an overview of the working conditions to ensure the health and safety of the employees

Table 11 Use Cases and the ASSC Functionality

3.5.2 Specific use cases

This Section provides a detailed description for the IIoT use cases and how they can be addressed by the ASSC. The AMANDA system will consist of the AMANDA Core System, as it is described in Deliverable D1.2, and various sensors that are chosen for each specific use case. The list of the sensors, for each individual ASSC version, was finalized after analysing the end-user requirements from the companies' replies on the aforementioned questionnaire.

The main purpose of the sensors is to gather information that will help address specific issues for different use cases. The initial processing of the data will be done on the ASSC by the MCU and then, if needed, the ASSC can notify any external service, such as a server infrastructure, via its RF channels.

UC 18	
Use Case Name	Use ASSC for Cargo Transportation Conditions
Description	Collect information about temperature, CO_2/Smoke levels, noise levels and distance from a set point to ensure proper conditions and safety for the cargo and its means of transportation
Challenge	The challenge we have here is to collect all the necessary information that are useful from the cargo and to compile the results needed by the users that are related to the ASSC's features
Involved Actors	Logistic companies Shipping companies Waste Management companies
Realization Concept	The information that the ASSC records should be displayed to the user in real time. The user should be informed about the status and location about his products
Evaluation Criteria	Ease and flexibility from the user's perspective and also how realistic the data will be to reflect the actual conditions prevailing within the Cargo

Table 12 UC Cargo Transportation Conditions

UC 19	
Use Case Name	Use ASSC for Indoor asset tracking
Description	Keep track of a company's high value assets and their condition
Challenge	One of the challenges here is to be able to provide a complete overview for the objects that have high value to each company. Moreover, a live broadcast of the space will help with the control of all these objects. The information will be continuously available to the users via the ASSC

Involved Actors	Security companies Municipal authorities
Realization Concept	The ASSC should record the space in real time and inform the user if a violation is made. The user will be continuously updated on the situation that prevails in the monitoring area according to the capabilities offered by the ASSC
Evaluation Criteria	The quality of the information recorded and the results provided from the ASSC

Table 13 UC Indoor asset tracking

UC 20	
Use Case Name	Use ASSC for Worker comfort level monitoring
Description	Ensure comfort levels for the employees to increase their efficiency and motivation
Challenge	The challenge here is the proper recording of the workers' comfort conditions. Another potential threat could be the accurate detailed description of the workplace comfort conditions after the environment adaption. Depending on the data received from the ASSC, then the proper actions should be taken from the respective devices (Windows, A/C etc.) to ensure that comfort levels should be constant
Involved Actors	All companies that have workforce
Realization Concept:	The ASSC will record the status of the employee and will communicate with peripheral devices so that there are the levels of comfort that are appropriate for him. In addition it can provide customization according to the needs of the user
Evaluation Criteria	The most important criterion is whether the system can reach a realistic conclusion regarding the comfort conditions of the workforce

Table 14 UC Worker comfort level monitoring

UC 21	
Use Case Name	Use ASSC for Workplace Information delivery
Description	Keep the overview of the working conditions to ensure the health and safety of the employees
Challenge	The challenge here is the implementation of the ASSC itself and whether it should be recording all the parameters related to the workplace environment and how these data will be handled in order to establish a safe and healthy environment for the personnel
Involved Actors	All companies that have workforce

Realization Concept:	The conditions prevailing in the workplace should be recorded by the ACCS. All information should be graphically visualized. The user should be able to know all the information and be informed when there are dangerous working conditions
Evaluation Criteria	The most essential aspect of this UC is whether the ASSC can have real-time information flow to avoid any potential threat for the employees' health and safety

Table 15 UC Workplace Information delivery

3.5.2.1 Cargo transportation conditions (UC18)

Nowadays, there are more and more companies involved in the transportation of products. Such firms are interested in monitoring the conditions of the goods during this transportation phase. For this use case, apart from the data concerning the product's environment, another essential aspect is the timing of the readings and their time intervals. The best scenario would be to have a real time overview and inform a database or a pre-assigned employee for any corrective action that might be needed. Short range communication (lower power consumption) is preferred for real time monitoring, and long range communication can be used to provide alerts about exceptional conditions (Temperature or sound level exceeding a set threshold for example).

That way, industries can have a set of information to help them track the conditions that transport their products such as the temperature, the humidity, the smoke levels, etc. Lastly, the ASSC could provide information of the space the products occupy within the containers so that their transportation can become more time efficient and less time and cost consuming.

The modules that can support this use case (UC18) are the following:

- Temperature sensor: measures the temperature of products in a container. It includes a database for any temperature increase or decrease that could cause damage to the products
- CO_2/smoke detector: measures the carbon dioxide levels in the atmosphere and helps in the detection of a fire (UC14)
- Acoustic sensor: records noise levels and analyses the surrounding ambient sound. It can be essential for a cargo's security in spaces with high levels of noise pollution or with restrictions on noise levels

3.5.2.2 Indoor asset tracking (UC19)

A fundamental need for the companies today is an overview of the management, processing, security and delivery of their high value assets. Even though several alternative solutions have been introduced it still remains a challenging task to tackle. Another solution the AMANDA card can provide is an overview of the people that enter or leave a building when they are equipped with an ASSC. This solution could also provide information on the number of people within the working place and help identify the exact working conditions they have, environment wise, as also covered by UC1.

This scenario includes the following sensors:

- Temperature sensor: measures the temperature of the asset's location and creates a database for any increase or decrease to it that might affect the asset
- CO_2/smoke detector: measures the carbon dioxide levels and helps avoid a possible fire or avoid any damage to a product or its location
- Acceleration sensor: understands the surroundings of an asset better and provides a better insight of the asset's whereabouts

- Light sensor: measures the lux of an asset's location and calculates its proximity to another object or obstacle
- Acoustic sensor: records noise levels and analyses the surrounding ambient sound which is essential for the asset's security in spaces with high levels of noise pollution or with restrictions on noise levels
- Positioning sensor (such as BT Smart): indicates rough location of asset or person in a room or smart building
- Imaging sensor: can determine the number of people in a room and or changes in the physical environment.

3.5.2.3 Worker comfort level monitoring (UC20)

Buildings in which people work can have systems that monitor and adjust the working environment to ensure the workers' comfort level. Such systems consist of heating, ventilation and air conditioning (HVAC) systems, lighting systems, etc. These control systems could be rather simple, such as maintaining the temperature, e.g. by using a thermostat. Although there is a strong correlation between temperature and human comfort, a better comfort index could be temperature combined with relative humidity. In essence, for this use case, the ASSC will ensure that the conditions for workers will be optimal and assist in improving their efficiency and motivation levels.
The sensors that need to implement this scenario are:

- Temperature sensor: measures the temperature of a workplace and ensures it does not vary away from the appropriate levels
- CO_2/smoke Detector: measures the carbon dioxide levels and helps avoid a possible fire or avoid any damage to the workplace and ensure the safety of the employees
- Light sensor: measures the lux of a room/building so that there is sufficient light for the workforce
- Sound sensor: records noise levels and analyses the surrounding ambient sound which is essential for the personnel's security in spaces with high levels of noise pollution or with restrictions on noise levels
- Humidity sensor: measures the humidity levels of the workplace and create a database for any variation to it that might impact the working conditions of the personnel

3.5.2.4 Workplace information delivery (UC21)

Health and safety from dangerous situations are some of the biggest necessities of an industrial place in order to ensure a proper working environment. It is important to measure any fluctuation that may affect the building's climate such as temperature, noise level, CO_2 levels and might affect the working conditions for the employees. This is why the ASSC should provide the aforementioned information and even provide conditions that might affect the safety of the environment in the industrial place (UC21).
The following sensors will be needed to perform this scenario:

- Temperature sensor: measures the temperature of the workplace and creates a database for any increase or decrease to it that might impact the personnel's working conditions
- CO_2 sensor: measures the carbon dioxide levels and helps to quickly react to a possible fire (UC14) or avoid any damage to the workplace and ensure the safety of the employees
- Sound sensor: records noise levels and analyses the surrounding ambient sound which is essential for the personnel's security in spaces with high levels of noise pollution or with restrictions on noise levels

- Imaging sensor: keeps an overview of the workplace and ensures its security. Moreover, it can provide the last known condition of the working place in case of an accident/theft.
- Humidity sensor: measures the humidity of the workplace and creates a database for any increase or decrease to it that might worsen the personnel's working conditions.
- Light sensor: Measures the illumination level in order to decide if the imaging sensor should be active. This saves a lot of energy in dark conditions (no image capture and transmission) when there is little or no energy to harvest.

3.5.3 Qualitative analysis

The Section below summarizes the different sensor models, RF units, power sources and main control units that will be included in the IoT use cases that were proposed from end users via questionnaires. An overview of the modules is provided in Table 16:

Sensor Type	Manufacturer Part Number
Temperature	MS1089
CO_2/smoke Detector	ADUCM355
Noise Level	SPH0645LM4H-B
Imaging	CLCC48
Acceleration/force	LIS3DHTR
Capacitive	MS8892
Light	OPT3001
Humidity	BME680

Table 16 Sensors used for the IoT use case implementation

The proposed RF chip alternatives in combination with the different use cases are shown in Table 17:

Use cases	RF Chip alternatives
Cargo Transportation Conditions	Lora, Nb-IoT, Sigfox
Indoor asset tracking	BLE, LoRa
Worker comfort level monitoring	BLE, LoRa
Workplace Information delivery	BLE, LoRa, Nb-IoT

Table 17 RF chip and use cases relationship

An overview of the proposed model for RF chip is shown in Table 18:

RF chips	Manufacturer Part Number
BLE	RSL10
LoRa	SX1261
Nb-IoT	nRF9160
Sigfox	S2-LP

Table 18 RF Chips used for the IoT use case implementation

The proposed energy harvester (PV) and energy storage unit (battery) for the IIoT use cases is provided in Table 19:

Power	Manufacturer Part Number
PV	QFN28
Battery	Stereax® M250

Table 19 PV and Battery used for the IIoT use case implementation

An overview of the proposed main control unit (MCU), power management integrated circuit (PMIC) for use cases is provided in Table 20 below:

Other electronics	Manufacturer Part Number
MCU	ARM Cortex-M 32-bit
PMIC	QFN28
FRAM	MB85RS64TU

Table 20 MCU, PMIC, FRAM used for the IIoT use case implementation

3.5.4 Quantitative analysis

The industrial IoT devices use case is useful for facilitating the different needs created in the industrial environment. However, their capabilities should also be adapted to the energy and space profile of this environment. It is therefore necessary to present the power consumption and footprints of the components used for the IoT use cases to conclude if the use of the card will benefit in the industrial environment. In this Section, an overview of the power analysis for all sensors, RF chips and the hall system for the ASSC, as described in the above use cases is provided, together with a Table with the dimensions of each sensor, power source, MCU, PMIC, FRAM and RF chip. An overview of the footprints for the proposed components is provided in Table 21 below:

Sensor type	**Power consumption**					**Dimensions**
	Quiescent current (lowest sleep mode/OFF)	**Quiescent current (standby mode)**	**Wake -up current**	**Active current**	**Peak current**	
Accelerometer	Power down: 0.5µA	No standby, either power down or operation	n/a	Normal: 2µA@1Hz Normal: 11µA@50Hz	Low power: 6µA@50Hz	3 x 3 x 1mm
Audio	Sleep: 3µA max. 10µA	No standby, either sleep or operation	n/a	600µA	n/a	3.35 x 3 x 1mm
CO_2/Smoke Detector	4µA/switch off externally	2mA	20mA	Average:20mA	Peak:30mA	5 x 10 x 1mm
Humidity	n/a	Sleep mode 0.15µA	n/a	RH, P, T: 3.7µA @ 1Hz		2 x 2 x 0.75mm
Capacitive	50nA	50nA 720nA (oscillator enabled for periodic measurement)	n/a	Average: 770nA at 2 measurements / sec 1.5µA at 32 measurements / sec	11µA	1.52 x 1.03 x 0.64mm
Imaging	~15µA	~15µA	/	Average: ~300µW@8fps (~100pj/pixel/frame)	~1mA	10 x 10 x 40mm

Light	Power down: 0.3-0.4µA	-	n/a	Active: 1.8-3.7µA	n/a	2 x 2 x 0.65mm
Tempera-ture	15nA max. 20nA	15nA max. 20nA	n/a	Average: 80nA	Peak: 75µA	1.39 x 0.93 x 0.84mm
Distance	n/a	n/a	n/a	12µA	n/a	3.5 x 3.5 x 1.25mm
PV	-	-	-	-	-	10 x 10 x 1.5mm
Battery	-	-	-	-	-	25.5 x 10 x 0.7mm
MCU	280nA	850nA (RTC + 8kB SRAM re-tention)	n/a	29µA/MHz	n/a	10 x 10 x 1.2mm
PMIC	200nA	n/a	n/a	n/a	n/a	5 x 5 x 1mm
FRAM	9µA	n/a	n/a	0.8mA (Max@10MHz)	n/a	2 x 3 x 0.7mm
BLE	Deep Sleep, IO Wake–up, 25nA	With 32KHz running and data retention 100nA	-	Peak Tx: 4.6mA (3V. 0dBm) Peak Rx: 3.0mA (3V)	-	6.4 x 6.4 x 1mm
Lora	160nA	Osc + re-tention 1.2µA	-	Tx:45mA @+14dBm Rx.8.2mA	-	4.1 x 4.1 x 1mm
Nb-IoT	PSM floor current: 2.7µA	-	-	Active Tx current (+23dBm) > 250mA (peaks 380mA)	-	10 x 16 x 1mm

Sigfox	-	-	-	Rx 8.6mA, Tx (+14dBm) 20mA	-	4 x 4 x 0.9mm

Table 21 Power consumption and footprints of the components for the IIoT use cases

Another aspect that was taken under consideration and has a big impact to the potential future customers of the end product of the ASSC is the cost in each different use case. Unfortunately, for the time being, it is not easy to determine the exact price of the product because it depends on the final list of the components that will be used. In order to provide a better insight, a point of reference from the market is presented together with a comparison to the average budget of the AMANDA platform. Some products with similar specifications to the ASSC are regarded as IIoT solutions are:

- The product series eWON COSY 131 Series Remote Access (a full platform costs €623) used for indoor asset tracking. [11]
- The SmartSensor from DHL which is used for cargo tracking. [12]
- The Oden Technologies IIoT solution which provides info regarding the workplace [13]
- The Cube Comfort Monitor from Deakin University, that analyses the comfort levels of an office space (which is currently under development) [14]

3.6 Additional applications

3.6.1 Key end-user requirements

This Section considers additional potential applications and use cases which are not encompassed in the four main use cases addressed by AMANDA (Building automation, Smart cities, Wearables, Industrial IoT). The applications in this Section have been identified through direct discussion with end users and via discussions at industry conferences, workshops and tradeshows. Of those applications which do not fit the four main use case categories, medical, aircraft and automotive applications were identified as the most relevant in terms of disruptive potential of the ASSC, market size and potential impact on a European scale. Medical, aircraft and automotive applications require a deeper level of customization and system integration than the other use cases. The end-user requirements identified in this Section provide a guide to specific ASSC variations which can be used to engage in further discussions with the relevant sectors. Some of the requirements of the medical, automotive and aircraft sectors may be even more demanding than can be fully addressed by the AMANDA ASSC. These requirements will be captured for future development by the AMANDA Partners.

3.6.2 Specific use cases

The main other use cases that cover the key end-user requirements are:

- Health and condition monitoring
- Aircraft cabin interior monitoring
- Automotive sensing and cabin interior monitoring

This Section provides a detailed description for these additional use cases and how they can be addressed by the ASSC. The AMANDA system will consist of the AMANDA Core System, as described in Deliverable D1.2, and various sensors that are chosen for each specific use case. The list of the sensors, for each individual ASSC version, was finalized after analysing the end-user requirements gather in one-to-one meetings and at trade shows attended by the AMANDA project partners. The ASSC addresses the common challenges of weight reduction to increase energy efficiency (automotive and aircraft), modular systems for reduced overall system complexity and maintainability (medical, automotive and aircraft) and flexible deployment unrestricted by power/data cable limitations (medical, automotive and aircraft).

The medical, aircraft and automotive use cases have in common that they are in regulated industries, with high barriers to entry and stringent requirements for the adoption of new technologies. The use cases considered here will therefore focus on non-safety critical applications within these sectors.
The main purpose of the sensor is to gather information autonomously, that will help address specific issues for different companies, with some local signal conditioning or data processing on the ASSC and data transmission via the ASSC's RF channels to the automotive, aircraft or medical system.

3.6.2.1 Health and condition monitoring (UC23)

The low power consumption of the ASSC and the potentially rapid response of its on-board sensors makes the ASSC very suitable for point-of-care, patient-operated medical devices such as COPD analysis, asthma analysis, respiratory illnesses and sports medicine.
High-speed measurements and rapid response are frequently required, as well as real-time monitoring and the ability to take discrete measurements. The necessity for portable equipment drives the requirement for ultra-low power consumption.
For example, respiratory disease is one of the world's largest therapy areas. An autonomous and fast response sensor system will allow accurate, real time monitoring of breath in a system that is both portable and affordable for patients.

3.6.2.2 Aircraft cabin interior monitoring (UC24)

The aerospace industry is on the verge of the same digital transformation trend that is occurring in other industries and applications. This transformation has been slower than most industries due to size, weight and power challenges associated with widespread sensor deployment, the limited availability of communications and the challenge of certifying new technologies for deployment on aircraft. Initiatives such as the RTCA SC-236 committee on Standards for Wireless Avionics Intra-Communication System (WAIC) are enabling the deployment of wireless sensor networks on aircraft, however powering such sensors remains a challenge. Furthermore, there is a need for long lifetime (15+ years) and ability to withstand high pressures, requiring a solid-state design.
Specifically, an environmental control system can be integrated with the aircraft using the energy of compressed air bled from the main engines or auxiliary power unit compressors to cool the bleed air itself. Such a cabin environmental control system will result in fuel savings by reducing bleed air and controlling the recirculation ratio to maintain a target air cabin quality. The environmental control system will require a low power consuming and highly sensitive sensor system, which must meet a range of strict regulations. Of high importance is the longevity of the sensor system, as electronic changes are very costly particularly with aircraft. The sensor system also has to withstand high pressures and the ASSC solid state design is well suited for that.

3.6.2.3 Automotive sensing and cabin interior monitoring (UC25)

Automotive sensing is a fast-growing segment with applications in the monitoring of cabin air quality, exhaust gas emission control and leak control from vehicle air-conditioning/refrigeration gas. In particular, CO_2 sensors are used for applications in in-car air quality monitoring and in the detection of CO_2 leakage from car air conditioning units. This is becoming more and more important as automotive manufacturers are increasingly switching from refrigerant gases to CO_2 as the coolant gas of choice in automotive air conditioning systems. However, CO_2 must be continually monitored to prevent leaks in the air cabin which can create driver drowsiness and slow reaction times. Sensors can be integrated with the car's climate control systems to bring in more fresh air from the outside.

3.6.3 Qualitative analysis

This Section summarizes the different sensor models, RF units, power sources and main control units that will be included in other use cases which were discussed above. An overview of the modules is provided in Table 22:

Use case (UC)	Sensor types
UC23: Health and condition monitoring	Temperature, CO_2, acceleration/force, capacitive, light, humidity
UC24: Aircraft cabin interior monitoring	Temperature, CO_2, light, humidity
UC25: Automotive sensing and cabin interior monitoring	Temperature, CO_2, light, humidity, acceleration/force

Table 22 Sensors used for the other use case implementations

The proposed RF chip alternatives in combination with the different use cases are shown in Table 23:

Use cases	RF Chip alternatives
Health and condition monitoring	BLE, Nb-IoT
Aircraft cabin interior monitoring	BLE
Automotive sensing and cabin interior monitoring	BLE, Nb-IoT

Table 23 RF Chip and use case relationship

An overview of the proposed model for RF chip is shown in Table 24 below:

RF chips	Manufacturer Part Number
BLE	RSL10
Nb-IoT	nRF9160

Table 24 RF Chips used for the other use case implementation

The following energy harvester (PV) and energy storage unit (battery) can be used to create the other case demonstrators, as depicted in Table 25:

Power	Manufacturer Part Number
PV	QFN28

Battery	Stereax® M250

Table 25 PV and Battery used for the other use case implementation

An overview of the proposed main control unit (MCU), power management integrated circuit (PMIC) for use cases is provided in Table 26:

Other electronics	**Manufacturer Part Number**
MCU	ARM Cortex-M 32-bit
PMIC	QFN28
FRAM	MB85RS64TU

Table 26 MCU, PMIC, FRAM used for the other use case implementation

An overview of the proposed sensors for the other use cases is provided in Table 27:

Sensor Type	**Manufacturer Part Number**
Temperature	MS1089
CO_2/Smoke Detector	ADUCM355
Acceleration/force	LIS3DHTR
Capacitive	MS8892
Light	OPT3001
Humidity	BME680

Table 27 Sensors used for the other use case implementation

3.6.4 Quantitative analysis

The medical, automotive and aircraft use cases are useful for facilitating the different needs created in these environments. However, their capabilities should also be adapted to the relevant energy and space profiles. Therefore, it is necessary to present the power consumption and footprints of the components used for these other use cases to conclude if the use of the ASSC will be of benefit in the relevant environment. An overview of the available and required power analysis for all sensors and RF chips for the ASSC, as described in the above use cases, is provided in the Tables below. Table 28 provides information on the available light intensity, directly related to available power from the PV element, and energy required for measurement and transmission. Table 29 includes dimensions of each sensor, power source, MCU, PMIC, FRAM and RF chip, in accordance with the information available in Deliverable D1.2:

Specific use case (UC)	**Average illumination level (lux)**	**Energy/measurement required (mJ)**	**Measurement interval range required (s)**	**Energy/wireless transmission (µJ)**

UC23: Health and condition monitoring	300-500	~10	1-60	20 (BLE) – 100,000 (Nb-IoT)
UC24: Aircraft cabin monitoring	200-500	~10	10-600	20 (BLE)
UC25: Automotive sensing (cabin)	>1000	~10	1-60	20 (BLE) – 100,000 (Nb-IoT)

Table 28 Typical illumination available and energy levels required for each use case

Sensor type	**Power consumption**					**Dimensions**
	Quiescent current (lowest sleep mode/OFF)	**Quiescent current (standby mode)**	**Wake-up current**	**Active current**	**Peak current**	
Accelerometer	Power down: 0.5µA	No standby, either power down or operation	n/a	Normal: 2µA@1Hz Normal: 11µA@50Hz	Low power: 6µA@50Hz	3 x 3 x 1mm
CO_2/Smoke detector	4µA / switch off externally	2mA	20mA	Average:20mA	Peak:30mA	5 x 10 x 1mm
Humidity	n/a	Sleep mode 0.15µA	n/a	Average VoC: 12mA@1Hz VoC: 0.9mA @ 1/3Hz VoC: 0.1mA@1/300Hz RH, P, T: 3.7µA @ 1Hz	Peak: 12mA for VoC	2 x 2 x 0.75mm

Capacitive	50nA	50nA 720nA (oscillator enabled for periodic measurement)	n/a	Average: 770nA at 2 measurements / sec 1.5µA at 32 measurements / sec	11µA	1.52 x 1.03 x 0.64mm
Light	Power down: 0.3-0.4µA	-	n/a	Active: 1.8-3.7µA	n/a	2 x 2 x 0.65mm
Temperature	15nA max. 20nA	15nA max. 20nA	n/a	Average: 80nA	Peak: 75µA	1.39 x 0.93 x 0.84mm
PV	-	-	-	-	-	10 x 10 x 1.5mm
Battery	-	-	-	-	-	25.5 x 10 x 0.7mm
MCU	280nA	850nA (RTC + 8kB SRAM retention)	n/a	29µA/MHz	n/a	10 x 10 x 1.2mm
PMIC	200nA	n/a	n/a	n/a	n/a	5 x 5 x 1mm
FRAM	9µA	n/a	n/a	0.8 mA (Max@10 MHz)	n/a	2 x 3 x 0.7mm
BLE	Deep Sleep, IO Wake–up, 25nA	With 32KHz running and data retention 100nA	-	Peak Tx: 4.6mA (3V. 0dBm) Peak Rx: 3.0mA (3V)	-	6.4 x 6.4 x 1mm
Nb-IoT	PSM floor current: 2.7µA	-	-	Active Tx current (+23dBm) > 250mA	-	10 x 16 x 1mm

				(peaks 380mA)		

Table 29 Power consumption and footprints of the components used for the other (medical, automotive and aircraft) use cases

The expected cost for the energy harvester clearly depends on the application type. Although more difficult to launch (due to stringent certification requirements), medical products typically can accept a higher premium. For example, current breath analysis equipment can cost above €10,000, and the market is looking for solutions which allow for remote monitoring at point-of-care in order to reduce equipment and patient costs. Alternative solutions should target a price range between 100's of euro (wearable versions) and few 1,000's of euro (static equipment) depending on the device functionality and complexity. Aerospace and automotive will have similar sensing requirements, automotive being more cost sensitive. There are currently thousands of sensors in cars, therefore the acceptable price would range from few euros to tens of euros.

4 End user and business functional and non-functional requirements

Table 30 is a compilation of the end-user requirements as they were acknowledged from stakeholders' input, as described in Section 2.1.1. This data provides an overview on the level of coverage of the user needs by the different ASSC implementations and can be used to determine whether they constitute viable solutions to the stakeholders' demands. Moreover, Table 31 below shows the functional and non-functional requirements for each of the use cases that have been selected and described in this report.

Use case and description	End user requirements
Building automation	
UC1: Environmental room indicator Measure different environmental parameters in a room and give feedback to occupants	The ASSC should provide measurements about the environmental parameters in a room. If the indications are not optimal, the end user should be notified in order to act and maintain a healthy room environment
UC2: Automated room controller Data from room sensors is used to adjust room conditions	The ASSC should adjust the room conditions according to the pre-set room's optimal conditions
UC3: Adaptive room controller Data from room sensors and other predictive information is used to control the system	The ASSC should predict and adapt the building environmental conditions according to predefined optimal conditions
Smart cities	
UC4: Parking slot occupancy Detect a car arriving to a parking spot. Detect the departure of the car from the parking spot. Collect environmental data	The ASSC should determine a parking lot's occupancy and transmit the results to a data collection entity
UC5: Weather Station UC6: Air quality station Collect data on temperature, humidity, air pressure, humidity, UV index, and concentrations of toxic gases in the air.	The ASSC should act as a weather and air quality station and share its collected information wirelessly
UC7: Personal identification card with toxic gas detector Collect data on temperature, humidity, air pressure, noise, and concentrations of toxic gases	The ASSC should be used by each individual employee and warn them in case the surrounding environmental conditions become unhealthy
UC8: FMCG tracking and monitoring for food delivery Collect data on temperature, humidity and transport time	The ASSC should track and monitor food delivery and condition-related information

Smart agriculture	
UC15: Cattle tracking Monitor position and grazing pattern of cattle	The ASSC should monitor the cattle's position and grazing pattern and alert the user for any abnormal animal condition or activity
UC16: Smart irrigation Monitor temperature. Light intensity and soil humidity.	The ASSC should keep an overview of the farm environmental conditions and automate its irrigation
Wearables	
UC17: Behaviour monitoring Capture data to study the behaviour of subject carrying the card.	The ASSC should monitor the behavioural habits of the user
Industrial IoT	
UC18: Cargo transportation conditions Capture environmental data during transport of goods via cargo	The ASSC should provide an overview of the cargo's environmental conditions during transport
UC19: Asset tracking (indoor) Locate a valuable asset within a warehouse or large building	The ASSC should track a company's assets within its premises
UC20: Worker comfort level monitoring Monitor environmental parameters affecting human comfort	The ASSC should monitor and ensure each individual office/work place's comfort levels
UC21: Workplace information delivery Monitor environmental information related to health and safety	The ASSC should ensure a safe and healthy environment for the employees
Other IoT applications	
UC23: Health and condition monitoring Real-time monitoring of physical parameters and brutal changes (fall event)	The ASSC should monitor in real time the user's health condition and send alerts in case of abnormal readings
UC24: Aircraft cabin interior monitoring Monitor air quality within a plane	The ASSC should monitor the environmental conditions within a plane's cabin
UC25: Automotive sensing and cabin interior monitoring Monitor ambient environmental parameters within a vehicle	The ASSC should monitor the environmental conditions in a car

Table 30 End user requirements

Functional requirements include sensing type, measurement frequency, wireless protocol, encryption type. Non-functional requirements include location of the device and any size or mechanical constraints.

Use case and description	Functional	Non functional	Restrictions, remarks
	Building automation		
UC1: Environmental room indicator	Sensing: Measure Temperature, Humidity, CO_2 Sampling rate: 2 per minute Store measurements in FRAM Communication: Send data to User's smartphone (use BLE ADV). 6 ADV events per minute Data may be AES-128 encrypted	Card on user's desk Card in the room, office Indoors > 400 lux, 8 hours per day Fitting enclosure, holder needed LoRa gateway in building	An appropriate app is needed
UC2: Automated room controller	Sensing: as above Processing: Aggregate/average data Communication: Send data to building's gateway (use LoRa. Fastest every 10 mins Data is AES-128 encrypted Other: Sampling speed can be adjusted by LoRa feedback. Server uses data to control system	Cards in chosen illuminated places in building/room Indoors > 400 lux, 8 hours per day Fitting enclosure, holder needed LoRa gateway in building	More than 140 LoRa frames possible if working at lower SF. Depends on environment
UC3: Adaptive room controller	As above. Extra entry for server. Data coming from weather prediction stations.	Cards in chosen illuminated positions in building or room. Indoors >400 lux Fitting enclosure/holder LoRa gateway in building	
	Smart cities		
UC4: Parking slot occupancy	Measure Temperature, Humidity, Light, Magnetic field, Acceleration Sampling rate: 4 per minute or less	Sensor placed above parking lot (on ceiling or wall) Indoors. Active 24/7 Fitting enclosure	No ultrasonic sensor in Amanda Is illumination sufficient?

	Processing: Detect car arrival/departure Communicate with LoRa: Ping every 15 sec Tx results about car lot free/not free: 3 per hour Rate to communicate Humidity, Temperature, CO_2 values: N.A.	LoRa gateway placed at 300m max Illuminance: 40 - 200 lux	Can magnetometer do detection at 2m? This could be a critical use case Reduce frequency of ping and humidity, temperature and CO_2 measurements
UC5: Weather Station UC6: Air quality station	Sensing: Temperature, Humidity, Pressure, Light, CO_2, Volatile Organic Compounds (VOC), Sampling rate: 4 per hour Data is collected and transmitted directly using LoRa. Communication: Use LoRa. 4 per hour	Outdoors (3-10 Klux) Active 24/7 LoRa gateway at 2km max	No UV sensor in Amanda For gases: only CO_2 in Amanda Limited use case, unless appropriate sensors integrated Enough energy should be collected to allow work during the night. Any other buffer? That will determine the size of the storage.
UC7: Personal identification card with toxic gas detector	Sensing: Temperature, Humidity, Pressure, Light, CO_2, Sound Sampling rate: 20 per hour Process data to detect limit Communication: with LoRa:. 4 per hour Ping 30 per hour	Sensor placed above parking lot (on ceiling or wall) Indoors. Active 8 hours per day Fitting enclosure LoRa gateway placed at 300m max Illuminance: industrial (700 lux)	
UC8: FMCG tracking and monitoring for food delivery	Sensing: Temperature, Humidity Sampling rate: 4 per hour Data is collected and stored in memory	There is no direct gateway. LoRa network in the city should be used	No light in food bag, so energy storage must be filled before

	Communication: use NFC to mark start of travel, end of travel	Special enclosure needed for food transportation.	Amanda has no display. How to mark start/end delivery? NFC suggested here Critical use case. Illumination is bad.
	Smart agriculture		
UC15: Cattle tracking	Sensing with accelerometer Position determined using LoRa and gateways with accurate time stamp Accelerometer values pre-processed and sent every 10 mins. Communication: With LoRa: 6 per hour	Appropriate enclosures required Outdoors 3-10 Klux	Amanda card does not include a GPS
UC16: Smart irrigation	Temperature data is locally pre-processed and transferred. Communication: With LoRa: 1 per hour Transfer data to gateway	Appropriate enclosure needed Soil humidity sensor needed Outdoors 3-10 Klux	Amanda card does not include a soil humidity sensor
	Wearables		
UC17: Behaviour monitoring	Sensing: Temperature, humidity, light, sound, acceleration, CO_2 Sampling rate N.A. Preprocessing: N.A. Communication: protocol N.A. Data encryption needed (AES-128)	Indoors/outdoors, depending on the subject Appropriate sensor Size restriction (worn)	Specific cases need to be defined for further description. Processing power for sensor fusion is important.
	Industrial IoT		
UC18: Cargo transportation conditions	Sensing: Temperature, CO_2, sound, distance, imaging Sampling: 1 per minute to 4 per hour Store measurements in FRAM	Card mounted to product Product located in cargo container Fitting enclosure, holder	Container must be equipped with a gateway, allowing the ASSCs attached to the different products

	Communication: Send data to container's gateway (BT Smart) Other: Analyse measurements and compare with limits, send message if limits violated	Battery must be fully charged at the start of the journey	to communicate over short range
UC19: Asset tracking (indoor)	Sensing: Temperature, CO_2, sound, acceleration, light, position Sampling: 4 per minute to 4 per hour Store measurements in FRAM Communication: Send data to building gateway in exception case (use LoRa or BT Smart), Full data readout by NFC, use BT Smart for indoor positioning Other:	Card mounted to asset or carried by person, exposed to illumination Fitting enclosure, holder	If high value asset must be protected from fire, a frequent sampling of the CO2 is mandatory Accelerometer must measure very frequently to be able to capture dynamic events
UC20: Worker comfort level monitoring	Sensing: Temperature, CO_2, light, sound, humidity Sampling: 1 per minute Store measurements in FRAM Communication: Send data to building gateway every 15 minutes (use LoRa or BT Smart)	Cards in chosen illuminated positions in building/room Indoors Fitting enclosure, holder	
UC21: Workplace information delivery	Sensing: Temperature, CO_2, sound, imaging, humidity, light Sampling: 6 per hour Communication: Send data to building gateway every 10 minutes (BT Smart)	Cards in chosen illuminated positions in building/room Indoors Fitting enclosure, holder Disable image capture in dark conditions	Imaging sensor requires to send each image after it's captured (no image storage or image processing capability)
Other IoT applications			
UC23: Health and condition monitoring	Sensing: Temperature, CO_2, acceleration/force, touch, light, humidity Sampling: 1 per second to 1 per minute Store data in FRAM Communication: Send data to building gateway (LoRa, Nb-	Cards in chosen illuminated positions close to patient or carried by patient Indoors Fitting enclosure, holder	

	IoT) or medical personnel's mobile phone (BLE, NFC) Other: Server uses data to alert medical personnel		
UC24: Aircraft cabin interior monitoring	Sensing: Temperature, CO_2, light, humidity Sampling: every 10 seconds to every 10 minutes Communication: Send data to aircraft gateway (BLE)	Cards in chosen illuminated positions in the aircraft cabin Indoors Fitting enclosure, holder	
UC25: Automotive sensing and cabin interior monitoring	Sensing: Temperature, CO_2, light, humidity, acceleration/force Sampling: 1 per second to 1 per minute Communication: BLE, Nb-IoT	Cards in chosen illuminated positions in the car cabin Indoors Fitting enclosure, holder	

Table 31 Functional and non-functional requirements for all selected use cases

5 Core ASSC platform

Three different versions of the ASSC are anticipated in the AMANDA project: indoor (stationary), outdoor (stationary or mounted on mobile assets) and wearable (indoor/outdoor). The need for the three versions of the ASSC has been confirmed by the use cases detailed in Section 3 of this document.

The differentiating factors of the three card versions are presented in Section 6 below. Besides these factors, all card versions require certain core functionalities, which should be present in all versions of the card:

- **Energy Harvesting**. Enough energy should be harvested for the application. The size of the solar cell should therefore be chosen accordingly or features of the application might be limited by that size.
- **Power management**. The power management is used to manage the harvesting and the storage, as well as the efficient power conversion in order to deliver the power to the system at the right voltage.
- **Energy storage**. The energy storage should match the following:
    - Store enough energy to deal with periods when the solar cell does not deliver enough energy for the application.
    - Make up for the energy peaks. That means the short energy busts of the application. This is specially demanding when the system is transmitting data using LoRa communication. More than 100mJ should be delivered in less than 2 seconds.
    - Minimize the energy losses (small internal resistance) especially when transmitting.
    - Enough recharge cycles to match the expected life time of the product.
    - Small leakage.
- **Processing**. A processor is needed to control the whole system, including power management, sensors and communication.
- **Communication**. The system integrates 3 communication possibilities that depend on the application requirements:
    - Bluetooth Smart. This short-range communication system will be used in situations where short range communications is preferred. For instance, when the cards are not directly accessible and are several meters away from the reading equipment. BLE is also good in situations where positioning/location services are required. It includes the capability to work at lower baud rates and thus to improve range. BLE requires less energy than LoRa. Therefore, whenever possible, BLE should be preferred to LoRa.
    - LoRa. It can be utilized when it is not possible to use BLE, especially when communication over hundreds of meters is needed.
    - NFC. This method is required for fast and near field interaction. For instance, when pairing/commissioning using a smartphone is important, such as the secure transmission of an encryption key. Fast transfer is also possible between a smartphone and the card. For instance, to quickly transfer a lot of data between the card and a smartphone. In emergency cases, when there is not enough energy stored in the card, the NFC chip can also be used to quickly recharge the energy storage.
- **Wake-up** from the lowest power sleep state. The lowest power sleep state is a hardware-configurable mode where only the PMIC and the touch sensor are powered and active, giving the touch sensor the hardware capability of turning the MCU on via the PMIC.
- **Time keeping**. The RTC is used for time keeping. It can also be used as external and accurate wake-up signal for the microcontroller, allowing the rest of the system to go

in a really low power consumption. A periodic wake-up will allow for a regular polling/scheduling of activities.

- In systems where the user can take the card in the hand, the touch sensor can be coupled with the RTC to allow a low-power "wake on touch" functionality.

A core ASSC platform has been conceived, as presented in Table 32, which will incorporate these basic functions, and which will serve as the basis for the different card versions.

Components in the core platform	**Short description**
Card	The credit-card sized encapsulation for the components and PCB
PCB	PCB carrying and interconnecting the electrical components
Energy Storage Units	Printed batteries with Ilika technology for storage of the harvested energy
PV harvester	Photovoltaic energy harvester (solar cell), which is the main source of energy for the AMANDA ASSC
PMIC	Power management IC, • Collects the energy from the PV cell, and charges the battery with high efficiency • Provides regulated power to system components (MCU, radios, sensors)
MCU	Main controller and data processing unit
BLE + Zigbee radio	Short range wireless communication interface
LoRa/LoRaWAN radio	Long range wireless communication interface
NFC interface	Near field communication interface for fast transfer of larger amounts of data, and also usable for fast-charging the battery in exceptional cases
Capacitive sensor	Interface for system wake-up from lowest power sleep state using human touch
RTC Timer	Real time clock for time keeping and periodic wake-up of the system from a low power sleep state.

Table 32 Elements forming the core ASSC platform

6 Versions of the AMANDA ASSC

From the core ASSC platform, three card versions are derived by adding different sets of sensors, selecting the suitable radio interface and loading application-specific software.
Besides the three card versions, as shown in Figure 12, the ASSC platform might be used as the basis to develop a teaching platform for IoT education at technical education institutions.

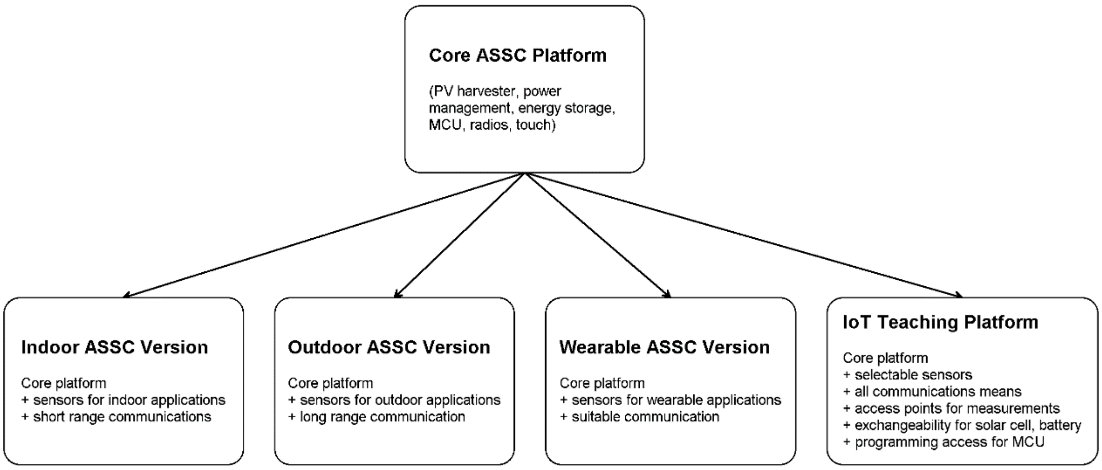

Figure 12 Illustration of inheritance of the ASSC versions

The differentiation between the three card versions is shown in Table 34 and is based on the following parameters:

- Cost. Only those components (sensors, radios) should be mounted, which are required to cover the assigned use cases. A cost-effective encapsulation should be employed, depending on the environment in which the card will be used. Outdoor and wearable versions of the card must be protected from rain, snow, dust, etc.
- Space. The minimum required set of components should be employed in order to facilitate the intended card size and thickness (credit card size, max. 3mm thickness).
- Energy budget and energy requirement. The size of the PV harvester and the number of batteries might be different in the different card versions, depending on the operating environment (light intensity) and the energy requirement of the different use cases (set of sensors, measuring rate, communication method and amount of data).

Table 33 and Table 34 below show the use cases and types of sensors respectively, that can potentially be addressed by each of the "commercial" versions of the ASSC (indoor, outdoor and wearable):

Indoor	Outdoor	Wearable
UC0, UC1, UC2, UC3, UC4, UC5, UC6, UC7, UC8, UC9, UC11, UC14, UC15, UC18, UC19, UC20, UC21, UC22, UC24, UC25, UC26	UC4, UC5, UC6, UC8, UC9, UC10, UC11, UC14, UC15, UC16, UC18, UC24, UC25, UC26	UC7, UC13, UC17, UC20, UC22, UC23, UC26

Table 33 List of use cases potentially met by each of the ASSC versions (indoor, outdoor, and wearable)

Indoor	Outdoor	Wearable
Temperature	Temperature	Temperature

Imaging	Imaging	Imaging
CO_2	CO_2	CO_2
Relative Humidity	Relative Humidity	
VOC	VOC	
Magnetometer	Magnetometer	
Noise	Noise	Noise
Light	Light	
Fingerprint		Fingerprint
	Air Pressure	
	Accelerometer	Accelerometer
		Human body detection

Table 34 Overview of sensing capabilities in the different card versions

6.1 Indoor

The indoor version of the card is meant to be installed at a fixed indoor place or a moving indoor asset. It could be used as:

- Environmental room indicator and adaptive controller (UC1, UC2, UC3)
- Indoor parking slot occupancy (UC4)
- Air quality and weather station (UC5, UC6)
- Personal identification card (UC7)
- FMCG tracking and monitoring for food delivery in warehouse, trucks (UC8)
- Indoor asset or cattle tracking (UC15, UC19)
- Cargo transportation (UC18)
- Comfort level estimation (UC20)
- Workplace information delivery (UC21)
- Aircraft cabin or automotive interior monitoring (UC24, UC25)

In order to track indoor air quality and to estimate occupancy and comfort levels, the temperature and CO_2 levels are an important factor. For indoor air quality, strong indications are also the relative humidity level and volatile organic compound (VOC) concentration. VOCs can be difficult to discriminate and also consume more power, due to the internal heating element required. Actual implementation of additional sensors (including VOC) within the ASSC will therefore depend on the amount of light available. Indoors exhibit typically less than 500 lux light intensity which may increase the measurement period of additional sensors (including VOCs) to several minutes or even hours in some use cases. For the comfort of people living in an indoor space, light and noise levels are important as well. Personal identification can be implemented with face recognition via an imaging sensor and fingerprints can be used as well. For the fire detection option, the temperature sensor can be utilized. A magnetometer can be added for indoor parking slot occupancy. Indoor asset tracking can be implemented via BLE positioning. Considering the above, the indoor version of the card should have the following sensors:

- Temperature
- Imaging

- CO_2
- Relative humidity
- VOC
- Magnetometer
- Noise
- Light
- Fingerprint

6.2 Outdoor

The outdoor version of the card is meant to be installed at fixed outdoor locations of moving outdoor assets, such as cars and other vehicles. The use cases to be covered are the following:

- Car space occupancy (UC4)
- Weather station (UC5)
- Outdoor air quality station (UC6)
- Outdoor FMCG tracking and monitoring for food delivery (UC8)
- Cattle tracking (UC15)
- Smart irrigation (UC16)
- Outdoor cargo transportation (UC18)
- Aircraft cabin or automotive monitoring close to windows (UC24, UC25)

For the weather station operation, the basic measurement requirements include the air temperature, relative humidity and air pressure. Light is a good indication of sunny or cloudy conditions. For the outdoor air quality, the levels of CO_2 and volatile organic compounds (VOC) are important indicators. Actual implementation of additional sensors (including the VOC) within the ASSC will therefore depend on the amount of light available. Outdoor applications will have at least one order of magnitude more light intensity than indoors applications and should provide sufficient light for all sensors operation, at a relatively fast measurement rate (every minute or less). For the car space occupancy scenario an imaging sensor along with a magnetic sensor can be used to detect whether a car is present or not. Outdoor asset tracking and data mapping can be implemented by the LoRa positioning feature. An accelerometer can be used to track if outdoor assets are moving as well. Based on the analysis above the following sensing capabilities must be implemented in the outdoor version of the card:

- Temperature
- Imaging
- CO_2
- Relative humidity
- Air Pressure
- VOC
- Accelerometer
- Magnetometer
- Noise
- Light

6.3 Wearable

The wearable version of the card is meant to be worn by people and used in the following use cases:

- Personal identification card (UC7)
- Behaviour monitoring (UC17)
- Comfort level estimation (UC20)
- Health and condition monitoring (UC23)

In order to implement fall and harm detection, an accelerometer must be used that can detect peaks in forces applied to the wearable device and thus to the person wearing it. For the comfort levels of a worker that moves in different spaces, the temperature, CO_2 and noise levels are important factors. For personal identification, the card could include an imaging and a fingerprint sensor as well.

For use cases where the card is worn directly in contact with the body (which is the case with commercially available wearable devices like fitness trackers, smart watches, in-ear phones, etc.), the card should be able to detect if it is worn, or if it is lying around unused. The card should only be active if it is worn and enter a low power sleep mode if it is not used.

Considering the above analysis, the wearable version of the card should have the following sensing capabilities:

- Temperature
- Imaging
- CO_2
- Accelerometer
- Noise
- Fingerprint

6.4 Platform for IoT teaching

There is a need for a platform that can be used for teaching. ZHAW for instance requires several boards every year for students taking the IoT class. In that course, students are introduced to various wireless systems (LoRa, 802.15.4, BLE), pairing, security in IoT, Energy Harvesting, the need for low-power. AMANDA is uniquely placed to be used in such a case. According to ZHAW, such a platform should include the following:

- Energy harvester and power management
- Appropriate storage
- Bluetooth Smart and 802.15.4
- LoRa and LoRaWAN
- Different sensors
- At least one microcontroller
- Observation points for energy measurement on power analyser
- Observation points for oscilloscope
- Connector points for programming the microcontroller(s)
- Possibilities for another solar cell
- Possibilities for another storage element (flat capacitor)

Students at ZHAW normally receive a kit each during the class. They can keep the kit after the class. The price for such a kit should therefore be acceptable. So far, it has been around 30 Euros. The variation for teaching should be in the same order.

7 Recommendations

This Section presents a summary of recommendations from the voice of the customers in relation to the different use cases for the AMANDA ASSC. The collection of information was done through questionnaires sent by CERTH and Penta to the customers of industrial enterprises.

7.1 Building automation

On average, people spend 90 percent of their time indoors [15]. It is important to end users that IoT systems can operate regardless of their location, e.g. especially indoors. For building automation, reliability of the service is particularly important. Building users wish to have the possibility of interacting at any point in time with the system that should be able to operate even when users are not present in the building. An autonomous wireless sensing card such as the one developed as part of the AMANDA project (ASSC) will be an attractive technology for building automation provided that it can work reliably and be cost effective (e.g. compete with battery or wired products already on the market). The miniaturized size of the system is less critical for building automation, unless the final product needs to be hidden. The main recommendation from building automation sector is thus to focus on innovative technology that will operate in a reliable and maintenance-free way.

7.2 Smart cities

Digital networked technology is the foundation for the development of smart cities. Getting accurate information in a timely manner is indeed a basic precondition for successful management of many aspects within smart cities, such as traffic information or collection of meaningful environmental data. The rapidly growing legal regulations, advocating the use of green energy, will set new requirements and criteria that smart cities should fulfil.

The AMANDA project has the ambition to provide a safe and accurate input element (the ASSC) into the monitoring, control and management systems of smart cities. The multi-sensing approach, autonomy (e.g. self-powered), reduced footprint, and expected competitive price of products with regard to the number of supported sensors are significant benefits of the ASSC over similar products on the market.

By analysing questionnaires and discussions with end users, research should certainly continue in the field of protection and detection of pollutants and toxic gases. Although the AMANDA platform will aim to be modular by design (and therefore compatible with future pollutant sensors that can meet size and power consumption requirements), the development of such sensing technologies for measuring pollution is beyond the scope of this project. We will focus on the many use cases that can be addressed by sensors specified in Deliverable D1.2. For example, the capability of the ASSC to detect parking space occupancy provides a large market potential for such a product. Monitoring and control of food delivery conditions should contribute to an increased quality of food delivery services and may help FMCG companies meet upcoming food-safety related standards.

The Voice of the Customer has provided a clear direction in which further research should focus. We will endeavour to develop a product platform that can meet most of the end users' requirements.

7.3 Wearables

There is a clear need to investigate the behaviour and habits of consumers in order to increase their wellbeing and efficiency, for example at work. The system (e.g. the ASSC), which is monitoring the impact of surrounding environment on user's behaviour of people, is attached on a wrist or worn by end users. It should therefore be non-obtrusive. Otherwise it will affect the behaviour of the tested subject. The average weight of the human is 62kg. The user should not be aware of any electronic system on his body and perform its normal activity. If the wearable node weight more than 0.5% of the user weight, then it will not be widely accepted. The full autonomy is nice feature even if consumers currently accept a periodic charge of devices. Extending functionality time of the system would be valuable and full energy autonomy would be an even better additional feature. However, as mentioned above, size and weight should be the focus for technical solutions. The components selected for the wearable ASSC version, as discussed in Section 5, should meet these criteria.

7.4 Industrial IoT

There are several use cases that the AMANDA ASSC could cover in an industrial environment, as can be also seen from the questionnaires of Section 3.5. The Industrial IoT is a sector that, right now, is rapidly developing and this is why there are certain concerns that should be taken under consideration in order to ensure the best possible conditions for the final product. Some of them are:

- **The volume of the IIoT within an industry**: refers to the extent that the processes of an industry need (and can) be automated and the increased demand for it in order to lower costs.
- **The IIoT integration**: the increase in automation demands accumulated many different technologies and platforms with different manufacturers which complicated more an already complex problem. Moreover, due to the interconnectivity of global enterprises the overview of the knowledge management within itself has become more and more confusing for the employees.
- **Lack of standards**: there isn't any standardization when it comes to IIoT. This has created an imminent demand for security that was previously negligible due to the isolated nature of the industry.

When it comes to the AMANDA project, some recommendations for these issues would be:

- **The volume of the IIoT within an industry**: the ASSC should be a standardized version that provides specific measurements for specific aspects of the industry
- **The IIoT integration**: the integration of the ASSC to the existing industry's solution should be as simple as possible and its assimilation to the industry's systems should happen as fast as possible. Lastly, there should be an API that is easily combined with other platforms to increase the visibility with regards to the measurements from the ASSC.
- **Lack of standards**: a number of specific standards for the ASSC security should be established and enforced. Furthermore, individual change management processes should be created, for each industry that will integrate the AMANDA platform, in order to ensure that it can be accommodated together with the current configuration.

8 Conclusions and future work

This Deliverable, D1.3 Voice of the Customer completed report is part of **Task 1.2: System requirements and needs**. The Deliverable provides a comprehensive document on the preliminary end-user requirements including a detailed Voice of the Customer. A qualitative and quantitative analysis has been performed to select key sensors/RF/electronic components that will be included in the core platform. This core platform will be modular and adapted into three versions (indoor, outdoor and wearable) that will comprise specific sensors with corresponding firmware to address key identified use cases.

Section 2 described the Voice of the Customer methodology and outcome. In Section 3, detailed use cases (classified in key application areas) were presented with a focus on qualitative and quantitative requirements. A list of functional and non-functional requirements was given in Section 4. Section 5 described the core ASSC that will be developed during the AMANDA project. The core platform, refined into several designs to address key use cases, was identified in Section 6. Finally, in Section 7, comprehensive recommendations were given for further directions for the Project while in Section 8 conclusions for this work were drawn.

Future work will focus on continuing the interactions with key stakeholders and end users for all the applications targeted by the projects. Since it will not be possible to test the AMANDA ASSC in all the use cases described in this report, the consortium will select and further refine a key use case in each application area, based on end-user pull and technical feasibility.

The work conducted in this Deliverable will help in the definition of the complete system's requirements under **Task T1.5 – System specifications, architecture and design** leading to **Deliverables D1.6 – Full system specification and BOM delivered** and **D1.7 – Architecture design of the AMANDA system delivered (for both breadboard and integrated/miniaturized system)** as well as to **Milestone MS1 – AMANDA systems specifications and Architecture**.

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Annex I: Questionnaires

The feedback is mostly provided by existing business partners. That is the reason why it was decided to conduct intensive surveys at all the events organized. Each questionnaire or interview consists of:

- General information of the company
- Issues in the area of interest
- Questions about useful technical features
- Questions about application/usage

A) General information about your company

- Company/institution name:

  ____

- Primary activity of the company / institution

  ____

- Number of employees / students

  ____

- Contact Email

  ____

B) Questions about areas of interest

•

- What is your professional field of work?

• ____

- Have you ever experienced working with the IoT technology (If the answer is "Yes", specify in which area)?

• ____

- Evaluate how much could the usage of IoT technology improve the quality of work in your workplace? (rate 1-10)

• ______________ (1-10)

C) Questions about Useful Technical Characteristics)

- Which sensors do you consider useful for your area of work / interest?)
  - o Temperature
  - o CO_2
  - o Image
  - o Movement and acceleration
  - o Humidity
  - o Air pressure
  - o Light intensity
  - o Smoke detector
  - o Fingerprint
  - o Magnetic sensor
  - o UV sensor
  - o Toxic gas detector
  - o Other :_______________

  - Define the signal range required, from sensor site to gateway. E.g. in cities we do not need more than 500m, while in nautical tourism we need up to 50km):

• ____

- Which possibilities of the IoT technology would be of a significant benefit in the smart cities? (rate 1-10)
    - *Autonomy*: ___________ (1-10)
    - *Multi-sensor array*: ________ (1-10)
    - *Reduced size*: ___________ (1-10)
    - *Acceptable price*: _________ (1-10)
    - *Networking more IoT objects*: ____ (1-10)
    - *Availability of the data readings*: _____ (1-10)
    - Other _________________________ (1-10)

D) Questions about Application

- In which areas do you expect the maximum possible use of an autonomous multi-sensory card (e.g. tourism, nautical tourism, building automation, security, traffic, industry, education ...... explain briefly)

• ____

- In which areas, the more significant use of the autonomous multi-sensing card, would improve the quality of life or reduce the cost of living in the city)
    - *Air quality control*
    - *Noise control*
    - *Traffic regulation*
    - *Waste management*
    - *Public lighting*
    - *Protection of archaeological monuments / sites*
    - *Fire detection*
    - *Other*__________________________
- In your opinion, what are the most important technical features of an autonomic sensory card?

• ____

- Which additional features should an autonomous multi-sensing card have?

• ____

- How important do you consider monitoring sensors data on public web sites or your smartphone? (Rate 1-10)

• ________________ (1-10)

- Do you already use the IoT technology? (If the answer is „Yes“, specify the type of sensors you are using, type and RF connection characteristics, as well as the number of interconnected sensors)

• ____

- If you already use specific sensors, can the autonomous multi-sensor card be integrated into your existing system? (if the answer is "Yes" briefly describe the possibility of integration)

• ____

Collection of feedback from end users will be a continuous process that will be performed throughout the duration of the project though participation to workshops, tradeshows, and technical conferences.