PILOT IMPLEMENTATION PLAN

Deliverable D3.1

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6GSNS

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SHORT ABSTRACT	Deliverable 3.1 introduces the implementation plans related to the energy vertical of the TARGET-X project. It describes trial sites, time plans, and test plans at different trial sites.
KEY WORDS	Testbed, Implementation, 5G, time plan, trial site, test plan, manufacturing, construction, robotics, energy, grid.
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Executive Summary

Currently, the roll-out of the 5G public and private networks is reaching the general public. Still, new use cases and opportunities in verticals like energy, construction, and manufacturing need to be explored. This is what we are aiming for in TARGET-X while keeping the big challenges of reduction of energy consumption in mind. To better understand the potential for optimization of energy consumption we deploy 5G energy monitoring devices, in the form of edgePMUs at multiple trial sites. This will not only help to better understand energy consumption but also increase energy awareness. This allows for the identification of a process and the linkage of real-world processes and their energy consumption.

This deliverable provides the implementation plan for the measurement device, three trial sites with their various types of energy consumption and a schedule on how the development and deployment for the energy trial sites are planned and what tasks need to be accomplished. Finally, a set of tests for the different trial sites are described and assigned to the trial sites.

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List of Acronyms and Abbreviations

5G	Fifth Generation
6G	Sixth Generation
D2D	Device-to-Device
QoS	Quality of Service
PMU	Phasor Measurement Unit
MQTT	Message Queuing Telemetry Transport
GOOSE	Generic Object Oriented Substation Event
RMS	Root Mean Square

1 Introduction

The global roll-out of the fifth generation (5G) wireless technology is acting as a catalyst for innovation worldwide. The deployment of 5G in various industries is paving the way for groundbreaking advancements. The TARGET-X project aims to speed up digitalization in verticals like energy, construction, automotive, and manufacturing. To achieve that, it explores and evaluates use cases for each vertical while using trials in multiple testbeds. The testbed discussed in this deliverable is situated in the 5G-Industry Campus Europe located in Aachen, Germany. By assessing the potential of 5G in this testbed, technologies like real-time communication, localization, self-description, digital twinning, and sensor-network data fusion can be evaluated and possible new features for 6G can be identified.

The energy vertical's deliverable 3.1 describes the implementation plans for the TARGET-X energy testbeds while creating a track towards the project. This pilot plan covers four different trial sites in Aachen, Germany, such as the RWTH campus distribution grid for an energy application, and for energy-related trials: the Laboratory for Machine Tools and Production Engineering (WZL), the machine hall of Fraunhofer Institute for Production Technology (IPT) for manufacturing and robotics, and the Reference Construction Site operated by Construction Robotics GmbH (CCR) for construction applications. The document further explains the pilot implementation plans for energy and energy-related trials, their test plans, development of the measurement devices, and deployment of the sensors and edge measurement devices at the trial sites. Further, a preliminary overview of the time plan for the implementations is described in this document while considering the coordination of all energy-related tasks in the trials and their scheduled durations. The objective of this deliverable is to plan the implementation for the energy vertical and other energy-related trial sites. This will ensure smooth deployment and operation of the energy vertical in the TARGET-X project. It will also result in implementing use cases related to energy monitoring for energy-aware services at each trial site.

1.1 Document overview

The document is organized as follows:

An introduction to the 5G edgePMU monitoring hardware is provided in Section 2, while Section 3 discusses in detail the energy-related aspects of three different trial sites. Section 4 presents an initial overview of the trial site's timeline using a Gantt chart, which visually represents the planned energy-related activities and their scheduled durations. Then Section 5 provides a preliminary overview of the planned tests to be conducted at each trial site and finally, Section 6 concludes the deliverable by summarizing the key findings and outcomes from the previous chapters.

2 5G edgePMU monitoring hardware

The measurement device used at the different trial sites is a Raspberry Pi 4 based data acquisition device. The device was developed by RWTH in the previous project edgeFLEX [EDG23] and will be further developed during this project. The device handles the time synchronization based on a GPS signal and can provide a time precision of up to 100 us. The edgePMU is equipped with 7 usable channels that have an input range of ±10 V. The input can be adapted with additional sensors to the specific use case, allowing for voltage and current measurements. The maximum sampling rate of 250 kSamples/s can be achieved with one channel active. When sampling on all channels in parallel a sample rate of 50 kSamples/s can be achieved. In its core the edgePMU is driven by the VILLASnode [VIL23] open-source software. VILLASnode is a software that can adapt from and to different signal sources and sinks. Some examples are the used USB data acquisition device, MQTT [MQT23], ZeroMQ [Zer23] IEC60870-104 [IEC60], GOOSE [IEC61] and others. In addition, the software allows for so called hooks. A hook can modify a signal. Such modifications include down sampling, RMS calculation, phasor estimation and more. The current version of the edgePMU is shown in Figure 1.

Figure 1: edgePMU with GPS and signal connection

3 Trial site description

In the following chapter the energy related aspect of three different trial sites is described. The general description of all trial sites within the TARGET-X project can be found in deliverable D6.1 Description of the testbed capabilities and envisioned evolution within the project. Within this chapter additional information about the planned positioning of sensors as well as the possible devices under test for the energy vertical will be given. Since this deliverable is written in an early stage of the project the specific tests and locations could change.

3.1 Energy monitoring at the construction trial site

The Reference Construction Site operated by the Center Construction Robotics at Campus Melaten, Aachen, Germany serves as a living lab for research in construction. As part of the TARGET-X project, a multi-material demonstrator will be created to investigate the real and technical feasibility of the cradle-to-cradle principle. To raise energy awareness and better understand the overall energy consumption of a construction site and its individual consumers, devices for current and voltage measurements will be deployed at several locations on the Reference Construction Site. These devices are called edgePMU and will measure the voltage waveforms or current waveforms of typical processes and their corresponding energy consumptions during the construction and deconstruction of the demonstrator structure. On the one hand, the measurement data will be used for process characterization. On the other hand, the data will be used to identify load peaks caused by single heavy consumers or many simultaneous consumers. Currently, consumers include four site containers which serve as temporary workspaces and prototype labs, a server room, a large tower crane and several other construction machines. Potential measurement locations are the tower crane, see Figure 2, the power distribution box, see Figure 3, and the server room at the Reference Construction Site, see Figure 4. The tower crane like most construction machines requires a three-phase current of 32A, [Lie09],[Bro20]. The edgePMUs are capable of three phase current and voltage measurements. Furthermore, the edgePMUs are 5G-capable and can transmit their measurement data wirelessly to a server via an existing 5G-network. The connection to the 5G-network also allows for the real-time monitoring of the construction processes. This provides the opportunity to identify potentials for an energy-optimized process orchestration.

Figure 2: Tower crane at the Reference Construction Site (in folded state)

Figure 3: Distribution box at the Reference Construction Site

Figure 4: Server room at the Reference Construction Site

3.2 Energy monitoring at the manufacturing trial site

3.2.1 Robotics trial site

Implementing energy monitoring sensors on the robotics trial site with autonomous mobile robots (Figure 5) and edge computing cluster communicating with 5G involves several steps. By the implementation on the robotics trial site with autonomous mobile robots, connected via 5G to an edge server, the setup can be compared with conventional robotic cells. The first step is to determine the scope of the energy monitoring system and identify the devices that will be monitored for energy consumption. On the trial sites, multiple autonomous mobile robots, the energy consumption of the edge server and communication devices can be monitored. The edgePMU will be installed on the devices and configured to communicate with the edge cluster computing devices through 5G. Data on the energy consumption of the autonomous mobile robots and edge server can then be collected and compared to the energy consumption of conventional robotic cells to determine the energy efficiency of the autonomous mobile robots. The data collected can be analyzed to identify areas where energy consumption can be optimized. Overall, implementing an energy monitoring system is essential for organizations that want to optimize the energy consumption of their robotics trial sites and ensure energy efficiency over time.

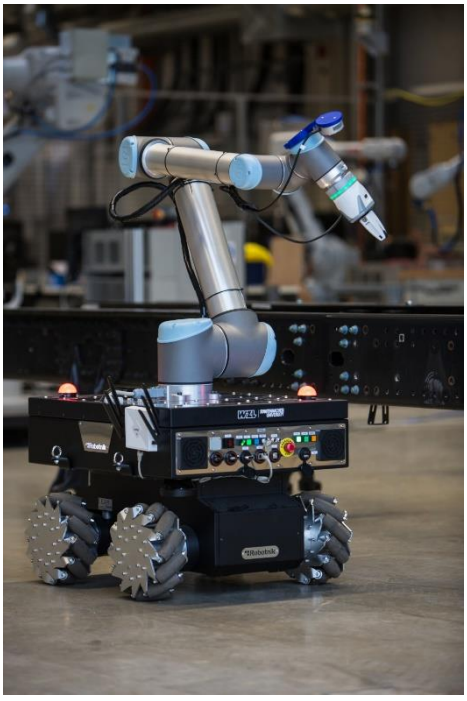

Figure 5: Mobile Manipulator Robotnik KAIROS at the WZL Machine Hall

3.2.2 Machining trial site

Energy monitoring sensors can be implemented on a machining site for monitoring of industrial air compressors and pumps, energy consumption of machine tools or wireless sensor systems for process monitoring. This process involves several steps, starting with identifying the machines that will be monitored for energy consumption. Next, suitable energy metering sensors should be integrated into the machines, edge computing devices, and communication. With the sensors in place, data on energy consumption during machining processes can be collected and analyzed to

identify areas for optimization for the milling process and find anomalous energy peaks during the process. The aim is to reduce energy consumption and improve the overall efficiency of the machining process. By implementing an energy monitoring system, optimizing energy consumption during machining processes and appliances, and achieving significant cost savings is possible. A successful energy monitoring system requires continuous monitoring, optimization, and maintenance to ensure long-term energy efficiency gains.

3.3 Energy monitoring at the grid trial site

For the grid measurement trial site at different locations within the Melaten Campus in Aachen, Germany, edgePMU devices will be deployed. The goal is to derive a better understanding of the local grid voltage and the impact of the local 5G network on the measurement quality.

Currently it is planned to deploy the measurement devices at different locations of the E.ON Energy Research Center (ERC):

ERC Main-building

The ERC Main-building is mainly used as an office building. In addition, the mechanical and electrical workshop have a working space in the basements. Furthermore, the building contains server rooms and different types of laboratories. It is planned to place a measurement device within the mechanical workshop and one in the electrical workshop to measure the consumption of different kinds of drilling and milling devices. In addition, it is planned to place one device in the ACS server/real-time laboratory and one in the ACS measurement laboratory. Find below a picture of the three rooms that will be measured. In Figure 6 the electrical workshop is depicted, in Figure 7 some of the machining tools of the mechanical workshop can be seen and in Figure 8 the ACS server/real-time lab is shown. The different rooms represent different kind of loads. In the workshops most of the loads are motors where in the electrical workshop usually short load spikes for drilling holes are expected and for the mechanical workshop also longer machining operations could occur. In contrast to that in the server/real-time lab a lot of servers present a base load, and the simulations are expected to be seen on top of that base load. The expected base load for the measurement laboratory is dependent on the number of running servers and ranges from 100 W up to about 10 kW.

Figure 6: Electrical workshop at ERC Main-building

Figure 7: Mechanical workshop at ERC Main-building

Figure 8: ACS server/real-time lab

It is planned to acquire three phase current and voltage measurements. The type of sensor needs to be determined based on the power requirements of each room/building. The measurements are either processed directly on the edgePMU or transmitted to an edge cloud server where they could be processed or saved as raw samples.

4 Time plan

This chapter provides a preliminary overview of the trial site time plan. This includes a preliminary Gantt chart that provide information about the deployment and planning of development, measurement campaigns and evaluation. The Gantt chart (Figure 9) lists the time plan for the four different trial sites that are participating in the energy vertical. Due to the evolving nature of the different trial sites the planning will be updated regularly. The time planning is divided into six main blocks. At first the trial sites will be investigated, and the overall approach will be planned within the “Energy Trial Planning”. Then based on the acquired information the measurement device will be further developed, to fit as good as possible for the different trials use cases. This is done during the “Hardware and Software Upgrade of Measurement Device”. In the third phase the devices will be deployed in the trial sites and then in phase four the different verticals will start the measurements in close cooperation. This is done during the “Measurement Campaigns for the Participating Verticals”. After the testing at the trial site the evaluation phase starts. Finally, a feedback cycle will be done to evaluate the outcomes and the impact.

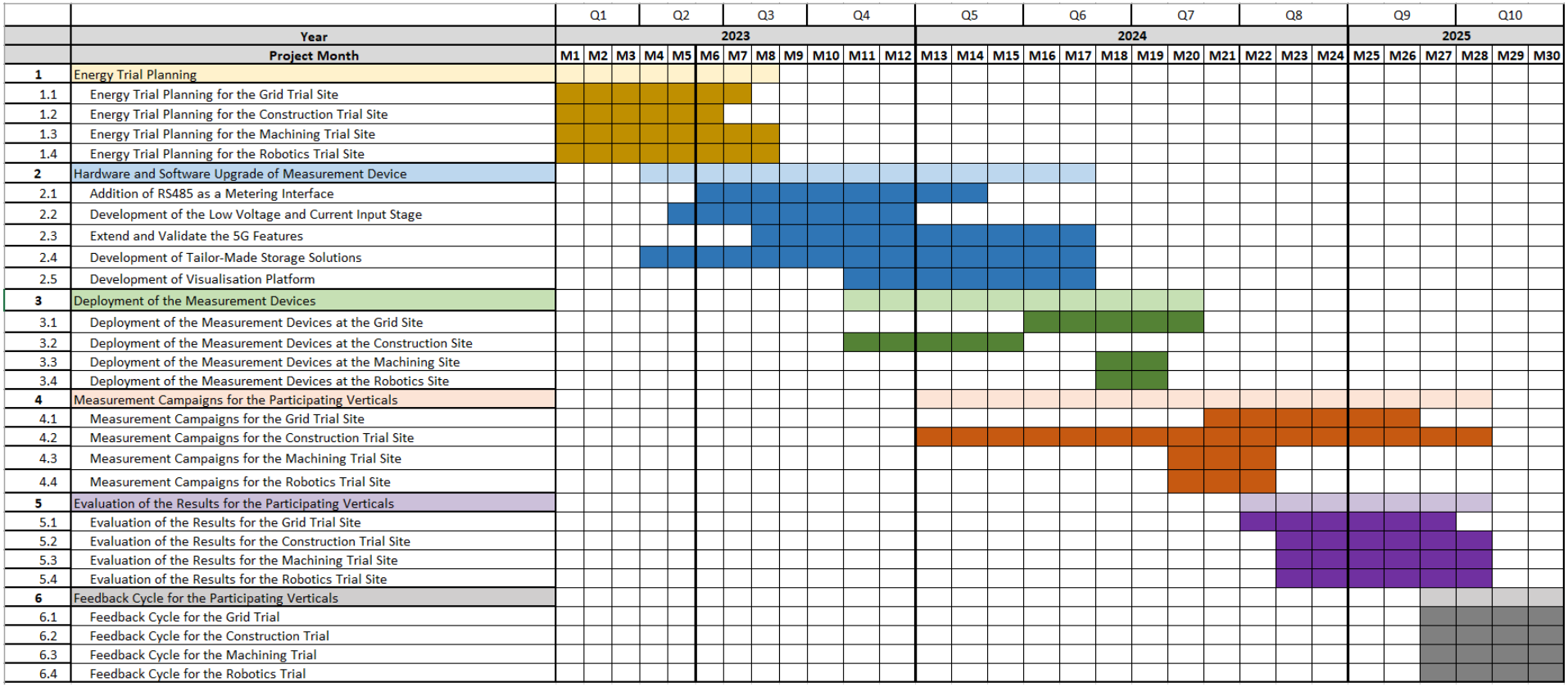

Figure 9: Trial site integration Gantt chart

5 Trial site test plan

This chapter will provide a preliminary overview of the planned tests at the different trial sites. Since this deliverable is provided at an early stage of the project, changes to the planning might occur due to changed requirements and conditions at the trial sites. Furthermore, the same test can be performed at different trial sites in order to study the behavior and performance of the measurement devices in varying setups or environments.

5.1 Deployment of multiple acquisition devices and impact on 5G campus network

In this test multiple data acquisition devices will be deployed within the campus network. The devices will then acquire measurements and stream in parallel to the same edge computing platform.

Objectives:

- Test the performance of a 5G campus network
- Validate the impact on QoS for different load situations
- Validate the stability of the communication channel

5.2 Testing of different storage solutions for high sample rate measurement data

In this test different data formats and database technologies are investigated to store a large number of samples by also allowing fast access of the data utilizing of the shelf mid-range server hardware.

Objectives:

- Validation of the performance for different data storage technologies
- Validation of hybrid solutions for data access
- Analysis of needed data storage for possible scaled up solutions

5.3 Evaluate acquisition device accuracy

In this test the acquisition device will be validated and compared to other measurement devices that are available. The validation will mostly be done using controllable test signals.

Objective:

- Validate the performance and accuracy of the used sensors
- Validate the functionality of the used algorithms and software

5.4 Accuracy of time stamping

This test focuses on a single device deployed at a predefined consumer within the campus network. The device will acquire measurements of the consumptions of characteristic processes and stream these to an edge computing platform. There the time stamps will be compared to those of other sensor data of the same process for the purpose of process identification.

Objectives:

- Test the accuracy of time stamps
- Identification of processes using the time stamps of current or voltage measurements

5.5 Plug and play sensors with 5G/6G connectivity

In this test the seamless integration of 5G sensor systems into the existing infrastructure is evaluated. One large cost driver for the deployment of low-cost sensor systems is the deployment procedure both for software and hardware. The focus for this test will be put on the software side. This test will evaluate the software side of the deployment procedure including the integration into customer software infrastructure.

Objectives:

- Identify the impact of the different steps of integration
- Provide feedback for optimization of the process

5.6 Scalable framework for the long-term integration of multiple sensors

This test evaluates the computational footprint of multiple sensors integrated in an on-premises infrastructure. Adding sensors via 5G connectivity is only a first step to utilizing the acquired data. As a core element of the framework also the backend data bus needs to be investigated. Depending on the types of sensors and the data rates, also the backend data bus, for example MQTT or Apache Kafka need to be considered. This test will evaluate different data buses based on real world data.

Objectives:

- Evaluate the performance of different data buses
- Provide feedback for future framework developments

5.7 Device-to-Device (D2D) communication tests

In this test the device-to-device communication via a private 5G network, the potential to enhance the monitoring, control, and analysis of power systems by enabling direct and efficient data exchange will be investigated. In this case D2D communication is viewed from the user plane perspective, meaning that between the devices there could be a base station or other hardware. Evaluating the impact of such an infrastructure is part of this testing.

Objectives:

- Test and evaluate cumulative end-to-end delay
- Test the possible Bandwidth for D2D communication

5.8 Energy and power monitoring

In this test the energy consumption and power use over time for different types of loads is monitored. The goal is to identify different processes based on analyzing the measured load. To optimize and better understand the energy consumption of different processes the first step is to measure the process and analyze the resulting data. In this test this will be done for different kinds of loads.

Objectives:

- Measure electrical consumption and power use for different real-world loads
- Correlate the acquired measurements with the monitored physical process

The following table gives an overview of the planned tests for each of the trial sites.

Table 1: Overview of the planned tests for each trial site

	Grid trial site	Construction trial site	Robotics trial site	Machining trial site
Impact of multiple acquisition devices on 5G campus network	x	x		
Data storage solutions for high sample rate measurements	x			
Evaluation of acquisition device accuracy	x			
Accuracy of time stamping		x		x
Plug and play sensors with 5G/6G connectivity			x	x
Scalable framework for the long-term integration of multiple sensors			x	x
D2D communication tests	x			
Energy and power monitoring	x	x	x	x

6 Conclusions

In conclusion, this deliverable describes the four different trial sites participating in the energy monitoring trials. The common goal of the trial sites is to test 5G and its potential for the use cases provided by the private 5G network and investigate possible features that could be included in the 6G wireless technology. Furthermore, the tests will help to increase energy awareness and may also show potential for reduction of energy consumption. The second part of the deliverable describes the planning for the different trial sites, and the third chapter provides an overview of the planned tests. At the time of this deliverable, not all parameters of the different trial sites are known, therefore minor changes to the time plan as well as a larger test set are expected.

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