# How Digital Experiments Support Sustainability in a Forest Machine Operator Company: A Case Study

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***Abstract*—Increasing number of organizations are adopting Green Information and Communication Technology (Green ICT) practices for their service operations. There are two main types of Green ICT in the organizational context. First, Green for ICT where ICT aims at reducing its own footprint and second, Green by ICT aiming at offering digital tools that reduce the environmental footprint of all business activities in the organization. In this paper, we present two digital experiments where green by ICT solutions for a forest machine operator company were engineered by software development practices. In this study, we aim to answer the research problem: How digital experiments support sustainability in a forest machine operator company? This embedded case study is based on two consecutive digital experiments conducted in Finland with a large scale forest machine operator company. The first digital experiment focused on tank level monitoring and the second experiment on mass monitoring. Our results highlight the challenges in receiving sustainability data from subcontractors and IT providers. Additionally, IoT-enabled monitoring services can eliminate traveling to remote storage areas and thus may reduce CO2 footprint remarkably.**

***Keywords*—*Green ICT; software system; Internet of Things;***

## I. INTRODUCTION

An increasing number of organizations are adopting green computing practices to transition their operations toward greater environmental sustainability. Green computing includes actions such as decreasing energy consumption, recycling e-waste and environmental friendly usage of devices [1]. A recent study [2] conducted in Finland showed that companies' awareness and understanding of green ICT varies a lot. According to Raja, green computing refers to sustainable, environment-friendly computing [3]. Chaudhari and Kothoke [4] have identified challenges in green ICT including inadequate ICT-based informed decision-making, low ICT and the least Green ICT awareness, lack of matured inter/multi-disciplinary software tools and issues related to availability and reliability of data. Cater-Steel and Tan [5] have established green IT service management (ITSM) framework that contains four pillars: Green procurement, consolidation of IT resources, power management of IT equipment, decommissioning of unused/obsolete equipment.

Widdicks et al. [6] report that ICT can enable reductions in global emissions in other sectors but there are continuous uncertainties regarding ICT's carbon impacts. The study of Dubey and Hefley [7] proposes green extensions to IT Infrastructure Library (ITIL). In supplier management, service vendors can be evaluated by using various green metrics. For example, when an organization decides to purchase datacenter services, one can use metrics, such as datacenter power usage effectiveness (PUE) and data center infrastructure efficiency (DCIE). Singh et al. [8] present a green and sustainable software model that can be used in green ICT practices. Cloud computing plays an important role in green computing by enabling more efficient and sustainable use of computing resources [9]. Cloud computing utilizes virtualization techniques that allow cloud providers run multiple virtual machines on a single physical server. Additionally, cloud computing enables on-demand usage of computing resources where resources are allocated only when needed. One of the key challenges in green ICT from IT company's perspective is that IT customers do not want to pay extra for greener services. Often, companies have to make trade-offs between costs and gains when they make decisions on implementing green and sustainable information systems [10]. If companies could assess and report their positive environmental contributions, it would provide more accurate knowledge and support for green initiatives [11]. The Internet of Things (IoT) represents a rapidly evolving network of interconnected devices that communicate and exchange data, offering huge transformation potential across various business domains. An IoT-based system consists of multiple configuration items, such as sensors, IoT devices, applications, cloud services, data networks and gateway devices. According to the definition by Dorsemaine et al. [12], IoT is "a group of infrastructures interconnecting connected objects and allowing their management, data mining and the access to the data they generate". Hatzivasilis et al. [13] discuss how IoT technology can be used for circular econonomy purposes, such as to administrate the lifecycle of the deployed electronic equipment and manage related supply chains. IoT provides significant improvement opportunities from green by ICT perspective. Tran et al. [14] have used IoT to collect vibration signals on engines of ships. Additionally, Gantert et al. [15] collect and use sounds produced by machine components to improve corrective maintenance of machinery.

Concerning the research gap, although IoT technologies have been widely used in several domains, existing research has not dealt with how forest machine operator companies are using IoT to increase automation and productivity. The novelty of our research lies in demonstrating how we applied IoT in our digital transformation experiments within a new business context—monitoring forestry assets as well as showing how these experiments supported the sustainability goals of the case

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organization.

The remainder of the paper is organized as follows: In Section 2, research methodology of the study is presented. In Section 3, case study results are provided. Section 4 is the analysis and finally, the conclusions are given in Section 5.

## II. Research Problem & Methodology

This exploratory case study aimed at answering the following research problem: How digital experiments support sustainability in a forest machine operator company? The case study can be defined as ”an empirical inquiry that investigates a contemporary phenomenon within its real-life context” [16]. Our research problem was divided into following three research questions:

- How sustainable and green practices are addressed by the forest machine operator's staff during digital experiments?
- How are the sustainability concepts visible in the service operation of the forest machine operator?
- What type of challenges are related to sustainability & green ICT from the perspective of a forest machine operator?

Regarding the case selection, the case organization was selected from the pool of industry partners and the university has collaborated several years with the case organization in EU funded projects. Additionally, the case organization participated in the green ICT research project carried out by the university. Thus, the project enabled an easy access to the case organization. While this case study was exploratory in nature and our first attempt to study green ICT, we used high level research questions focusing on green practices, visibility of sustainability concepts and challenges to answer our research problem.

### A. Case Organization

Motoajo is one of the leading forest machine providers in Finland. The company is as a family-owned business with around 80 employees. The company operates almost 60 forest machines in North Karelia. Motoajo has a long expertise in the management and maintenance of forestry machinery, Motoajo provides professional services that enhance the efficiency and sustainability of forest operations. The services provided by Motoajo include harvesting, wood transportation, heavy machinery maintenance and repair; and excavator services, such as soil tilling. The company takes environmental responsibility into account, supports the circular economy, and has an up-to-date carbon footprint calculator. Motoajo is committed to providing logging services sustainably and profitably while respecting the environment and laws.

Motoajo was selected as a case organization because the Digital Innovation Hub network DIH World had announced the call for digital experiments and smart forestry was one the topics of that call. Together with Motoajo, our DIH applied funding for the tank level monitoring experiment The 2nd experiment focused on monitoring the mass of forestry assets (how many litres/kg of liquid remain in the container) by using industrial scale and IoT technologies. .

### B. Data Collection Methods

Data for this study were collected from multiple data sources and multiple researchers between August 2021 - May 2025 by the university research team. Data was collected from two digital experiments related to applying IoT technologies. According to Eisenhardt [17] triangulation and usage of multiple data collection methods provides stronger substantiation of constructs and hypotheses. The following data sources, recommended by Yin [16] were used:

- Documentation: The sustainability report of the case organization, Tekelek tank level sensor product sheet, safety instruction documents, PCE RS 2000 specifications document
- Archival records: the public website of the case organization, a job onboarding questionnaire designed for case organizations employees, DEFRA GHG conversions factors spreadsheet used in calculating emissions for traveling between remote storage areas, online forms for truck drivers and forest machine operators
- Interviews/discussions: Green ICT group interview in May 2025 with CEO, foreman and quality manager; project discussions during work meetings with foreman of Motoajo, and interview with CEO related to digital transformation, online meetings with AWS consultants
- Participative observation: Digital experiment work meetings in target organization's facilities, multiple visits to the case organization, participative observations during visits in the organization's storage areas in Nurmes and Riistavesi, system testing workshop during the second experiment in the IT provider organization's facilities in Mikkeli
- Physical artifacts: videos that showcased how forestry liquids and forestry waste were stored and processed in the storage area: videos were shot while implementing a virtual job onboarding system; PCE RS 2000 industrial scale, various containers used for storing forestry liquids, such as marking dyes and diesel exhaust fluid; Tekelek tank level sensor
- Direct observations: Observations during physical visits to the case organization's main storage area and remote storage areas. A visit at the forest logging site during the winter.

## III. Results

The research team including the first and second author and Motoajo received EU funding from DIH World project's Call for experiments. The funding enabled implementation of a digital experiment where the goal was to build a prototype for a solution that monitors and measures tank levels by using Internet of Things technologies. The experiment highlighed the following challenges in the forest service machine operator's operations. At that moment, Motoajo did not have accurate view on inventories of forestry liquids that forest machines consume. This resulted in situations that forest machine drivers may not get mandatory liquids. Frequent trips to remote storage areas were needed to check whether critical liquids

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consumed by forest machines are available. Additionally, better job introduction was needed for managing forestry liquids safely and according to green practices.

### *A. Green and digital forest service management experiment for tank level monitoring*

Initial discussions on the experiment objectives addressed the need to monitor fuel containers in forest logging sites. We started studying external factors, such as legal, environmental and technical issues that affect fuel operations: ”The process of transporting fuel to logging sites is tricky and might not be fully automated; typically a fuel truck driver needs to call anyway the forest machine driver to give location information.” We observed that forest certificates prevent storing fuel containers in the forest in groundwater areas. Additionally, case organization’s staff reported that forest machine settings and driving patterns affect the fuel consumption (also CO2 footprint of harvesting).

Due to complexity of fuel operations, we decided to focus on other business-critical liquids: Fungicide, marking colours and diesel exhaust fluid ADBlue. The case organization’s representative stated: ”We have many types of containers in several locations and dropping points: metal containers, plastic IBC containers”. We also observed that the company had already invested in technology that helps collecting data on vehicles and analyzing factors that affect fuel costs: ”Our vans have automatic driving logs where we can see where vehicles are and where they are moving. Additionally, we can observe driving behaviour and patterns.”

Forest machine operations require various types of liquids (fuel, marking dyes, diesel exhaust fluid) and availability of those liquids is critical to Motoajo’s harvesting business. Containers of liquids are stored in main storage area of Nurmes, Finland and remote storage areas. We observed that consumption of liquids is monitored manually and this activity requires frequent travelling to remote storage areas: ”One employee spends at least one working day per month due to driving to remote storage areas and checking the availability of liquids and items”.

In the specification phase, we asked user requirements for the monitoring system. The case organization’s CEO addressed especially the usability requirements ”The system should be very easy to use; even in a situation when a truck driver or a forest machine driver comes to the remote storage area during the winter gloves in his hand and when there is no daylight”. Additionally, the CEO commented that it should be easy to interpret results provided by the monitoring solution ”The mobile app could show the level of liquids with traffic light colour codes; additionally how much liquid a specific driver took from the container”.

The research team made a visit to one of the remote storage areas during the winter and played the role of a truck driver. While the CEO had commented on data needs ”If possible, a delivery truck driver should use the app to provide information about the refilling”, we observed that there was a QR code attached to a container and opening the QR c led to an online form that was designed for both capturing data on refilling events and retrieving events. We opened the form during our field visit and observed that there was room for improvement


Fig. 1. TILHI application for tank level monitoring

in the usability of the form. We interpreted that in order to increase usability, it might be better to separate these forms from each other. This could be one root cause for missing data on liquid refills and retrievals.

Technical specifications for the IoT system were outlined based on the user stories. The key objectives of technical specification stage was to define the hardware and software requirements for the TILHI IoT system, including sensor calibration, dashboard interfaces, and data handling. The project team consumed a lot of time for selecting a right sensor for monitoring liquid levels. Meetings and discussions were organized with various sensor service providers and IoT platform providers. The sensor that was finally selected was Tekelek LoraWAN-enabled ultrasonic sensor. This sensor module had been used in many sensor projects in Finland and it was also available in the LoraWAN network provider’s (Digita) sensor catalogue.

The core development of the IoT system took place over several months, culminating in the review of the completed development in February 2022. This phase covered both the mobile application and the web interface. Figure 1 shows the user interface of the tank level monitoring system TILHI that was implemented in the experiment. The key objective of this stage was to build the IoT system, including features such as sensor calibration, container management, and liquid tracking. We experienced minor challenges both in ordering the sensors and installing the sensors to the container.

The deployment of the system was performed February-April 2022. Deployment activities occurred after successful testing of the system. The deployment phase aimed at ensuring that the IoT system was integrated into the forestry operational processes, with all essential components functioning as expected. Our key objective was to roll out the tank level monitoring system to end users in forestry operations. In the end of the experiment, we found out that data submission frequency of sensor modules is every six hours, not hourly as we expected. We asked the reason in a telephone discussion with the service provider ”Frequency on sending IoT data affects the sensor module battery duration.” We also delivered this information to the case organization’s representative that considered the data submission frequency adequate but not optimal. The IoT experiment ended with a Continual Improvement meeting with

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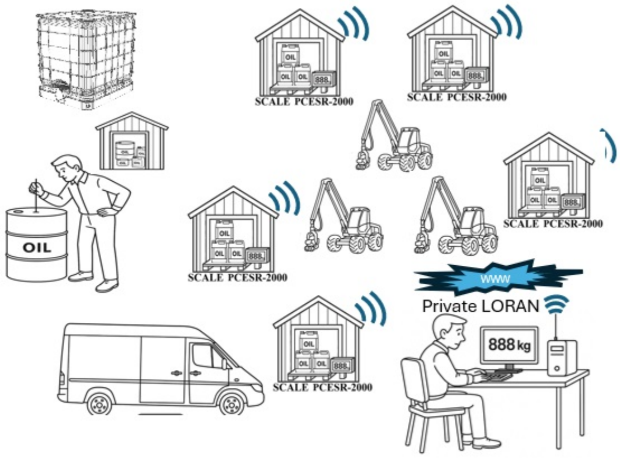


Fig. 2. The context of the weight monitoring system for forestry liquids

a discussion on what went well and what could have been improved. The experiment was considered successful despite the slow start and many changes in monitoring target.

## B. *Smart mass monitoring experiment*

At the end of the first experiment, the case organization provided idea for a new experiment. The main goal of the new experiment was to place an industrial-level 'scale' under a standardized IBC tank to allow for real-time mass measurement of the liquid content of the tank (see Fig. 2). Another use case was to measure the truck pallet containing hydraulic oil canisters. Initially, we selected the public LoRaWAN network for data transmission, however, this was changed later to the private LoraWAN because we wanted to minimize the number of third party services, such as public LoraWAN network provider.

The experiment started with studying which components were needed for the system. The main hardware components (industrial scale PCE RS 2000 [18] and Enless Wireless Signal Transmitter) were identified and selected by measurement technology unit located in Kajaani, Finland Hardware components were purchased and calibrated. After this, the research team initiated discussions with the cloud service provider. The public sector Amazon Web Services representative and cloud consultants helped the research team to identify which cloud services were needed to implement the system. The IoT reference architecture by AWS provided a good basis for discussions.

The next step in the experiment was to find an ICT company that could implement the system in AWS cloud. The first author of this paper participated in Solver X reverse pitching event and from the event we received eight potential IoT providers that were interested in implementing the system. We performed a public bidding process and selected the provider based on price and quality of implementation. The hardware components were transported from one city to another to the selected IT provider with a light commercial vehicle that could accommodate the industrial scale (1200 x 1200 x 100 mm; 85 kg). After few months, the research team had a small system testing workshop in October 11, 2023 (see Fig. 4) with the IT provider where the hardware (the scale and the signal transmitter) and software components (AWS cloud services) were tested together.

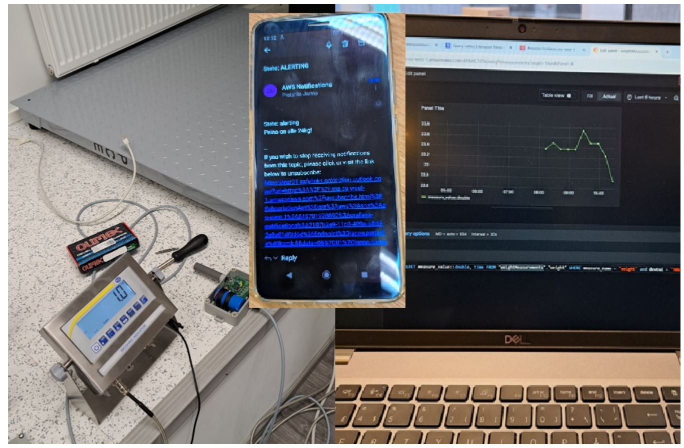

Fig. 3. A system testing workshop in IT provider's facilities

In May 14th 2025, the research team had a field visit to the case organization including discussions on green ICT and the monitoring target of the mass monitoring experiment. We asked whether they pay attention to sustainable choices while procuring IT equipment and they answered: "We purchase equipment to our own needs, not based on green ICT. If the system results in positive environmental impact, it is fine".

The case organization reported that they measure carbon footprint of their operations automatically from invoices by using an add-on ICT module installed in accounting software. The main challenges related to green approach seemed to be related to changing requirements: "The requirements in forest standards and legislation keep on changing. It will be increasingly challenging to get employees or forest machine drivers. Who has courage to start harvesting while there are so many requirements that you have to know?". The interviewees of the case organization commented that large customers are already asking information on sustainability and perhaps they should also start requiring information from their sub-contractors: "If our customers require sustainability information from us, we should have similar rights to request this information from our subcontractors."

During the visit we had an opportunity to see the storage facilities and observed that the mass monitoring target was an IBC container with metal frames and wooden truck pallet under the container (see Fig. 4). Discussion with the case organization's representatives showed that they would like to receive an alert when there is approximately 20 percent of liquid remaining in the container (200 litres). The case organization's representatives asked whether the system can be used also for other types of containers.

Additionally, the CEO stated that transporting the water causes $CO_2$ emissions for them: "If we could transport only the chemical instead of water, this would definitely decrease $CO_2$ emissions." It is mandatory for forest machine operators to take preventive actions for forest diseases, for example,

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Fig. 4. Observing the monitoring target during the field visit to the case organization's facilities in Nurmes, Finland

chemical control is carried out with a strong urea solution and biological control with a solution of gray mold fungus: " Regarding monitoring operations, some customers have started to request information such as what is our portion on using gray mold fungus and urea solution."

If the remote monitoring service would be used in all remote storage areas of the case organization, carbon footprint of traveling could be reduced approx. 192 kg (2,66155 x 72 l = 191,63 kg CO2) based on driven kilometres (692 km) between several remote storage areas with a light commercial vehicle MB Sprinter, traditional diesel as fuel, calculated according to UK emission conversion factors [19]. This would be a significant saving. Additionally, the remote monitoring could save more than one working day per month .

## IV. Analysis

Next, analysis of case study results reflecting the four research questions are presented. The source of evidence has been marked by the following abbreviations: IN= Interviews, AR= Archival Records, DI= Discussions, DO= Documentation, PO= Partic. observation, DOB= Direct observation, PA= Physical artefacts. Table 1 shows our findings from two experiments related to the first research question: How sustainable and green practices are addressed by the forest machine operator's staff? Our results showed that sustainability talks were closely related to the forestry operations, such as recycling, reusing the oil canisters and grease tubes. The company addressed that decision making on ICT purchases focuses on how well the system or the device supports their business objectives rather than how environmental friendly the system or the device is.

Table 2 shows our analysis on how sustainability concepts are visible in the organization based on the data from two experiments. Based on the interview with the CEO and foreman, we observed during the Experiment 2 that environmental concerns of the case organizations customers and knowledge requirements for forest machine drivers had increased since the Experiment 1. Sustainability issues were evolved remarkably after the first experiment: The company had introduced

TABLE I. Analysis related to RQ1: How sustainability concepts are addressed?

| **Finding** | **Source** |
|---|---|
| Automatic driving diaries show the location driving behavior | IN, DI |
| The entire staff and subcontractors have been trained in responsible for sustainable operations and risk management. | IN, DO |
| We are committed to providing timber harvesting services sustainably and profitably, respecting the environment and adhering to laws. | IN, DO |
| We support the circular economy and recycle the most important waste generated in our ops, such as oils, metals, batteries, and tires | IN |
| When there is sufficient amount of liquids in containers, no extra trips are needed due to empty containers. | IN |
| Personnel is our most important resource, so employee well-being and safety are of utmost importance to us. | DO |
| We purchase equipment to our own needs, not based on green ICT. | |
| It is fine if the system results in positive environmental impact | IN |
| There are marked areas for forestry waste in the storage. | PA, IN |

carbon footprint calculation and published a company-wide sustainability report. They had clear plans to start auditing their subcontractors and providers to receive sustainability data. They commented that some of their customers had also started to request sustainability data from them. Environmental issues were somehow visible in the company's marketing and communication during the first experiment but during the second experiment we observed that company was spreading the sustainability message more actively both inside the company and externally covering all the stakeholders of the organization.

TABLE II. Analysis related to RQ2: Visibility of sustainability concepts in the organization

| Finding | Source |
|---|---|
| The company has a quality and environmental management handbook | DOC, IN |
| Forest Act, the Nature Conservation Act, PEFC, and ISO standards used in harvesting | IN |
| The company invests in projects that optimize resource consumption | PO, IN |
| The entire staff and subcontractors have been trained in responsible operations and risk mgmt. | IN, DO |
| Sustainability is very visible in the company's values and marketing, such as 'Nature is our friend' | PO, AR |
| The company has a sustainability report on their website | AR |
| The company calculates carbon footprint for operations | IN |
| Sustainability and environmental friendly way of operating is communicated to new employees starting from job onboarding | AR, IN |

Table 3 shows the analysis regarding the third research question: What type of challenges are related to sustainability and green ICT? We identified both Green ICT challenges that software or system engineers should pay attention to in the future. First, receiving data from subcontractors and IT providers is a precondition for succesful carbon footprint calculation. The organization calculates at the moment carbon footprint based on invoices from their financial management system. However, in order to calculate the CO2 emissions of the whole value chain or digital-enabled services where several forestry actors, platform providers and system providers participate in, reliable emission data is needed.

Second, more complicated the system structure, more difficult it will be to calculate the CO2 footprint. In the first experiment, we would need to calculate energy consumption of an AWS-backed mobile app, a third party IoT data ingestion platform, IoT sensor modules and receive data on system usage hours. Calculating the CO2 of the second experiment might be simpler because it uses only AWS cloud, AWS hosted Grafana and the industrial scale with a signal transmitter. Additionally, interviewees reported challenges in managing the knowhow

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TABLE III. ANALYSIS RELATED TO RQ3: CHALLENGES IN SUSTAINABLE AND GREEN PRACTICES

| Finding | Source |
|---|---|
| IT providers are not able to provide data on their CO2 emissions | PO |
| Cloud platforms provide CO2 reporting but allocating emissions for a specific customer or a service may cause challenges | PO |
| Frequent IoT data submission affects the battery of IoT sensor | PO, DO |
| The requirements in forest standards and legislation keep on changing | IN |
| It is difficult to recruit forest machine drivers because of ever increasing knowledge requirements | IN |
| Transporting the water causes unnecessary CO2 emissions | IN |

because forest machine drivers must know forest machine settings, forest standards, requirements set by customers etc.

## V. CONCLUSION

This study aimed at answering the research problem: How digital experiments support sustainability in a forest machine operator company? There were three research questions in the study. Regarding the first research question, we observed that sustainability &green practices were addressed by the forest machine operator's staff in terms of respecting the environment, promoting circular economy, such as recycling forestry assets and emphasizing safety and wellbeing of employees. While purchasing services, systems and devices, the company values their suitability to business over green IT causes.

Concerning the second research question, we found various ways how sustainability and green concepts were visible in the case organization and its service operations, such as improvement projects that advance digitalization and sustainability, the sustainability report and the environmental handbook and the carbon footprint calculator. The third research question highlighted the challenges, such as lack of emission data from IT providers, challenges in measuring carbon footprint of xomplicated systems, and increasing knowledge requirements for forest machine drivers.

There are certain limitations related to this case study. First, the second experiment is still in the work-in-progress status waiting for that software components, such as AWS cloud resources and Grafana dashboard are configured properly. Second, the results of the study might be difficult to generalize to other forest machine operator companies because the size of the company matters. Companies that operate only few machines do not need expensive monitoring mechanisms and they do not have so many remote storage areas. Third, data was collected during only two digital experiments from one organization. The results of this study may be used by software & system engineers to identify how digital transformation projects and experiments can contribute to sustainability thinking as well as how IoT-based systems can be designed, deployed and introduced to cater corporate sustainability objectives. Further research on this topic could focus on studying Green for ICT aspects of IoT-based monitoring services.

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