PILOT SITES ENERGY

DELIVERABLE D3.5

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SHORT ABSTRACT	This deliverable provides an overview of the running demonstrations for the energy vertical. The demonstration is deployed at the construction, robotics, and energy testbed.
KEY WORDS	Energy, 5G, Digital Transformation, Real-Time, Demonstration
CONTRIBUTOR(S)	Manuel Pitz, Marit Zöcklein, Lucas Manassés Pinheiro de Souza

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Executive Summary

Within the TARGET-X project, the integration of 5G in the energy, construction, manufacturing, and automotive verticals is evaluated. The goal is to identify already available features and possible features for 6G that can benefit these verticals. The energy vertical targets mainly the topics of monitoring, energy awareness, and consumption. The developed software and hardware are not only used for grid-specific use cases, but also in other verticals to evaluate the energy consumption of a specific process.

This deliverable provides an overview of the demonstration within the energy, construction, and robotics vertical. The first deployments and screenshots of measurements are shown for the different testbeds. This includes the Meter-X device within the energy, construction, and robotics vertical as well as a 5G edgePMU within the energy vertical. It is shown that with the measurements, new insights in the power consumption of different types of processes can be acquired. Furthermore, design modifications driven by the field trials are also described.

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List of Acronyms and Abbreviations

5G	5th Generation
5G NSA	5G Non-Standalone
5G SA	5G Standalone
6G	6th Generation
GPS	Global Positioning System
PMU	Phasor Measurement Unit
ROS	Robot Operating System
UI	User Interface
URDF	Unified Robot Description Format

1 Introduction

Within the TARGET-X project, the 5G energy vertical is strongly focused on monitoring and energy awareness. This is especially important for the low voltage grid, where, until now, monitoring is not too common. Especially with the increase in volatile energy sources which are often deployed in the low voltage grid, a better understanding is key for a stable operation in the future. To achieve this goal, a major component needed is a 5G-enabled software and hardware architecture.

This deliverable provides an overview of the running demonstrations within the energy vertical. Three test sites were selected and have deployed measurement devices for two use cases. The use case of energy awareness is deployed in the construction, robotics, and energy testbed. The use case of grid monitoring is deployed in the energy testbed. Within the deliverable, first measurements are shown, and the deployment is described.

The development of the used measurement devices is described in detail in Deliverable D3.4 [1] and the different trial sited are described in Deliverable D3.1 [2].

1.1 Document structure

This document is structured in six sections. Section 1 provides a brief introduction. Then Section 2 and Section 3 describe the demonstration in the energy testbed with the two use cases of energy awareness and grid monitoring. Following the energy testbed is the description of the energy awareness demonstration within the construction testbed in Section 4. Finally, the demonstration in robotics testbed is described within Section 5. The document is finalized with a conclusion for the three testbeds in Section 6.

1.2 Relation to other activities

This deliverable describes the current state of the demonstrations for the energy awareness and grid monitoring use cases. The demonstrations are run in the robotics and construction testbed, and therefore a strong relation to WP2 (Robotics) and WP5 (Construction) is present. Furthermore, the work is based on developments done within WP3 for the monitoring hardware and in cooperation with WP6 for the 5G communication infrastructure.

2 Building energy awareness

In the RWTH ACS building, the energy awareness use cases are realized. The goal is to better understand the power consumption in the mechanical workshop, the server room, and the electronics lab. To deploy the measurement points, the electrical system had to be modified by adding fuses and the metering hardware. The boxes are equipped with an ABB metering device and the communication and monitoring hardware is based on a Raspberry Pi 4. In addition to the deployment of the measurement boxes, the local private 5G Standalone (SA) network had to be extended with additional antennas. The deployments are shown in Figure 1.

Figure 1: Hardware deployment in energy testbed. Mechanical workshop (left), electronics lab (center) and server room (right).

The first results are also available via the deployed Grafana web UI. An example from the electronics lab is shown in Figure 2. It can be clearly seen that RWTH is connected to a tap changing transformer, as the voltage jumps twice a day. This can be seen in the top right plot. Furthermore, the different load types in the electronics lab can be seen in the top left plot. On phase three (blue) there is a constant load, which is the network equipment deployed in the lab. Phase two (yellow) shows large spikes, which is due to turning on and off the soldering equipment. Finally, on phase one (green) the impact of a fridge can be observed in the ripple like power consumption.

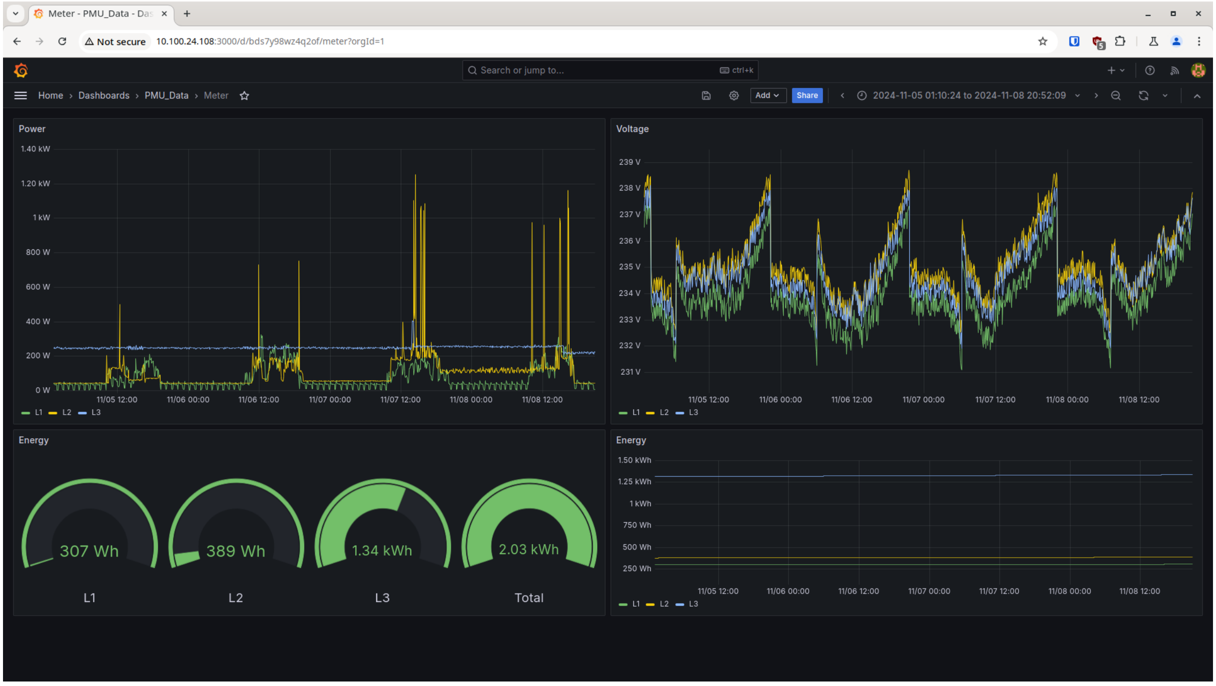

Figure 2: Readings of electronics lab metering device.

3 Building grid monitoring

For the grid monitoring use case a measurement point is deployed in the RWTH ACS electronics lab. The goal is to monitor the local grid voltage, phase, frequency, and change of rate of frequency on all three phases. For this use case the 5G edgePMU is used. The current test deployment is shown in Figure 4. In Figure 3 a first set of measurements is shown. The shown 5G edgePMU uses the local 5G SA network for connectivity. In addition, a local GPS distribution system is used to provide the time information. The shown data is recorded with 10 phasors per second per phase. This allows for high time resolution monitoring of the grid which also enables glitch detection and dynamics detection of the buildings grid. Advanced analytics of the grid are also possible in the context of big data analysis. Using a decoupled power supply, major disturbances in the grid like power outages can be recorded and analyzed afterwards.

Figure 3: Readings of 5G edgePMU with phasors.

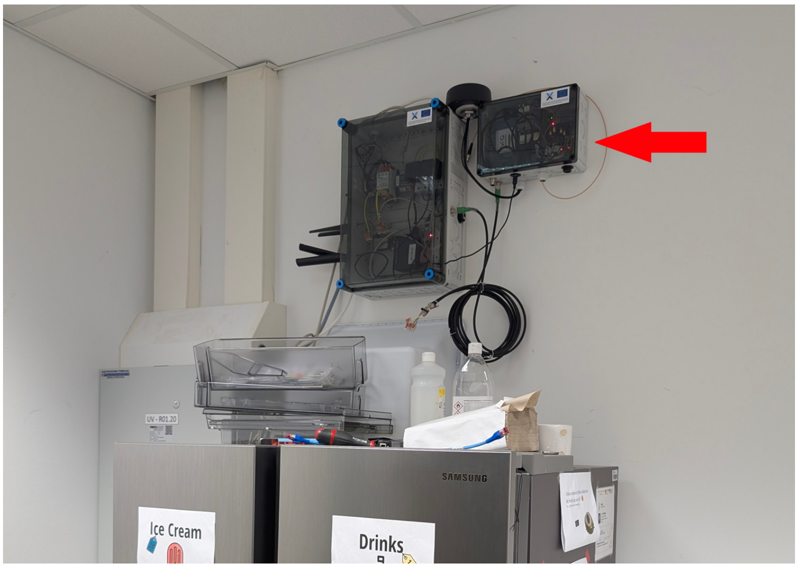

Figure 4: Mounted 5G edgePMU in electronics lab.

4 Construction site energy awareness

In order to decrease its environmental footprint, the construction industry needs to reduce its energy consumption. However, achieving this reduction requires awareness among consumers about their energy usage patterns. Unfortunately, not all consumers can be tracked accurately with built-in systems. Thus, there are unknown variables in the system. Meter-X can help erase those variables by providing a plug-and-play solution for metering of power consumption of machinery without internal sensors.

The first test to demonstrate fundamental functionality of Meter-X on the construction testbed took place in April 2024. During this test, Meter-X was connected to two exemplary construction machines, a material hoist, and a small tower crane to measure the power consumption of both machines in exemplary construction logistics processes.

Figure 5 shows an exemplary measurement of the total active power over time while the material hoist transported a sample load from the ground floor to the first floor and back. The measured power curve shows two peaks. The first peak marks the start of the process and the initial acceleration of the material hoist from its rest position. After this, the material hoist moves at a constant speed until it reaches the target height. The second peak marks the start of the downward movement for the movement from the upper floor to the first floor. It is noticeable here that the power is negative. This means that the freight elevator is feeding energy back into the system as it moves downwards.

While the first test on the construction testbed proved that Meter-X can be used to measure the data needed to create energy profiles of construction machinery, it also revealed some potential for reworking the design. These findings were incorporated into the two subsequent design iterations of Meter-X. The second Meter-X design already had a supporting structure so that it can stand upright. The third design iteration now also has a handle and wheels so that the device can be transported more ergonomically.

Figure 5: Measurement for the transport process in which a material hoist on the construction testbed transported an exemplary load from the ground floor to the first floor and back. Start of the hoisting upwards operation (1), and start of the hoist lowering operation (2)

Figure 6: Second design iteration of Meter-X connected to the material hoist on the construction testbed.

Figure 7: Second design iteration of Meter-X connected to a small tower crane on the construction testbed.

5 Robotics energy awareness

In modern manufacturing, robotics has become indispensable, particularly in assembly processes that demand high precision, efficiency, and scalability. Robots play a pivotal role in automating repetitive tasks, such as pick-and-place operations, which involve transferring components or products between specific points on a production line. While these tasks may seem straightforward, they require a level of consistency, speed, and accuracy that is difficult to achieve with human labor alone, especially at high volumes. By automating these processes, companies not only meet the growing demands for mass production but also reduce costs associated with human error, fatigue, and variability in performance.

In addition to efficiency, robots offer unparalleled flexibility in production. Unlike traditional machinery, which is often designed for fixed tasks, robotic systems can be reprogrammed and adapted to handle a wide variety of operations from assembling intricate electronics to packaging consumer goods. This adaptability allows manufacturers to respond swiftly to shifting market demands and customization trends, making robots essential not just for large-scale operations but also for smaller, more dynamic production environments.

Figure 8: Demonstration with Kinova robot of energy consumption.

To explore this potential, we recently conducted a demonstration (Figure 8) using a Kinova robot [3], a collaborative robot (cobot) designed to safely and efficiently work alongside humans. The robot executed repetitive pick-and-place tasks, with occasional variations in trajectory and object weight. During this demo, we closely monitored the robot's energy consumption to assess how different trajectories and payloads affected its efficiency (Figure 9). The data revealed how dynamic factors, such as the weight of the object and changes in motion patterns, influenced both energy usage and mechanical wear.

Figure 9: Power consumption for different weights. (1) four weights (2) only the fixture no additional weights

This real-world testing emphasized the importance of adapting motion planning to suit the specific conditions of each task. While the use of predefined trajectories ensured consistency and eliminated the need for real-time motion planning, this approach came with its own set of limitations. Objects had to be manually positioned to align with the fixed trajectories. Any misplacement would result in inaccuracies, which could accumulate over successive repetitions, potentially affecting the robot's performance. This revealed the need for more adaptive systems capable of dynamically recalibrating their trajectories to accommodate positional deviations and maintain precision in environments where conditions are unpredictable.

Furthermore, performing real-time motion planning on the robot's local hardware presents challenges of its own. Calculating optimal trajectories on-the-fly requires substantial computational resources, particularly when the environment is dynamic or when payloads are variable or demanding. This puts significant strain on the robot's hardware, leading to slower responsiveness and limited capacity to handle unforeseen changes. To address this, outsourcing computationally intensive tasks like motion planning to edge computing presents a promising solution. By offloading these tasks to nearby edge servers, which have greater processing power, robots can maintain low latency and reduce the computational load on their local systems.

This approach not only enhances efficiency but also enables more sophisticated algorithms, supporting scalable, adaptive robotic systems. The demonstration utilized the Kinova Gen 3 robot, a 7-degree-of-freedom robotic arm that stands out for its compact design, high precision, and smooth motion capabilities. Its lightweight yet robust construction makes it particularly well-suited for tasks requiring repetitive, accurate manipulation, such as pick-and-place operations. The robot was paired with a 2-Finger Robotiq Gripper [4], an adaptive end-effector capable of handling a wide range of objects with varying shapes and sizes. This gripper ensures a firm grasp and controlled release, making it ideal for maintaining reliable operation throughout the demonstration.

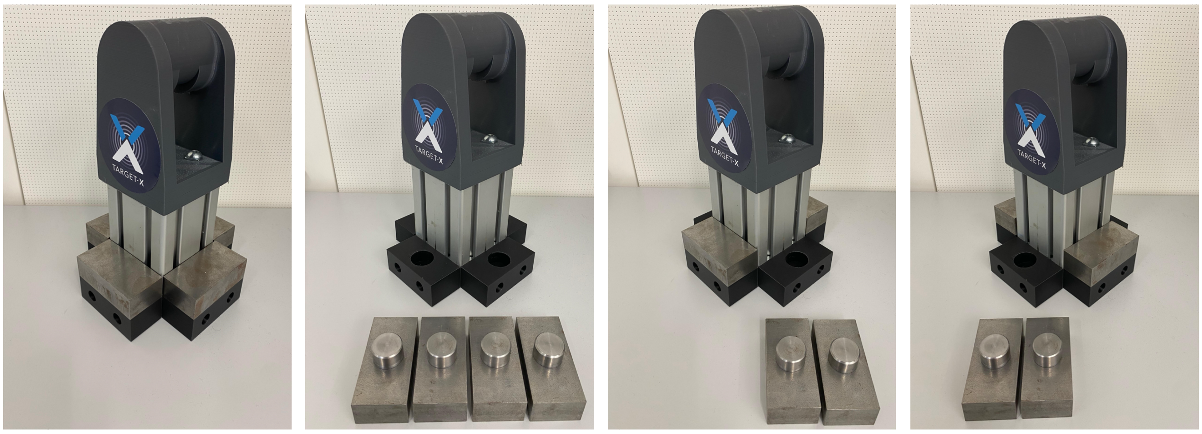

Figure 10: Weights used in demonstration

The demo also featured a custom weight (Figure 10), designed to be easily manipulated by the gripper. The base mass of the weight was 1.68 kg, with four removable weights, each weighing 0.67 kg. When fully assembled, the total weight reached 4.37 kg. This setup allowed for testing how the robot's energy consumption and motion accuracy varied under different payload conditions, with the precision of the removable weights ensuring consistent and reliable measurements throughout the trials.

The Kinova Gen 3 was connected via Ethernet to an Ubuntu 22.04 laptop, which served as the control interface for the robot. The laptop hosted a Docker container that encapsulated the entire software stack, ensuring consistency across development environments and simplifying deployment. This modular framework allowed for seamless integration of various components in the demonstration.

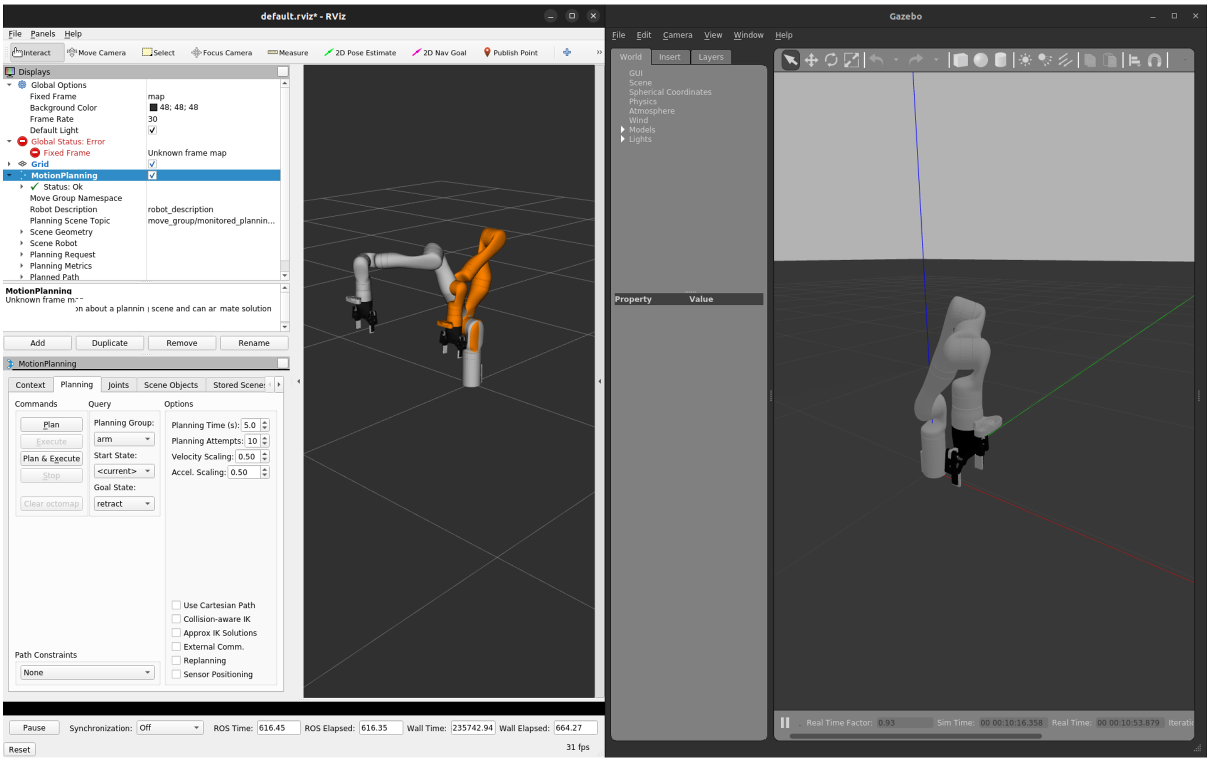

Figure 11: RViz and Gazebo running

Inside the Docker container, a Robot Operating System (ROS) interface with Kortex [5] was used to manage communication with the robot's drivers. This interface also incorporated the robot's Unified Robot Description Format (URDF) model into RViz and Gazebo (Figure 11), enabling the visualization of digital twins for enhanced monitoring and simulation of the robot's actions. RViz, a 3D visualization tool in ROS, was used to observe the robot's trajectories and environment in real time, while Gazebo, a robotics simulator, allowed for the testing of robot movements in a realistic virtual environment. Together, they provided critical feedback during the demonstration.

The motion planning node, developed with Python scripts, controlled the robot's pick-and-place movements, utilizing ROS's motion planning capabilities to ensure precise execution and seamless integration with the visualization tools. A key highlight of the demo was the open-source nature of the software, which emphasized transparency and enabled third-party contributions for further development and innovation. Additionally, Docker was used to enhance the system's modularity, simplifying future adaptations and extensions.

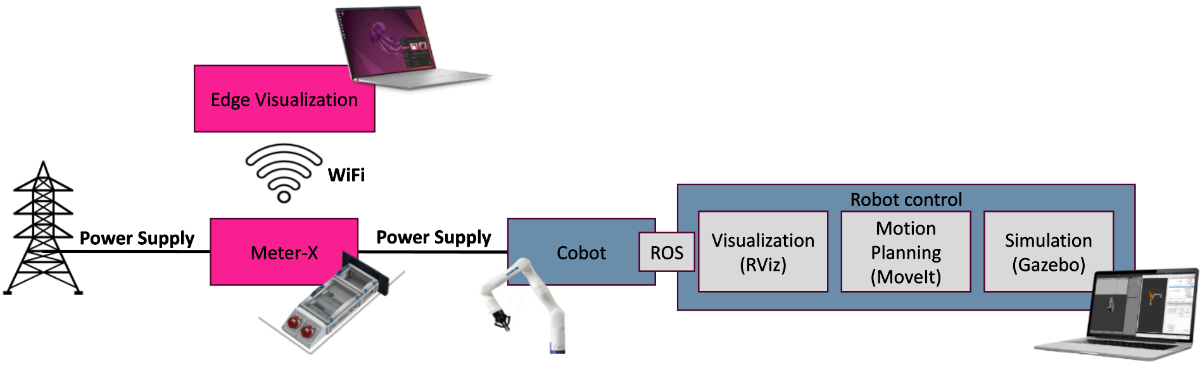

Figure 12: Current architecture of the project.

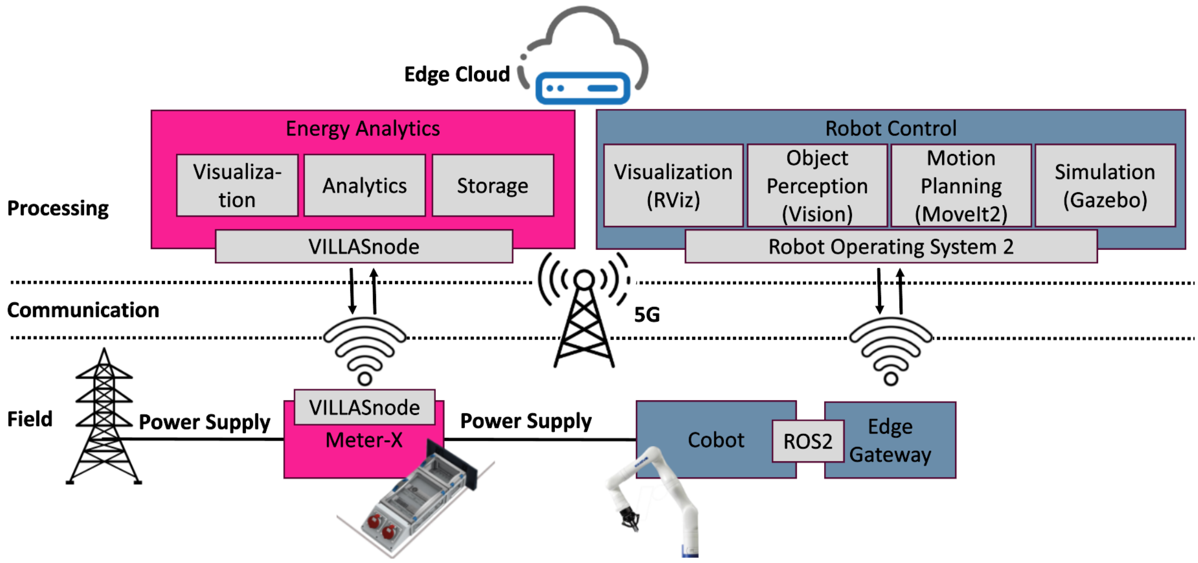

Figure 13: Architectural goal for the end of the project.

Looking ahead, the next steps involve transitioning from ROS to ROS2 and establishing a connection between the physical hardware and the Edge server via 5G. This will enable the offloading of computationally intensive processes, such as object detection, visualization, and motion planning, to the server. It is possible to see those improvements illustrated in Figure 12 and Figure 13. This shift will enhance system performance and scalability by leveraging the power of edge computing for resource-heavy tasks.

6 Conclusions

In conclusion, this deliverable provides an overview of the four demonstrations within the energy, construction and robotics testbed. It is shown that the devices are deployed, and first measurements are acquired. The energy testbed utilizes two different device types, a fixed version of the Meter-X in three rooms and one 5G edgePMU. The power consumption is shown for the energy awareness use case, and the voltage and phase angels are measured within the grid monitoring use case. For the construction testbed, the Meter-X device is shown while measuring a material hoist. First insights in the measurements and feedback for the ergonomics of the device are described. Finally, for the robotics testbed, the Meter-X device is used together with a robot arm, and it is shown how the device can be utilized to increase energy awareness. In that case the power measurements for different weights have been compared.

7 References

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