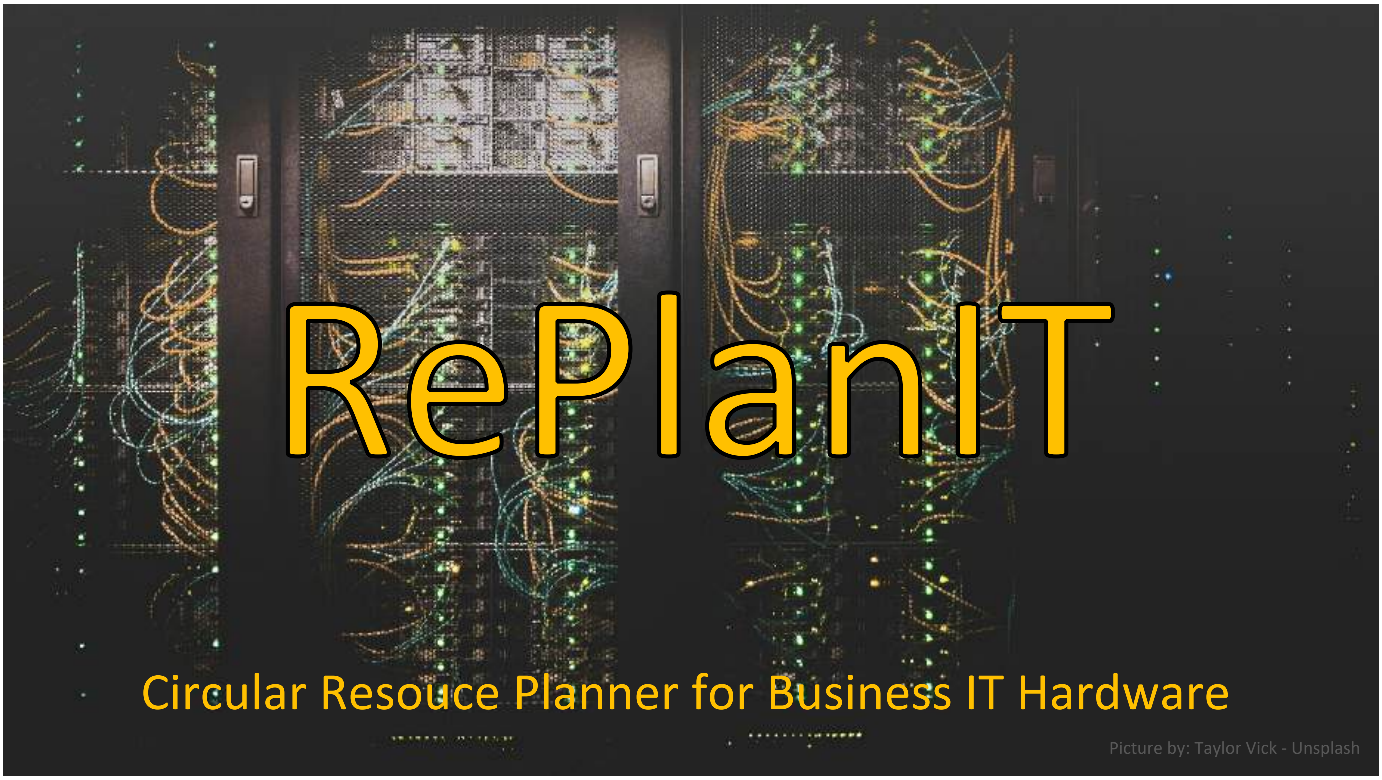


Final Report – public version

Date: 25-9-2024
Version: 1.2

Made possible with contributions from:

Rijksdienst voor Ondernemend Nederland

Amsterdam Economic Board

RePlanIT Government Partners:

Gemeente Amsterdam

Rijkswaterstaat
Ministerie van Infrastructuur en Milieu

RePlanIT Research & Project Management partners:

TU Delft

AMS Amsterdam Institute for Advanced Metropolitan Solutions

RePlanIT Business partners:

Circular IT group

Aliter Networks

Cool IT World Wide

IDEAL & CO EXPLORE

kpn

Table of Contents

1 Context & Problem statement

RePlanIT started from the observation that business IT hardware is only used for three to four years on average. This is not sustainable, especially in combination with the ongoing digitalization of business processes. The pressure on the environment, CO_2 emissions (including embodied energy) as well as supply risks to our digital infrastructure are getting bigger and bigger. The digital transition is competing with the energy transition for critical metals.

It is a known fact that we can reduce the demand for IT hardware if we could keep the existing hardware in use for a longer time. However, decision makers in business IT lack real-time, data driven decision support systems to steer on life time extension, environmental impact and supply security.

1.1 Project Goal & Approach: Dynamic Product Passport based Resource Planning & Configurating to extend life of ICT hardware

Main goal of RePlanIT is to develop products and services that help organizations to extend the life time of their ICT hardware, especially for organizations that use a lot of ICT hardware. This is the most effective way to prevent new ICT hardware from having to be made as well as preventing a huge amount of e-waste. Therefore, this will help the digital transition as well as reducing environmental impact.

We do so by creating:

- Dynamic Product Passports, where dynamic usage data is combined with static hardware data
- Circular Resource Planner, where ICT hardware decision makers get advice on alternative scenarios for how to manage the life cycle of their ICT hardware, including quantitative evaluation
- Circular Resource Configurator, where ICT hardware decision makers can get advice on alternative configurations for groups of hardware (e.g. for server parks) and insights into available refurbished equipment

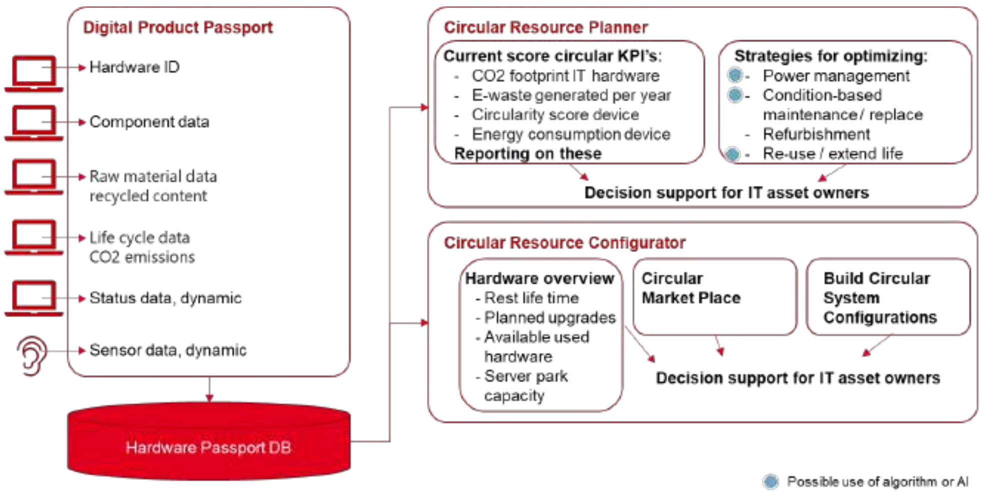


Figure 1: schematic overview of the prototype as planned

1.2 System size: business IT hardware consumes a huge amount of materials and electricity

Ecological footprint of ICT is growing rapidly though digitalization. Production and use of ICT are currently responsible for 3-6% of global greenhouse gas emissions (comparable to the cement industry). Researchers predict an increase of 14% in 2040 if no sustainability interventions are made.

Circular strategies aimed at extending life of ICT hardware don't get enough attention, as most initiatives focus on energy performance in use phase, or recycling strategies at end of life.

Researchers estimate the production phase of a server to account to 20-75% of the total GHG-emissions of a server. For laptops, the energy impact of the production phase is even 60-80% of the total energy consumption of a laptop. Extending life has more impact on carbon emissions than replacement by more energy efficient models.

To explore how we can tap into this huge potential for CO2 reduction, the project aimed to make direct impact within two organizations that would test out the prototypes of the Dynamic Product Passport, Circular Resource Planner and Circular Resource Configurator. Based on the figures for IT hardware usage before the start of the project, the potential was initially calculated to be as follows:

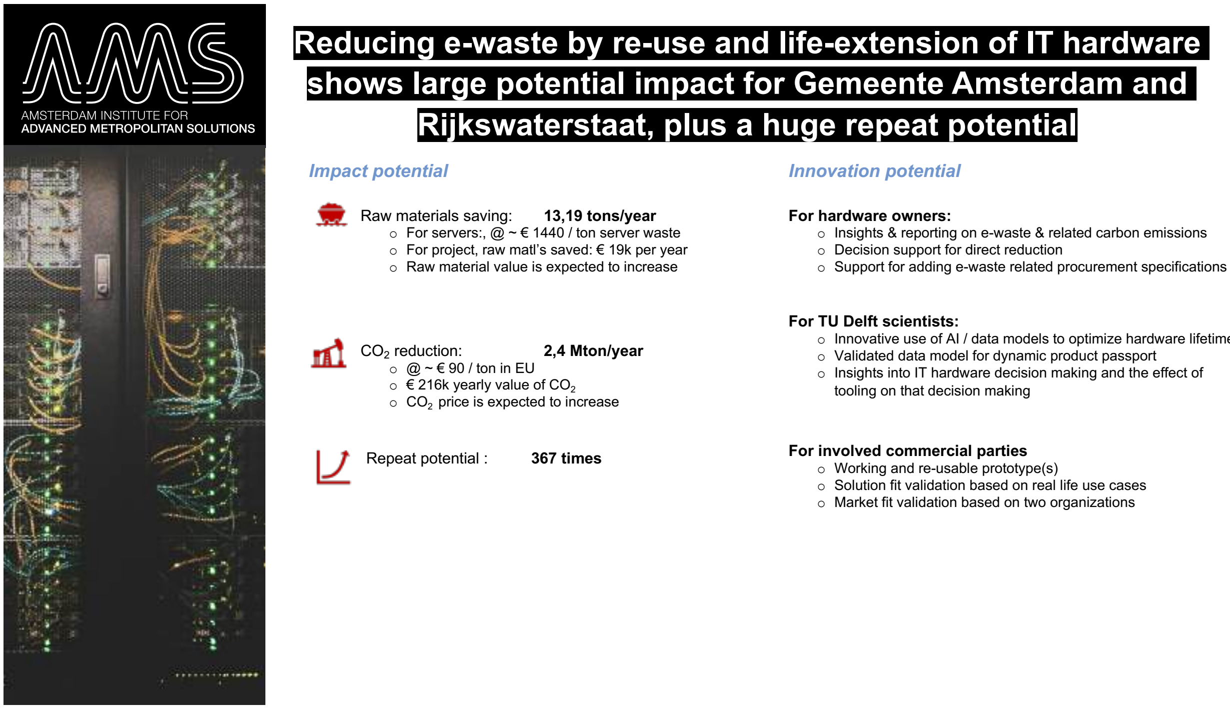


Figure 2: overview of impact and innovation potential

1.3 Recommendations for development and implementation of digital product passports

Based on the prototyping, use cases and tests, and scientific research in the RePlanIT project, the consortium has the following recommendations for the development and implementation of digital product passports for IT hardware:

1. Promote Ontology Reuse:

- Build on existing open-access ontologies wherever possible to reduce redundancy and enhance interoperability.
- Ensure that any new developments align with established best practices for ontology engineering, such as modular design and adherence to FAIR (Findable, Accessible, Interoperable, Reusable) principles.

2. Standardize Data for Digital Product Passports (DPPs):

- Advocate for a unified European standard for DPPs, leveraging the RePlanIT ontology as a foundational model for ICT-related devices.
- Encourage collaboration with stakeholders to define what data elements are essential for DPPs, ensuring they meet industry and regulatory requirements.

3. Facilitate Interoperability Across Domains:

- Use the RePlanIT ontology to bridge ICT, materials, and circular economy domains.

- Collaborate with other projects and organizations to align the RePlanIT ontology with upper-level and domain-specific ontologies, creating a shared framework for circular ICT practices.

4. Invest in Ontology Maintenance and Scalability:

- Establish a roadmap for regular updates to the RePlanIT ontology, particularly as new data types or use cases emerge.
- Secure funding or partnerships to maintain the ontology and related tools, ensuring their long-term utility and relevance.

5. Encourage Transparency and Open Access:

- Make the ontology and associated tools publicly available with comprehensive documentation, using platforms like GitHub or WIDOCO (Widely-Used Ontology Documentation Tool).
- Provide APIs and user-friendly interfaces to make ontology-based tools accessible to non-expert users, encouraging adoption across industry and academia.

6. Support Data Sharing and Privacy Compliance:

- Address data privacy and security challenges by embedding compliance mechanisms (e.g., GDPR) into the ontology and its applications.
- Develop policies to encourage data sharing while respecting intellectual property and privacy concerns, potentially through decentralized data-sharing approaches.

2 Project approach – goals, partners, timeline

RePlanIT project ran from 1-6-2022 to 31-8-2024 and consisted of 5 work packages, detailed below.

Work package 1: Dynamic Product Passport ICT hardware

Goal: Develop and validate a prototype of a scalable and dynamic circular product passport for ICT hardware (DPP).

Work package 2: Circular Resource Planner for ICT hardware

Goal: Develop and validate a prototype of a Circular Resource Planner (CRP) for ICT-hardware, with Laptops and Dataservers as use cases. The CRP aimst to make the information from the DPP (WP1) accessable to ICT service providors (suppliers and/or internal service providers) and refurbishers. This system enables them to report and steer on circular KPI's, by

a. Predicting the timing and necessity of maintenance, refurbishment or upgrading
b. Determining the rest life time of specific components
c. Developing (phased) circular design- and replacement strategies on system level

Work package 3: Circular Resource Configurator

Goal: develop and validate a prototype of a Circular Resource Configurator (CRC) voor ICT-hardware, with Laptops and Servers as use cases

The CRC aims to use the data from DPP (WP1) and predictions from CRP (WP2) to give an overview of:

1. Rest life time and planned upgrades from ICT hardware assets within an onganisation
2. Available and soon-to-be available hardware assets on the market

ICT service providers and refurbishers can use this to help fulfill the demands for hardware configurations conform the circular strategies from the CRP (WP2).

Connection to the ICT decision makers is crucial – the CRC needs to integrate the requirements for acceptance and trust from the user research (WP4).

Work package 4: Requirement trust, behavior and acceptance in the business market

Goal: Research into what prevents the adoption of circular ICT solutions within the business market and how the adoption can be enhanced with the RePlanIT system. Research into the requirements, behavior and acceptance will be used in an iterative design process for the different prototypes, so ensure adoption by different user profiles. Development of prototypes will be partially based on the knowledge from this work package.

Work package 5: Knowledge management and project lead

Goal:

1. Knowledge integration within the project and dissemination of project results to external parties, enabling continued development and scaling up of new services
2. Content management and administrative management of the project

3 Overview of what was realized

In this chapter, we explain in detail what we were able to achieve. We do this first from the perspective of the prototypes, as the working prototypes are, next to the scientific papers, the most tangible direct results of this project. In the schematics in the first paragraph of this chapter, an overview is given of what prototype-features we were able to realize. In the second paragraph, we show this again but then per work package. There you can read for each work package what we achieved.

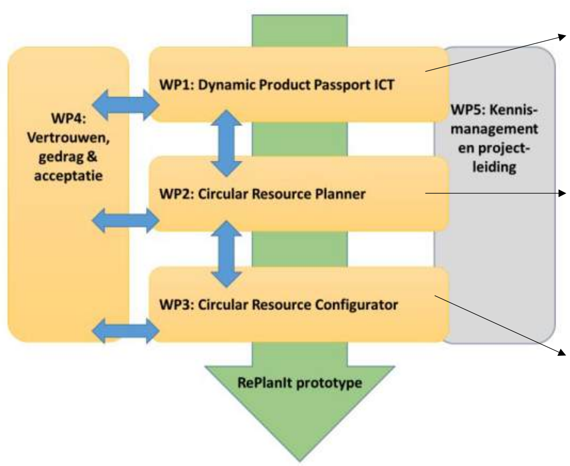
3.1 Feature realization overview of the prototypes

During this project, the prototypes were developed iteratively, as is common in software development and R&D. The final prototypes are the end-result of multiple iterations, where on several occasions an iteration has lead to adjustment of the development activities. The end result is described below, showing the interpretation of the features that were described in the original project plan – first zooming in on the laptop prototype, then on the server prototype and finally on the field labs:

Figure 3: Laptop Prototype overview

AMSTERDAM INSTITUTE FOR ADVANCED METROPOLITAN SOLUTIONS

Overview of Laptop Prototype



Realized	Alternative realized (A) or not feasible (X)
✓ Design of data ontology ✓ Laptop passports 3 models ✓ GHG emission data production and use phase ✓ API interface for front-end ✓ Partial material composition data (due to very limited availability)	A Data interface OEM suppliers A Data interface hardware IOT A Data interface ICT mgt system (whole laptop fleet in system) A Full Material composition data X Machine Learning / AI on dynamic data
✓ Laptop replacement scenario ✓ Laptop refurbishment scenario ✓ Laptop life-time extension scenario ✓ Circular, sustainability and business KPI's for reporting and decision making ✓ On system level, strategies for circular replacement *Extra* Expert advice for best -choice	X Laptop after end-of-life scenario's A Rest life duration for product and components X Condition Based Maintenance X On system level, strategies for circular design
✓ Research into customer journey for re-use, (also including purchase phase) including DaaS as best practice ✓ Proof of concept for current overview of laptops and rest-life, with 4 laptops in real life case ✓ Enabling circular product offering (value visualization of refurbished laptops)	A Current overview laptop fleet (status, rest life time, planned upgrades) for organisations and DaaS fleet owners A Overview of (soon to be) available hardware for refurbishment for organisations and DaaS fleet owners A Capitalisation of rest value X (Optional) Facilitating selling, renting or sharing between organizations

Figure 4: Server Prototype overview

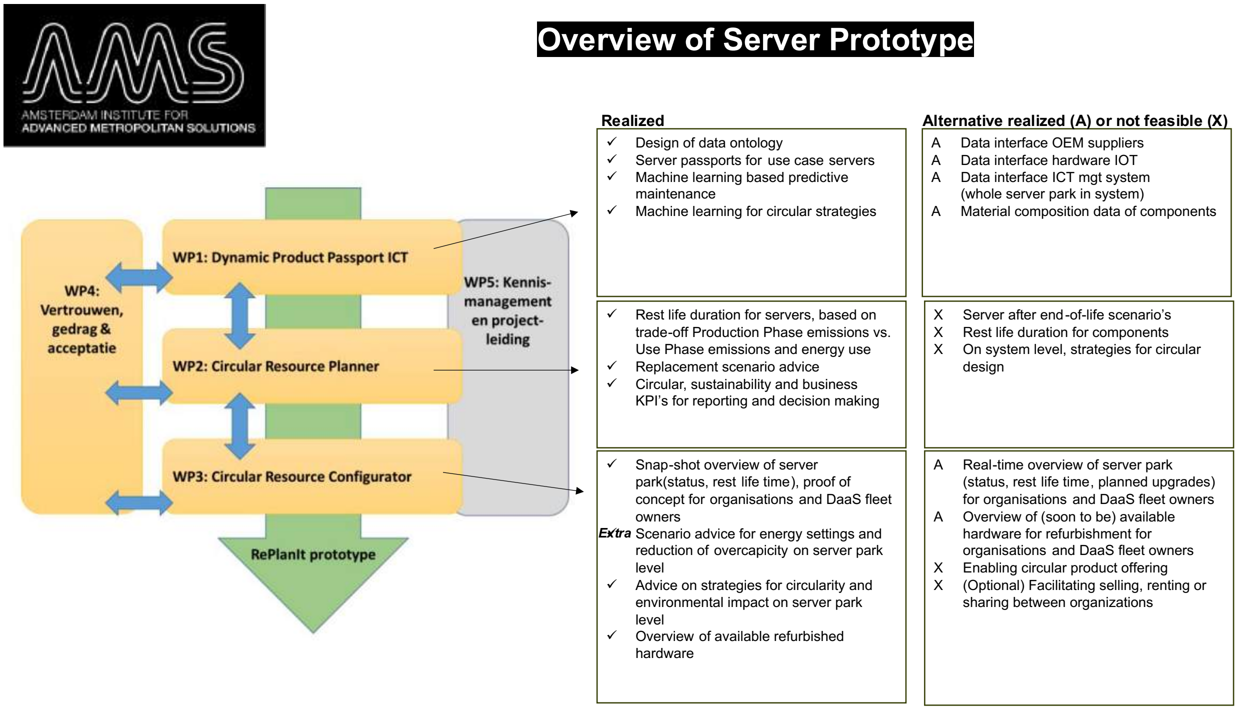
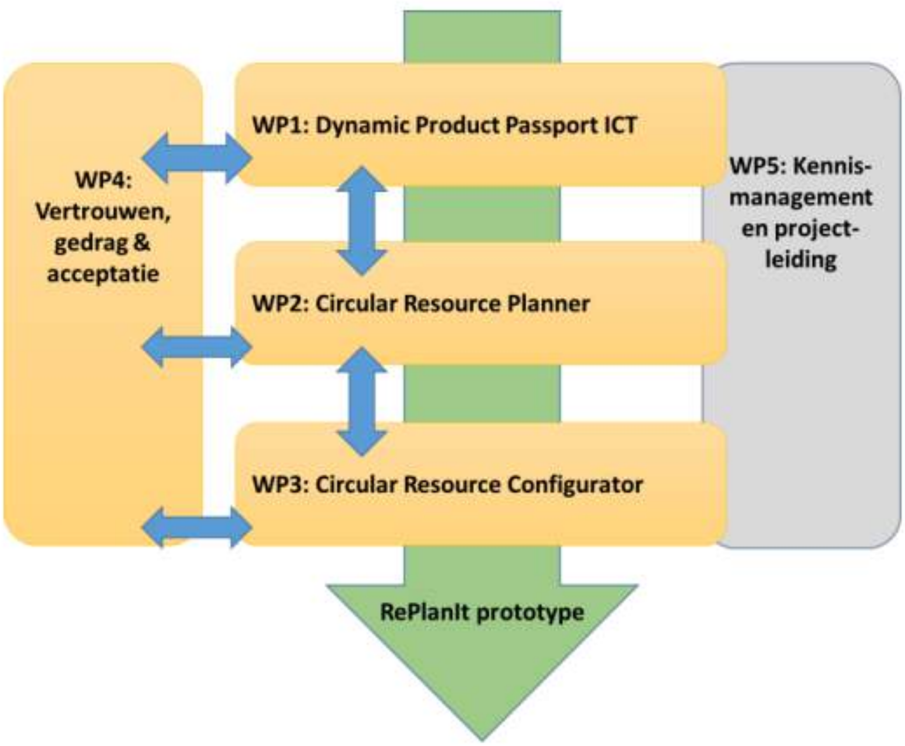


Figure 5: Overview of field labs



3.2 Overview of the realization per work package

Table 2: overview of realization per work package (table 1 not available in public report)

Work Package	Realized	Alternative realized or not feasible
1.1 Indicatoren en databronnen DPP	• Sufficient hardware LCA data was found • Relevant indicators were identified • Dynamic usage data for servers was secured, however with extreme delay, only a month before original end of project	• Material composition data was not sufficiently available, this was only found and included for a few example devices • Critical material content: no device-specific information was available • These aspects were, however, covered in the ontology, making the DPP implementation-ready
1.2 Stakeholder mapping en product journey mapping	• Relevant mapping was completed	
1.3 Systeemontwikkeling prototype DPP	• Datamodel / ontology • Functional back-end prototype • API interface to front end • Dynamic Product passports for laptops were created • Dynamic Product passports for servers were created • Data from ICT management systems of end-users was collected and added in single batch • Internet-of-Things data for servers (batch loaded, not real time) • Predictive maintenance and machine learning research for Servers	• Real time interfaces with systems of ICT suppliers (OEMs) – they were not part of consortium and there was no interest. Public hardware data from OEMs was used. • Real time interfaces with ICT management systems of end-users – there was no interest in making it real-time. We used data dumps as alternative • Internet-of-Things data for laptops was not available because of privacy and security reason • Predictive maintenance advice for servers: this was created, but there were not enough break-downs or replacements in the (extensive) data sets to predict maintenance in a useful manner
1.4 Test and validation program prototype DPP	• Laptop use case validated and tested • Partial testing and partial validation of Server use case; non-machine-learning features only	• Testing and validation of server use case was limited: machine learning research started late and data covered too little time. We ran out of time for proper testing & validating of the prototype. For the non-machine-learning features, the testing & validation has been done

Work Package	Realized	Alternative realized or not feasible
1.5 Validation and continued development of DPP	• Laptop use case validated and tested • Partial testing and partial validation of Server use case: non-machine-learning features only	• For the non-machine-learning features, the testing & validation has been done, but as stated above full testing was not possible.
2.1 Specs prototype CRP	• Fully realized	
2.2 System development prototype CRP	NB: CRP and CRC were developed as one integrated tool • Laptop prototype was developed • Server prototype was developed Realized features: a. Laptop replacement scenario b. Laptop refurbishment scenario c. Laptop life-time extension scenario d. Circular, sustainability and business KPI's for reporting and decision making e. On system level, strategies for circular replacement f. Expert advice for best-choice g. Rest life duration for servers, based on trade-off Production Phase emissions vs. Use Phase emissions and energy use h. Replacement scenario advice i. Rest life duration for servers, based on trade-off Production Phase emissions vs. Use Phase emissions and energy use j. Replacement scenario advice k. Circular, sustainability and business KPI's for reporting and decision making	Alternatives (A) realized or features not realized (x): × laptop after end-of-life scenario's – no need for this at field lab organizations and not possible with the available data A Rest life duration for product and components (laptop and servers). This was realized for whole laptops × Condition Based Maintenance: lack of data for laptops, lack of breakdowns in data for servers × Server after end-of-life scenario's – not possible within the scope of the use case and no clear need for this from ICT hardware owners A On system level, strategies for circular design – this was done for sever parks, where we identified server park design strategies for replacement and capacity
2.3 Test and validation program prototype CRP	• Laptop use case validated and tested • Partial testing and partial validation: non-machine-learning features only	• Full testing and validation of server use case: machine learning research started so late and data covered too little time. We ran out of time for proper testing & validating of the prototype. For the non-machine-learning features, the testing & validation has been done • It proved impossible to find server fleet owners that were willing to test the protoypes within our network within the timelines of the project.
2.4 Validation and continued development of prototype CRP	• Laptop prototype was improved base on testing	• Server prototype testing was done near end of project and no further development was possible

Work Package	Realized	Alternative realized or not feasible
3.1 Specs prototype CRC	• Fully completed	
3.2 Customer journey re-use hardware	• Completed, based on a best-practice Device-as-a-Service	
3.3 System development prototype CRC	NB: CRP and CRC were developed as one integrated tool • Laptop prototype was developed • Server prototype was developed Realized features: a. Proof of concept for current overview of laptops and rest-life, with 4 laptops in real life case b. Snap-shot overview of server park (status, rest life time), proof of concept for organisations and DaaS fleet owners c. Scenario advice for energy settings and reduction of overcapacity on server park level d. Advice on strategies for circularity and environmental impact on server park level e. Overview of available refurbished server hardware	Alternatives (A) realized or features not realized (x): A Current overview laptop fleet (status, rest life time, planned upgrades) for organisations and DaaS fleet owners – proof of concept created based on 4 laptops. A Overview of (soon to be) available Laptop hardware for refurbishment for organisations and DaaS fleet owners – proof of concept created based on 4 laptops A Capitalisation of rest value of laptops and enabling circular product offering – extended life potential was visualized A Real-time overview of server park (status, rest life time, planned upgrades) for organisations and DaaS fleet owners – data dumps were used as alternative to real time data A Overview of (soon to be) available hardware for refurbishment for organisations and DaaS fleet owners – proof of concept was realized × Capitalisation of rest value of servers and enabling circular product offering – not possible with the available data and insufficient interest from server park managers × (Optional) Facilitating selling, renting or sharing between organizations - Not possible to realize optional features within the time and resource constraints of the project
3.4 Test- en validatie program prototype CRC	See 2.3	See 2.3
3.5 Validation and continued development of prototype CRC	See 2.4	See 2.4
4.1 Requirements for adoption and acceptance RePlanIT	• Fully realized	
4.2 Interviews ICT decision makers, on drivers and roadblocks	• Fully realized	
4.3 Interviews ICT decision makers, on drivers and roadblocks	• Fully realized	

Work Package	Realized	Alternative realized or not feasible
4.4 Input for design strategies RePlanIT system	• Fully realized	
4.5 Evaluation user experiences RePlanIT system	• Realized for Laptop decision makers • Realized for server fleet owners, excluding machine learning results	• Full scale Laptop user testing within test organizations, integrated in daily use – this was not feasible or useful. Single tests were sufficient. • Full user test for servers: the prototype was finished too late into the project. Also, full integration in daily use was not feasible, nor was this deemed useful by asset owners.
5. Knowledge management and project management	• Fully realized	

4 Dynamic Product Passports for Laptops and Server hardware

4.1 Stakeholder & Product Journey Mapping

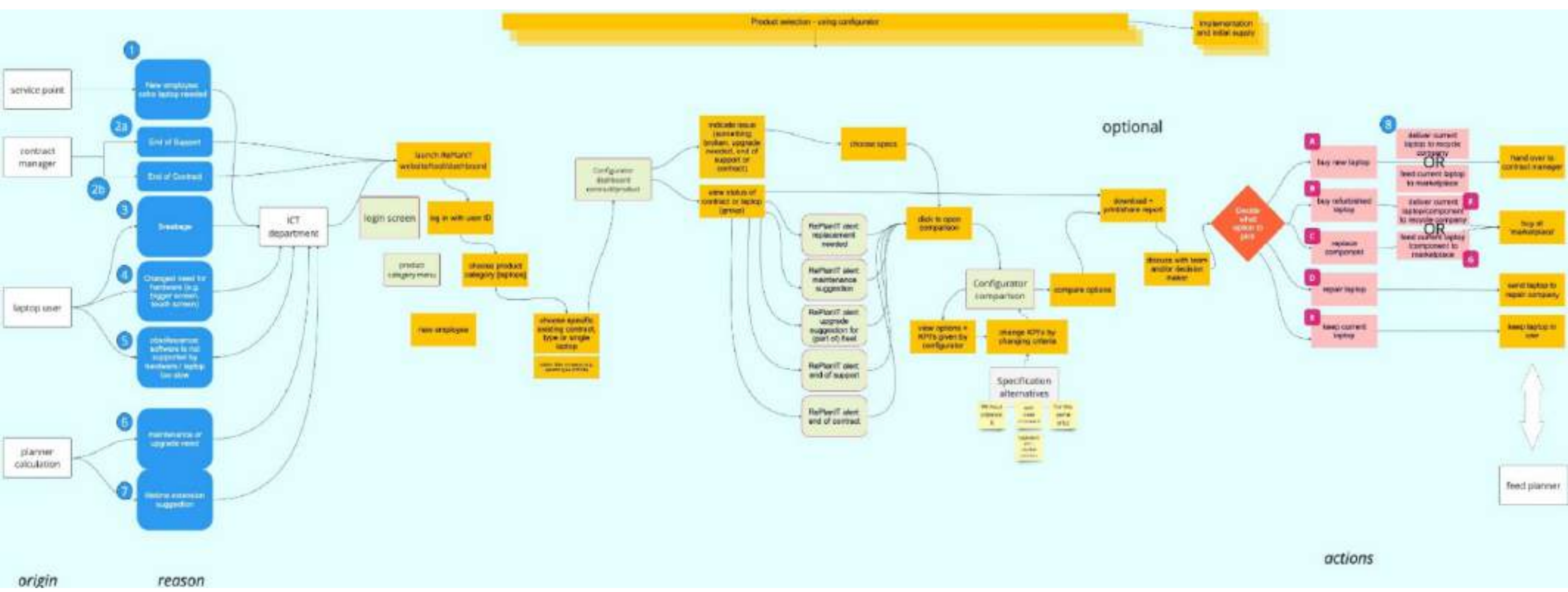
User journey mapping for the Laptop prototype

In this work package we investigated the following questions:

- What would be the reason to use the RePlanIT tool for laptops?
- What functionalities would the tool offer for different scenarios?

This resulted in a journey map, which is shown below. The scheme shows the different paths that a user could follow and what the resulting action can be. This journey formed the basis the prototype design.

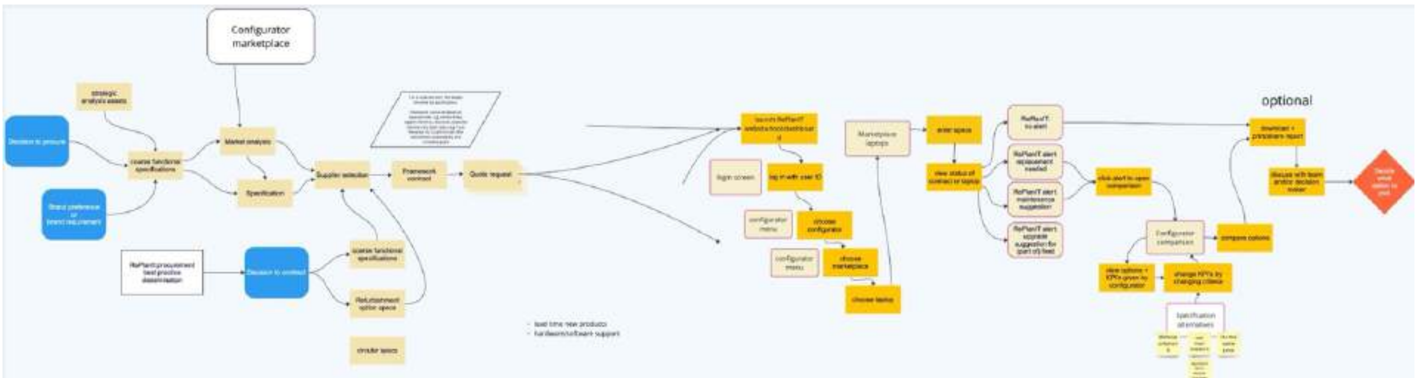
Figure 6: journey map Laptops



User journey for procurement of business ICT hardware

We also made a journey map for the procurement of hardware – see the scheme below. The thought behind this scheme is that a procurer can use ReplanIT tool to include sustainable product specifications into a tender or supplier selection criteria, in order to steer towards the procurement of sustainable products. This map was used as input for the design of the prototype, telling the designers which type of user would be using the tool in which phase.

Figure 7: journey map for procurement of business ICT hardware



4.2 Indicators & Data

For the Dynamic Product Passport and subsequent user tools, a selection of key performance indicators is made that allow users to make informed decisions. Both sustainability indicators and business indicators are included, so users can see the impact of different scenarios on the sustainability performance and the financial consequences.

Indicators for Laptops that were integrated in the RePlanIT DPP

Table 3: indicators for laptops

Indicator (unit)	Description
Carbon footprint production (kg CO_2 eq.)	The climate impact or the amount of GHG emissions emitted during production of the product. This data can be obtained from the manufacturers' EPD. When no EPD is available, the product can be excluded from the selection tool (or a fictional high carbon footprint could be assigned).
Carbon footprint use per year (kg CO_2 eq./year)	The climate impact or the amount of GHG emissions emitted during use of the product. This data can be obtained from the manufacturers' EPD. When no EPD is available, the product can be excluded from the selection tool (or a fictional high carbon footprint could be assigned).

Carbon footprint first year (kg CO_2 eq.)	= Carbon footprint production + Carbon footprint use per year
Circularity (%)	The degree to which the flow of resources fits a circular economy, with 100% circularity reflecting a product-system that requires no virgin materials (input side) and generates no waste (output side). = 100% - ($M\%_{virgin}$ + $M\%_{wasted}$ + $M\%_{downcycled}$ + $M\%_{scrap}$)/2 Where *M%* is the mass percentage of materials. Only limited data on the composition of products is currently publicly available. When no data is available, the manufactured product is assumed to have 0% circularity. When recycled materials are used, and when components or products are reused (e.g. in remanufacturing), the circularity score can be calculated for the specific scenario.
Virgin materials (kg)	The amount of virgin materials in the product. Only limited data on the use of non-virgin materials is available from a few manufacturers. When no data is available, the entire product is assumed to be manufactured from virgin resources.
E-Waste (kg)	The number of kilograms of electronic material that ultimately becomes waste. This is equal to the weight of the electronic product minus the portion that is refurbished, remanufactured or recycled after use.
Sales price (€)	The product price (for the organization)
Carbon footprint costs production (€)	= Carbon footprint of production * Carbon footprint price. The latter is currently set per organization.
True costs (at purchase) (€)	= Sales price + Carbon footprint costs production
Contains critical materials (yes/no)	This indicator reflects whether critical materials are contained in the product. As soon as data becomes available on the amount of critical materials per product, this unit could be expressed in kg/product.

Indicators for Servers/Datacenters that were integrated in the RePlanIT DPP

For servers/datacenters, similar indicators are used. Terminology is tuned towards the target audience (e.g. GHG emissions instead of Carbon footprint). Because energy use is a dominant variable for this product category, also the use (MWh) and costs (€) are included as key performance indicators, next to the GHG emissions that result from the use of electricity.

Table 4: indicators for Servers/Datacenters

Indicator (unit)	Description
GHG emissions (kton CO_2 eq.)	The climate impact or the amount of GHG emissions emitted during production, transportation, use phase, and disposal of the product.

GHG costs (€)	= GHG emissions * GHG price. The latter is currently set per organization.
Virgin materials (kg)	The amount of virgin materials in the product. Only limited data on the use of non-virgin materials is available from a few manufacturers. When no data is available, the entire product is assumed to be manufactured from virgin resources.
E-waste (kg)	The number of kilograms of electronic material that ultimately becomes waste. This is equal to the weight of the electronic product minus the portion that is refurbished, remanufactured or recycled after use.
Circularity (%)	The degree to which the flow of resources fits a circular economy, with 100% circularity reflecting a product-system that requires no virgin materials (input side) and generates no waste (output side). $= 100\% - (M\%_{virgin} + M\%_{wasted} + M\%_{downcycled} + M\%_{scrap})/2$ Where *M*% is the mass percentage of materials. Only limited data on the composition of products is currently publicly available. When no data is available, the manufactured product is assumed to have 0% circularity. When recycled materials are used, and when components or products are reused (e.g. in remanufacturing), the circularity score can be calculated for the specific scenario.
Electricity use per year (MWh/year)	The electrical energy used by the product, under average usage, per year.
Electricity costs (€/year)	= Electricity use per year (MWh)* electricity costs (€/MWh)

4.3 Data management

This section presents the data management plan for the data used in the Laptop prototype and the Server prototype.

4.3.1 Data Collection

The focus of UC1 are laptops, their hardware components, material composition and their sustainability characteristics. To represent a detailed specification of this data, RePlanIT has built a semantic model in the form of an ontology. The RePlanIT ontology is used as the basis of the dynamic product passports (DPPs) developed in work package (WP) 1 and is the main specification of the collected and used data within the RePlanIT project. Table 1 presents some of the main types of data that RePlanIT collects to build DPPs of laptops. As there is not one true and complete source of data, the data for the DPPs is currently collected manually from laptop manufacturers' websites, scientific publications, openly available datasets accompanying these publications and public datasets produced by well established companies in the sustainability field. The main sources of data for UC1 are presented in Table 2. The full specification of the data types included in DPPs of laptops is outlined in the online documentation of the RePlanIT ontology that is available at: https://kind.io.tudelft.nl/replanit/docs/

Table 5: Example of Data Types for Laptop Use Case

Category	**Data Types**
Laptop	Brand, Model, Year, Image, Purchase Cost, Current Cost, True Cost, Device Age, Available Support, Support Cost, Warranty Duration, Certification Type, Availability
Laptop Components (hardware and software)	Battery Type, Battery Capacity, BIOS Chip, Camera Type, Camera Resolution, Display Size, Display Resolution, Central Processing Unit (CPU) Type, CPU Load, CPU Capacity, CPU Speed, Graphics Card Type, Graphics Card Processor, Keyboard Type, Network Card, Port(s), Slot(s), Speaker(s), Storage Device(s), Hard Drive (HD) Type, HD Storage Capacity, Ram Size, Rom Size, Video Card Type, Wireless Card, Sensor Types (Fingerprint, Temperature), Software, Operating System
Materials	Aluminium Weight, Copper Weight, Glasses Weight, Plastic Weight, Steel Weight, Metals Weight, Other Material Weight
Sustainability	Circular Process, Circular Process Cause, Circular Process Status, Energy Consumption, Green House Gas (GHG) emissions during production, GHG emissions during use time, Material Circularity, Material Criticality, Product Circularity, Waste, Primary Resource, Non-Renewable Resources, Renewable Resources
Agent	Organisation, Person, Software, Responsibility, Role, Contact Details, Website

Table 6: Laptop Use Case Data Sources

Source	**Type**
C.W. Babbitt, H. Madaka, S. Althaf, B. Kasulaitis, E. G. Ryen, Disassembly-based bill of materials data for consumer electronic products. *NatureScietific Data* **7**, 251 (2020). https://doi.org/10.1038/s41597-020-0573-9	Laptop Material Composition
Dell[1]	Laptop Components, Software and Hardware Characteristics
Apple[2]	Laptop Components, Software and Hardware Characteristics

HP[3]	Laptop Components, Software and Hardware Characteristics
Boavizta[4]	Sustainability Data, Calculations
Ideal&Co[5]	Sustainability Data, Calculations

UC2 focused on servers. Two datasets with server performance data were provided. Similarly to UC1, we focus on servers and their hardware components, material composition and their sustainability characteristics. In addition, we investigated dynamic properties of servers such as performance metrics (e.g. energy consumption, CPU utilisation). The main purpose of the dynamic data is to drive machine learning, namely predictive maintenance into detecting when and under what circumstances a server fails. Table 3 presents knowledge about servers that we have represented in our RePlanIT ontology. The full specification of the data is available at https://kind.io.tudelft.nl/replanit/docs/. The main sources of data for UC2 and examples of scientific publications we found insightful are presented in Table 4.

Table 7: Example of Data Types for Server Use Case

Category	**Data types**
Server	Server type – Physical or Virtual, Brand, Model, Year, Server Generation, Purchase Cost, Current Cost, True Cost, Device Age, Available Support, Support Cost, Warranty Duration, Certification Type, Availability, Devices in Stock
Server Components (hardware and software)	Virtual machines (VMs) and hosts, CPU, Software, Operating system
Server Performance Metrics	Observations, VM host, CPU Cache, CPU Number of Cores, CPU Number of Cores in Use, Memory Slots, Memory Usage, NVDIMM Rank and Capacity, Energy Consumption, Total VMs, Battery Lifetime
Materials	Aluminium Weight, Copper Weight, Glasses Weight, Plastic Weight, Steel Weight, Metals Weight, Other Material Weight
Sustainability	Circular Process, Circular Process Cause, Circular Process Status, Energy Consumption, Green House Gas (GHG) emissions during production, GHG emissions during use time, Material Circularity, Material Criticality, Product Circularity, Waste, Primary Resource, Non-Renewable Resources, Renewable Resources
Agent	Organisation, Person, Software, Responsibility, Role, Contact Details, Website

Table 8: Server Use Case Data Sources

Source	**Type**
IT Service Provider 1	Dataset with performance data for servers
IT Service Provider 2	Dataset with performance data for servers
Dell	Server Components, Software and Hardware Characteristics
HP	Server Components, Software and Hardware Characteristics
Boavizta	Sustainability Data, Calculations
Ideal&Co	Sustainability Data, Calculations
Aliter	Knowledge sharing on servers and their performance
Cao, R., Yu, Z., Marbach, T., Li, J., Wang, G., & Liu, X. (2018, July). Load prediction for data centers based on database service. In 2018 IEEE 42nd annual computer software and applications conference (COMPSAC) (Vol. 1, pp. 728-737). IEEE.	Load prediction for data centers based on database service
Wang, G., Zhang, L., & Xu, W. (2017, June). What can we learn from four years of data center hardware failures?. In 2017 47th Annual IEEE/IFIP International Conference on Dependable Systems and Networks (DSN) (pp. 25-36). IEEE.	Insights on data center failures
Ceritos	Knowledge sharing on servers and their performance
Harryvan, D. H, (2021). The Idle Coefficients: KPIs to assess energy wasted in servers and data centers, IEA 4E Technology Collaboration Programme Electronic Devices and Networks Annex (EDNA)	Data center and server idle coefficient insights and calculations

Weckworth, J. (2013). The lack of transparency can be seen as a root cause of outages and incidents, Available at https://journal.uptimeinstitute.com/data-center-outages-incidents-industry-transparency/, Uptime Institute.	Insights on data availability, quality, process transparency and failures.

[1] https://www.dell.com/nl-nl
[2] https://www.apple.com
[3] https://www.hp.com
[4] https://www.boavizta.org/en
[5] https://www.ideal-co.nl

4.3.2. Data Storage

Currently, the data for the DPPs of laptops and data servers used within the RePlanIT system (see Table 1 and 3) is represented in the form of a knowledge graph, which follows the RePlanIT ontology data specification. The ontology is stored in a GitHub repository and has been publicly documented with WIDOCO[2] based on best practices. The data for the DPPs is stored in the GraphDB[3] graph database. Within the scope of the project and its duration, the free version of GraphDB is used. Currently, an instance of the database runs on a TU Delft server. TU Delft has administrator-level access to the database, while other project partners have been assigned user/viewer status. The DPPs are also available through several APIs (see section 1.3). Database back-ups are performed on a monthly basis and with every iteration of the underlying ontology. Currently, the database stores 0.40 GB of data in a knowledge graph format.

4.3.3 Data Availability

The RePlanIT ontology is publicly available at https://kind.io.tudelft.nl/replanit/docs/. The RePlanIT DPPs, which are stored in GraphDB and are the main source of data for RePlanIT are available through several Application Programming Interfaces (APIs) (see Fig. 1). Currently, the APIs are only available to project consortium members. However, the APIs will be shared for scientific purposes such as within scientific publications led by TU Delft for result validation and scientific collaboration. The UC1 APIs have been documented according to best practices with Swagger[1] and their specification is publicly available at:
https://app.swaggerhub.com/apis-docs/RePlanIT/RePlanITLaptopDPP/1.0.0

The data for UC2 (data servers) is private based on agreement with the project consortium data provider. It is stored in a secure database at TU Delft and can be currently accessed for research purposes only by TU Delft.

4.3.4 Data Sharing

By utilising Semantic Web technologies, namely ontologies and knowledge graphs, RePlanIT's DPPs already support FAIR data principles by design. Table 5 provides details on how each FAIR principle is achieved at machine and human levels. We have further elaborated on this in our accepted for publishing scientific paper: *Kurteva, A, et al. "Semantic Web and its Role in Facilitating ICT Data Sharing for the Circular Economy: An Ontology Survey." Semantic Web journal (2024).*

Table 9: RePlanIT's Implementation of FAIR Data Principles

FAIR Principle	Realisation	Technology
Findable	**Machine-level:** Ontologies, as a technology support the discovery of new and traceability of existing information in the ICT and CE domains via the interpretation of the URIs defined for each concept. **Human-level:** Findability of data is also supported by the user interface(s) (UIs) developed for RePlanIT.	Ontology, Knowledge Graph, APIs, Circular Resource Planner (UI)
Accessible	**Machine-level:** Ontologies help integrate disparate silos of data by defining a unified terminology of a domain, which represents all of the involved entities (people, organisations, software) their specific roles, access rights etc. The database is accessible through APIs that are public. **Human-level:** The RePlanIT ontology is openly available online in GitHub. The ontology has also been publicly documented. The DPPs can be exported in various formats (RDF, JSON, JSON-LD, CSV) through GraphDB's public SPARQL endpoint. The RePlanIT's UIs make the data accessible for non-expert users as well.	Ontology, Knowledge Graph, APIs, Circular Resource Planner (UI)
Interoperable	**Machine-level:** Ontologies transform unstructured data into information through the use of Resource Description Framework (RDF) triples and URIs and represent it in a machine interoperable format.	Ontology, Knowledge Graph, APIs, User Interface (Circular

	Human-level: The RePlanIT's UIs make the data understandable for non-expert users as it provides an overview of it and insights derived from it in a graphical format.	Resource Planner)
Reusable	**Machine-level:** The RePlanIT ontology is used as a standard unified data model within the project to showcase (in one place) what data is used and is needed for specific processing (e.g predictive-maintenance). This supports and simplifies data reuse for collaboration in and outside an organisation. The ontology itself is publicly available, which allows for its wider reuse and extension by the scientific community and industry. **Human-level:** The RePlanIT's UIs further supports the DPPs reuse by humans. The data from DPPs can be reused for different sustainability calculations that are made visible to humans on the UI.	Ontology, Knowledge Graph, APIs, User Interface (Circular Resource Planner)

4.3.5 Legal and Privacy Considerations

Currently, Laptop Use Case (UC1) prototype collects, stores and processes non-personal data. All of the data that has been collected in protoype is sourced from online resources that are publicly available and do not contain personally identifiable information (PII) (as defined by the General Data Protection Regulation (GDPR)'s [1] Article 4(1)).

Data for Server Use Case (UC2) is private and cannot be made publicly available as per the agreement between the project consortium members. A metadata scheme presenting the types of data in the data set will be provided in support of open science principles.

In the future, if the DPPs and the UI are to be integrated within an organisation's system, the data that is collected will most likely qualify as personal – each laptop is associated with an individual thus one of the six legal bases for GDPR (Art. 6) compliant data processing needs to be met. In such future cases each organisation will be responsible for ensuring GDPR compliant data processing and management. Each organisation will have to implement or extend the current implementation of its technical and organisational measures that support GDPR compliance.

A more recent legislation that needs to be considered if ML is trained on personal data is the AI Act, which categorise AI based on its use and the risks associated with it.

[1] https://github.com
[2] https://dgarijo.github.io/Widoco/doc/tutorial/
[3] https://graphdb.ontotext.com
[4] https://kind.io.tudelft.nl/replanit/docs/

4.4 Dynamic Product passport

This section presents background information on the topic, insights gathered from our systematic and in-depth survey of semantic models for ICT in a CE context and current developments towards RePlanIT's DPPs. These developments focus on building the RePlanIT ontology, its utilisation for annotating data (i.e. building the DPPs) and finally utilisation of the DPPs for machine learning and automated analytics aimed to support failure prediction. As discussed in this section, two datasets about servers and their performance were made available to us in the project. Details on their transformation into DPPs, analysis and ML use are presented in the following subsections.

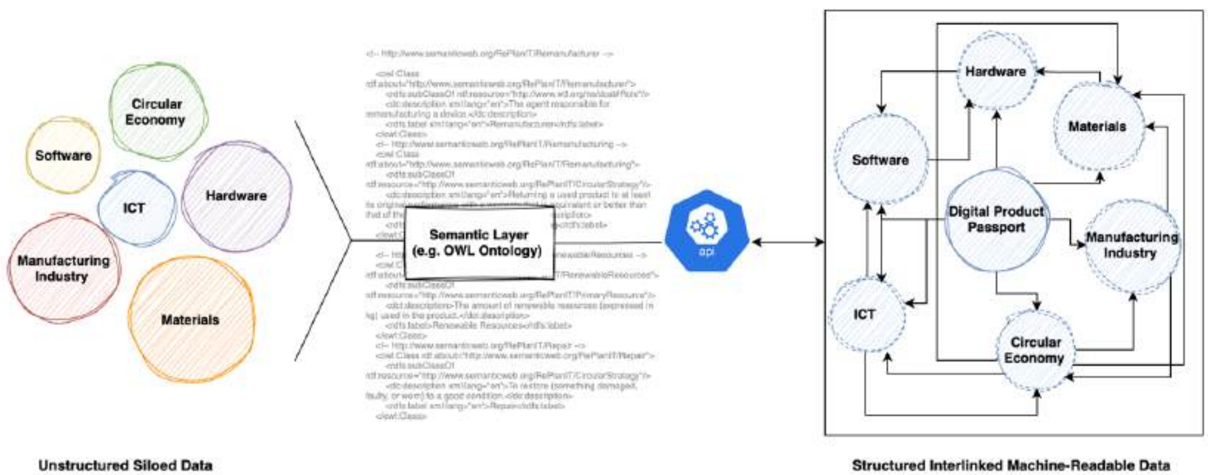


Fig 8. From unstructured to structured data with semantics in RePlanIT

3.4.1 Background survey and literature analysis of the domain

The rapid digitisation that we have witnessed in the past few years has resulted in increased Information and Communications Technology (ICT) hardware manufacturing, which is not sustainable due to the growing demand for critical materials and the greenhouse emissions associated with it. A solution is to adopt a circular economy (CE) approach. To facilitate this paradigm shift and boost the data economy and digital innovation in the field, the European Union has introduced the concept of digital product passports, which should provide information about a product's lifetime to bring more transparency into supply chains. Nontheless there are a number of data and process related (not only) technical challenges, which we summaries below.

- Limited availability, accessibility and interoperability of ICT, materials and Circular Economy (CE) data across organisations.
- Lack of digital infrastructures and tools that support knowledge exchange and interpretation between sustainability, ICT and technology experts in a standardised human and machine-readable formats.
- Lack of process transparency and data traceability along supply chains.

Utilising Semantic Web technologies such as ontologies and knowledge graphs is a possible solution. Table 10 summarises further the current challenges to circular ICT in relation to FAIR data principles and maps them to how semantic web technologies can solve them.

Table 10: FAIR Principles, ICT Challenges and the Semantic Web

FAIR Principle	ICT and Circular Economy Challenge	Semantic Web Solution
Findable	Lack of available information and knowledge about circular solutions among ICT decision-makers.	Ontologies, as a technology, can be used to support the dis- covery of new and traceability of existing information in the ICT and CE domains via the interpretation of the URIs defined for each concept
Accessible	Many departments (e.g. sales, IT, finance, delivery) are involved in the decision making process for the implementation of an ICT environment, which results in knowledge silos. Only authorised individuals can access specific data	Ontologies help integrate disparate silos of data by defining a unified terminology of a domain, which represents all of the involved entities (people, organisations, software) their specific roles, access rights etc
Interoperable	It is challenging for a non-expert in the domain to inter- pret materials and ICT data and make truly informed and impactful sustainability decisions.	Ontologies transform data into information through the use of RDF triples and URIs and represent it in a machine inter- pretable format. This can help build more intelligent tools (with artificial intelligence) to support informed human-decision making in the CE.
Reusable	Lack of standardisation and documentation that is pub- licly available. Data from one silo/department has to be translated and interpreted when used for other purposes by another department. For example, data on existing lap- top types in use by an IT department of some organisa- tion might be made available for the purpose of adopting CE strategies by the procurement department. However it first needs to be accessed, interpreted and translated for the purpose of circular decision making.	An ontology can be used as a standard unified data model within an organisation to showcase (in one place) what data is used and is needed for specific processing (e.g predictive-maintenance). As a recommendation, an ontol- ogy should be documented and can be publicly available to support its reusability (a recommended principle for ontol- ogy engineering) and extension.

Following this, we conducted an extensive literature review and systematic analysis of ontologies for our use cases: DPPs of laptops and data servers. The main sources for this survey were peer-reviewed scientific publications in the CE, ICT and Semantic Web domains, which we identified via Google Scholar, ACM Digital Library, IEEE Xplore, Scopus and DBLP. A search for resources (e.g. updates on CE's standartisaion, definitions) was also performed on the websites of standardisation bodies such as the British Standards Institution (BSI), the EU Commision, the Internationa Electrotechnical Commission (IEC) and the International Organisation for Standardisation (ISO). Our survey identified over 20 semantic models in the ICT, materials and CE domains. We present detailed reviews of each model in terms of scope, domain and limitations regarding reuse for our work in our publication.

To illustrate the complexity of interlinking the ICT, materials and CE domains we present a graphical representation on Figure 9 of and ICT device's life-cycle in terms its life-cycle provenance. An ICT device (e.g. a laptop) can be represented in terms of the components that it is comprised of. Each component has provenance information, which is a record of its material, sustainability and physical properties and changes in them that have occurred as a result of an implemented CE strategy. ICT and materials provenance and lineage is vital for supporting product lifecycle assessment, establishing responsibility along the supply chain and for implementing CE strategies such as predictive maintenance.

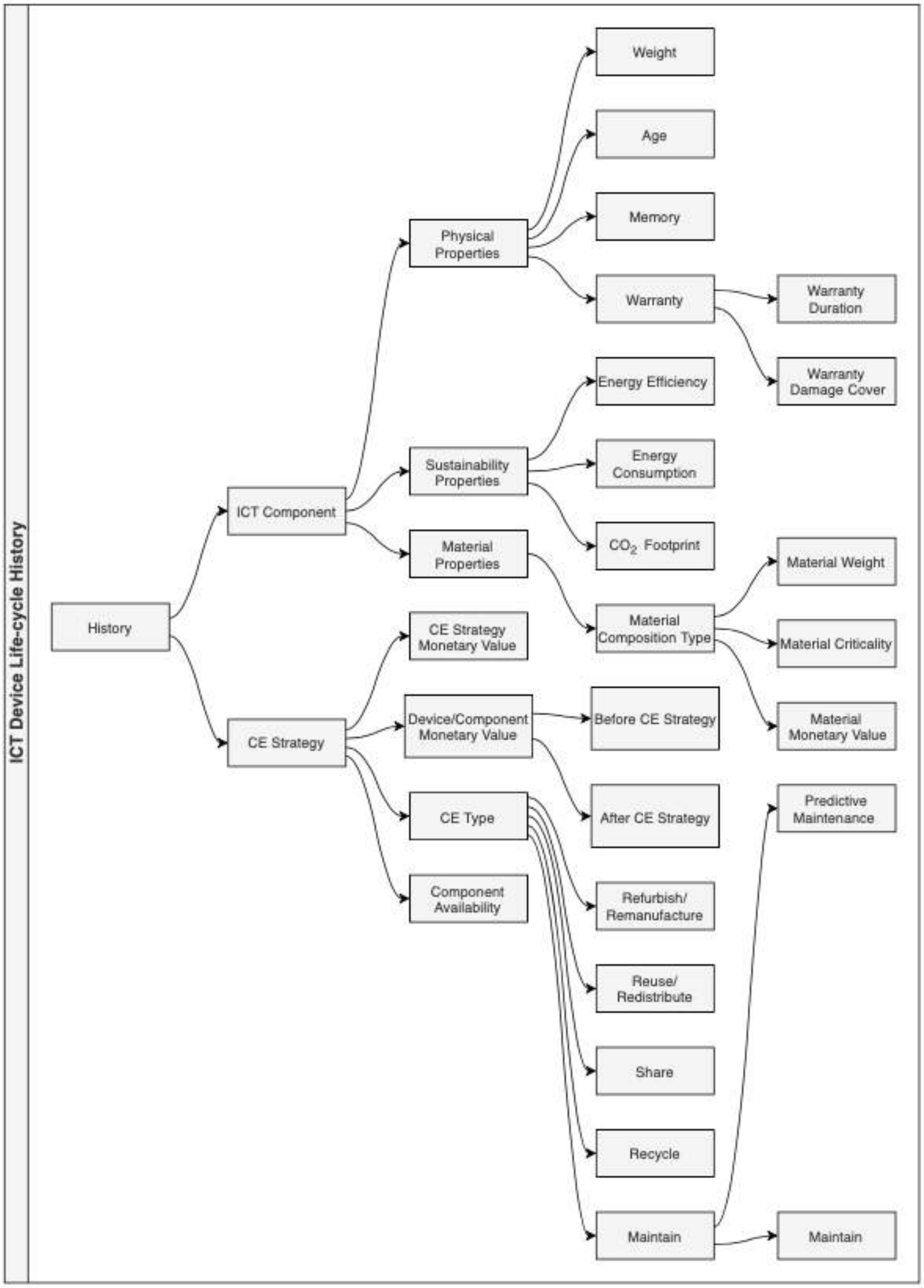


Figure 9. Conceptual Model for an ICT Device's Life-Cycle History

Based on this, we derived a set of 59 competency questions that an ontology for ICT DPPs should answer. The set is available in the appendix of our survey paper. Each one of the identified publicly available ontologies was analyzed against this set of questions. As discussed in our paper, none of the existing openly available ontologies thus far offers a full coverage of our use cases. We discuss all the limitations of the existing work in detail in our paper. Following our findings, we developed the RePlanIT ontology, which models all necessary data for building DPPs of ICT in a FAIR manner. Details on the ontology are presented in the next section.

4.4.1 The RePlanIT Ontology for ICT DPPs

Methodology for building the RePlanIT ontology

The overall methodology for building the RePlanIT ontology comprises 8 steps as presented in Figure 10.

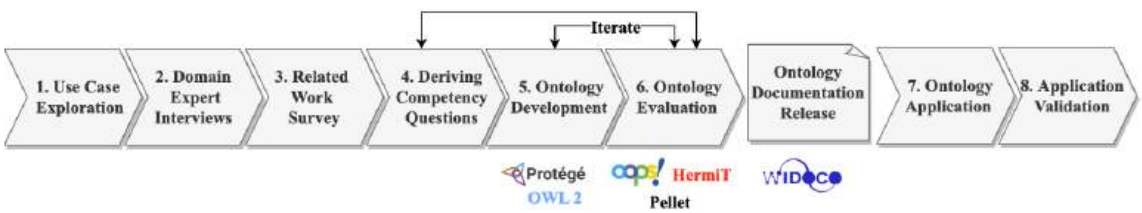


Figure 10: Followed Methodology

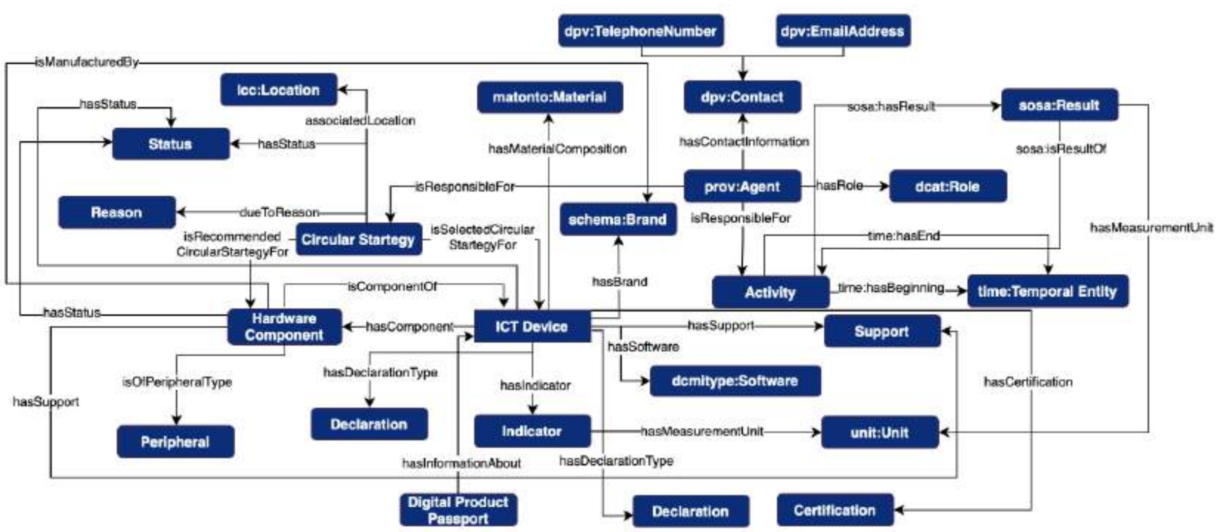
The work began with an exploration of the main use case's scope, namely building DPPs for laptops and their hardware components, and setting a hypothesis for the types of data that need to be modelled by the ontology. In the next step, we conducted interviews with 11 experts (over 5 public and private organisations) from the domains of organizational decision making for the procurement, maintenance, repair, and disposal of ICT equipment. The domain experts were asked about the existing procedures for each of these activities, the success or failure of new initiatives to introduce circularity into these activities, and the experienced or anticipated barriers to that introduction of circularity for each ICT-related activity. Further details and insights are presented in our paper. Next, we conducted an extensive literature survey of semantic models for ICT devices, their hardware components, materials and CE processes. The gathered information on the topic (from the interviews and the literature survey) led deriving a set of competency questions. The set of questions was refined and used as guidelines for the data that our ontology needs to represent semantically. The survey further helped identify existing ontology concepts (classes, data and object properties) that can already be reused within RePlanIT to answer the approach similar to the one in Schimizu et al. We began by defining high-level concepts (e.g., ICT Device, Hardware Component, Materials, CE Strategy, Indicators) that form modules of knowledge that are interconnected in RePlanIT. For consistency, an "isA" relationship was followed when defining classes and their sub-classes. Once all concepts for each module were defined, the relationships interconnecting the modules were specified. The ontology was then evaluated with standard ontology evaluation tools such as the OntOlogy Pitfall Scanner! (OOPS!), the Pellet and HetmiT reasoners in Protégé. The evaluation was also performed with the set of predefined competency questions (presented in Table 6. An iteration of the ontology to fix inconsistencies was performed, followed by ontology documentation with WIDOCO and its public release.

These steps comprise the ontology development process. The next sections present an overview of the main classes that comprise the RePlanIT ontology.

<u>RePlanIT ontology overview</u>

The RePlanIT ontology interlinks the ICT, materials and CE domains to represent machine-readable DPPs of ICT devices, namely laptops and data servers. Currently, the ontology (Figure 11) comprises of 295 classes, 72 object properties and 143 data properties, reuses concepts from 15 existing ontologies and defines new ones to represent highly granular DPPs at both device and device component levels. Further, the ontology represents different types of indicators that can be used to evaluate the economic and sustainability impact of a device. Figure 11 presents an overview of the main ontology concepts represented as classes and the relationships between them. A detailed ontology documentation, presenting descriptions of each class, subclass, object and data properties is available online at https://kind.io.tudelft.nl/replanit/docs/. The work presented in this section is part of our paper on the RePlanIT ontology which has been submitted for publication [3] at the Semantic Web journal (leading computer science journal for the Semantic Web field) and is currently under review.

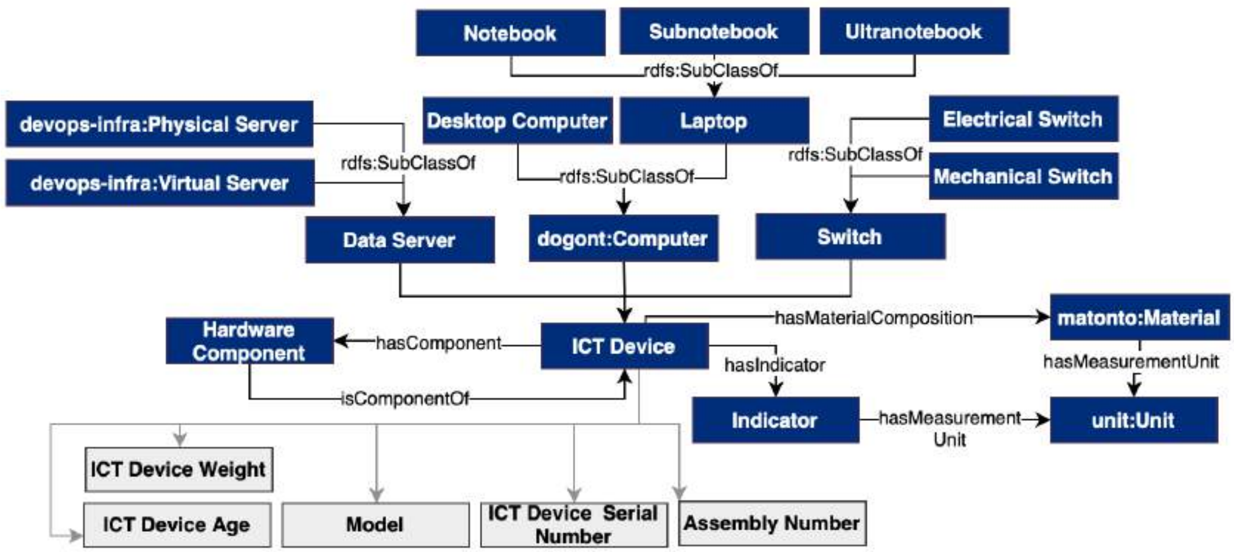
Figure 11. RePlanIT Ontology Overview



<u>Class ICT Device</u>

The concept of an ICT device is at the core of the ontology. As shown on Figure 12, we have represented three highly manufactured ICT devices – data server, computer (and types such as laptops). Specific ICT characteristics such as model, device weight, age, assembly number and serial number, which are subject to change through the device's lifetime have been represented as data properties. Each device has several hardware components, each with its specification (e.g. functional, sustainability and material characteristics). Information on this is presented in the next subsection.

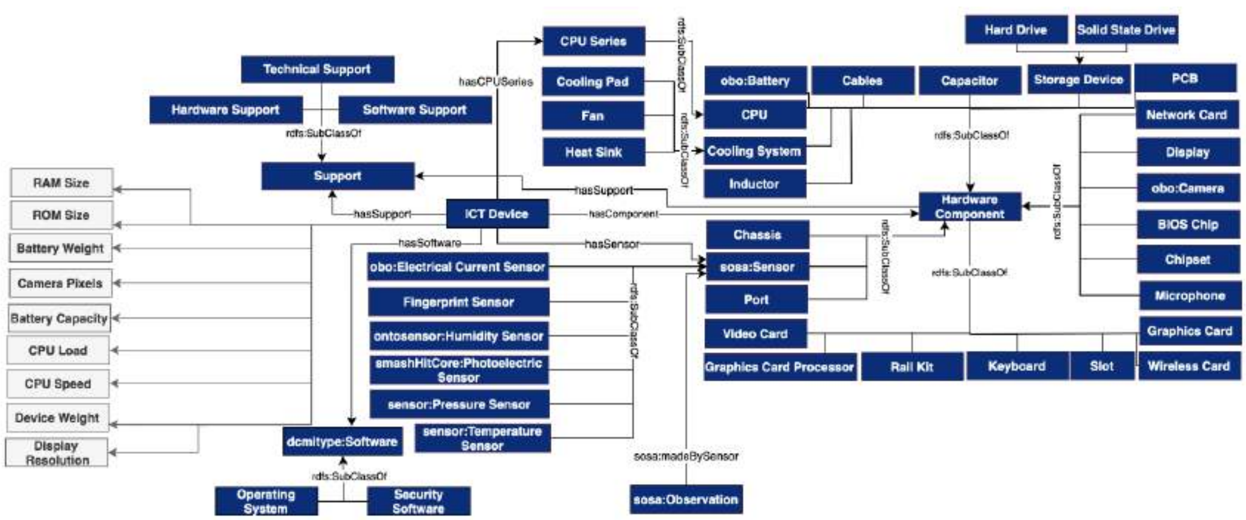
Figure 12. Class ICT Device



Class Hardware Component

The class Hardware Component (Figure 13) represents different types of hardware components that ICT devices such as laptops and data servers comprise of. To represent various hardware components and adhere to best practices for ontology engineering, several concepts (classes) from existing ontologies were used.

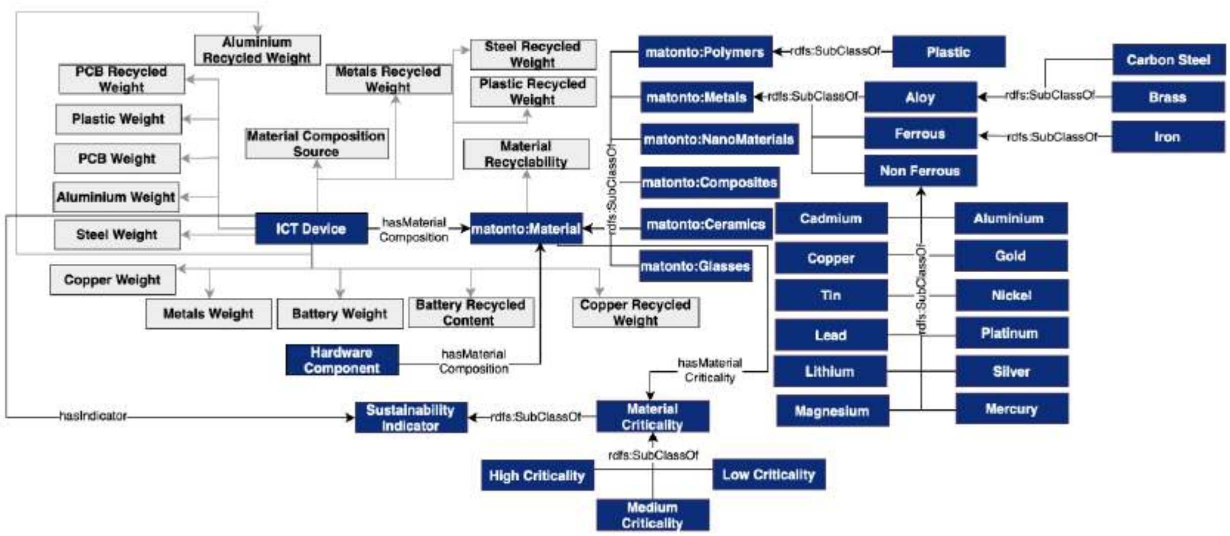
Figure 13. Class Hardware Component



Class Materials

To represent a classification of the different types of materials that can and are often used for the manufacturing of ICT devices, the class Material and its subclasses (e.g., Polymers, Metals, Glasses) have been reused (see Figure 14). RePlanIT expends the class *matonto:Metals* by defining specific types of metals (alloys such as brass, ferrous such as iron and non-ferous such as aluminium, copper etc.). An ICT device's material composition and material weight can be represented at both device and hardware component levels through the relationship *hasMaterialComposition* and specific data properties such as the weight of the material. An important property of a material is its recyclability (i.e. if a material is recyclable or not). This information can be recorded via the data property *MaterialRecyclability* of type boolean (either yes or no). To represent the content of each recycled material in a device specific data properties such as *AluminiumRecycledContent*, *CopperRecycledContent* can be used.

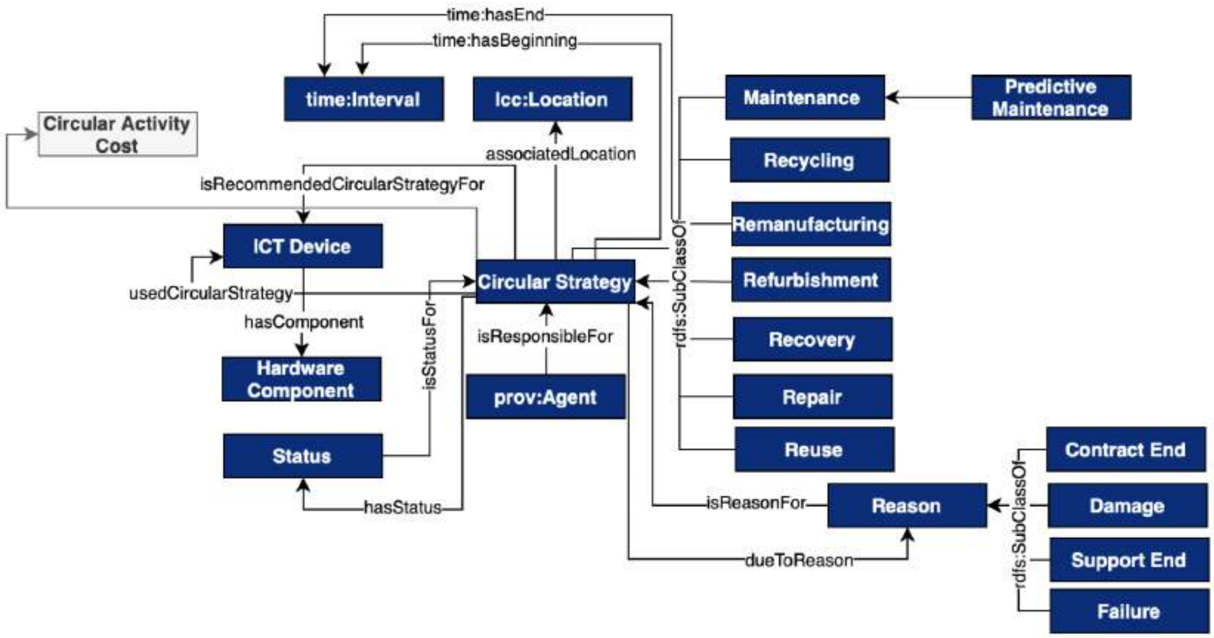
Figure 14. Class Materials



Class Circular Economy (CE) Strategy

The concept of a CE is represented through the processes (or strategies) (see Figure 15) of *Maintenance, Recycling, Remanufacturing, Refurbishment, Recovery, Repair, Reuse* that can be adopted for an ICT device to prolong its lifetime. Differentiating between a recommended (e.g. by AI or a CE expert) and used CE strategies, can be done by utilising the object properties *isRecommendedCircularStartegy* and *usedCircularStartegy*. To support the explainability and transparency of decision-making (e.g. using a specific CE) the class *Reason* has been defined. A CE strategy can be linked to a specific reason such as contract end, damage, support end and failure, by utilising the object property *dueToReason*. The ontology represents several types of reasons such as contract end, damage, support end and failure, which were highlighted in our interviews with domain experts and ICT procurers as most common reasons such as contract end, damage, support end and failure, which were highlighted in our interviews with domain experts and ICT procurers as most common reasons [see publication by Kate McMahon].

Figure 15. Class Circular Strategy



Class Indicators

To support users (e.g., sustainability experts, ICT procurers, ICT end users, ICT experts) in evaluating the sustainability, functionality and economic effects of an ICT device and its components, we have represented several types of indicators (Figure 16) which were derived based on interviews with end users and a literature survey. Functional indicators refer to functional characteristics of ICT devices that are of importance during procurement processes. Examples of these include the memory (in terms of *RAMSize* and *ROMSize*), the capacity, weight and lifetime of a battery, camera pixels, CPU load and speed. The monetary cost of a CE strategy, ICT device's purchase cost (brand new device) and current cost (device cost after CE strategy has been applied) are categorised as economic indicators. The true cost, defined as the sum of the purchase cost, greenhouse gas production and greenhouse gas use and the warranty duration also fall into this category. Last but not least, 27 (counting classes and subclasses) sustainability indicators have been identified and represented. Among these indicators are *EnergyConsumption, MaterialCircularity, GreenHouseGassEmissions* etc. produced during the manufacturing, use, distribution of a device and the produced Waste. Each indicator is measured with a specific unit. This is captured via the indicator's object property *hasMeasurementUnit* that links to the class Unit class (see Figure 17).

Figure 16. Class Indicator

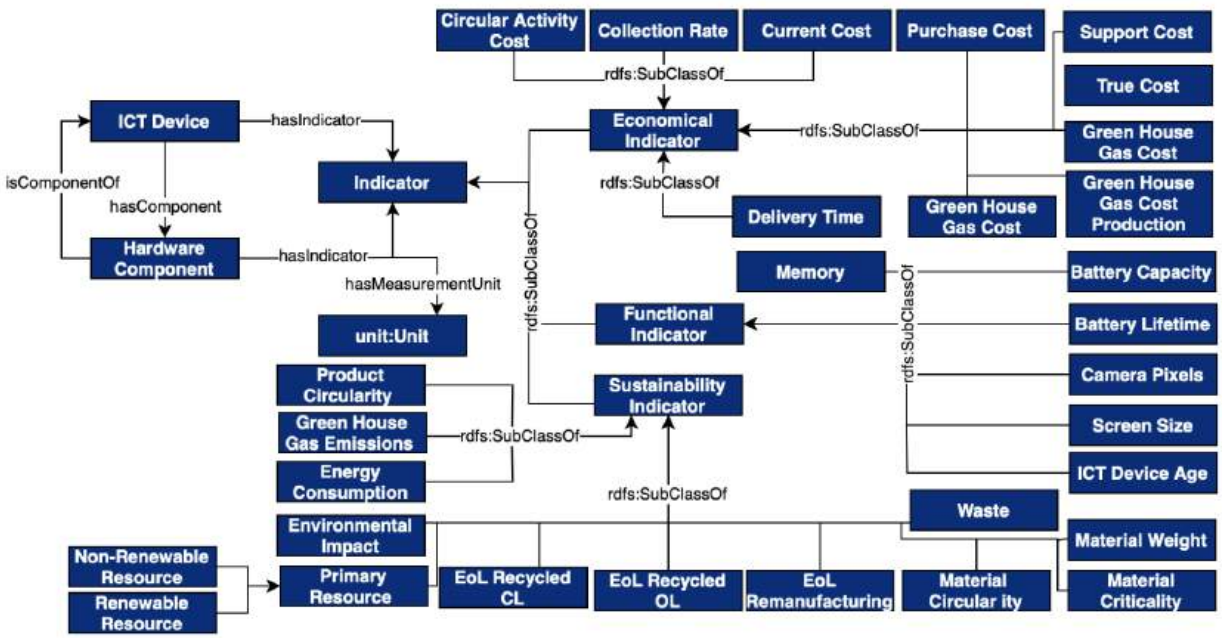
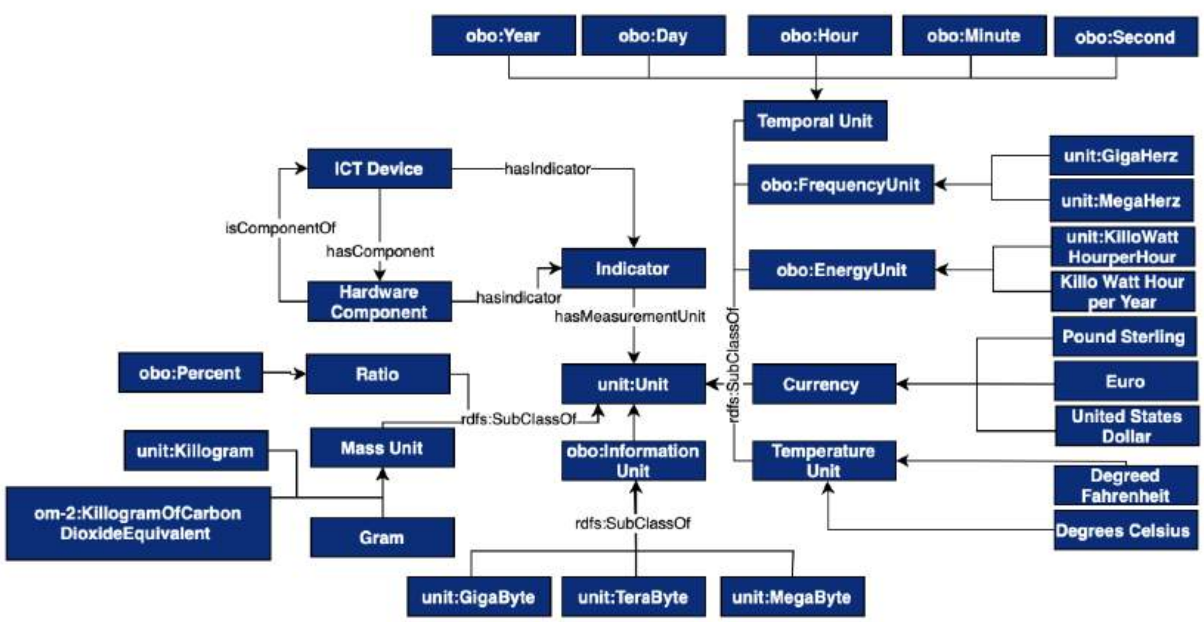


Figure 17. Class Unit (for Measurements)



Evaluation of the ontology according to best practices

The RePlanIT ontology was evaluated following best practices for ontology evaluation - against a set of competency questions based on an extensive literature survey and interviews with experts from the sustainability and ICT domains in the context of the use case, with the OOPS! ontology pitfall scanner throughout its development and with the HermiT and Pellet reasoners in Protégé. The validation with OOPS! was carried out iteratively throughout the ontology engineering process. The ontology was validated through its successful utilisation for **(i) building a knowledge graph of ICT DPPs as presented in the next section** and **(ii) by designing and implementing a UI, which utilises the knowledge graph based DPPs to support more sustainable ICT procurement in companies**.

Last but not least, RePlanIT not only reuses but also has already been reused for alignment with other existing ontologies to enable semantic interoperability between data spaces for CE's monitoring. Reuse itself is a common good practice for ontology engineering. Our work not only reuses existing ontologies but it is also already reused by the DATAPIPE project for aligning the batteries and electronics domains via the FEDeRATED upper-level ontology.

4.4.2 The RePlanIT Knowledge Graph (KG) of ICT DPPs

In this section we outline how the RePlanIT ontology is used to build DPPs of ICT which are stored in a knowledge graph (i.e. linked data format). All DPPs that we have created are stored in the GraphDB database that supports knowledge graph formatted data and are available through several APIs. Details are presented next.

The RePlanIT ontology is used as a schema for a knowledge graph, which comprises a total of 129 DPPs of (new, refurbished and repaired) laptops from different brands (commonly used by companies in the Netherlands). The DPPs modelled as knowledge graphs, store information about the laptop's hardware components and their functional characteristics, material composition, circular strategy history, and functional, economic and sustainability indicators that support decision-making. The DPPs were manually annotated with predefined SPARQL queries. The main data sources for the DPPs were laptop manufacturer's websites, open-source scientific publications stating material declarations of laptops and Environmental Product Declarations (EPD). Figure 18 & 19 present a visual example of how a DPP of a laptop looks like in a knowledge graph format stored in the GraphDB graph database. The source code version (in RDF format) of a DPP is available in the section 3 of the Appendix.

Figure 18. Visualisation (1) of a DPP from the KG

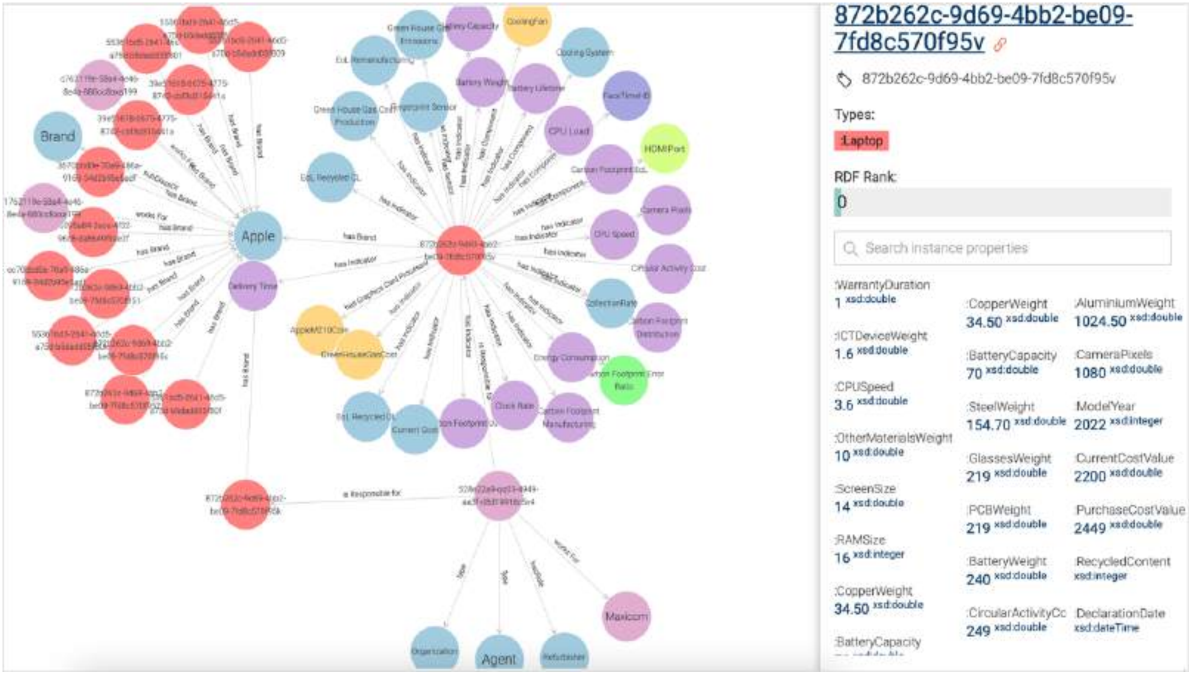
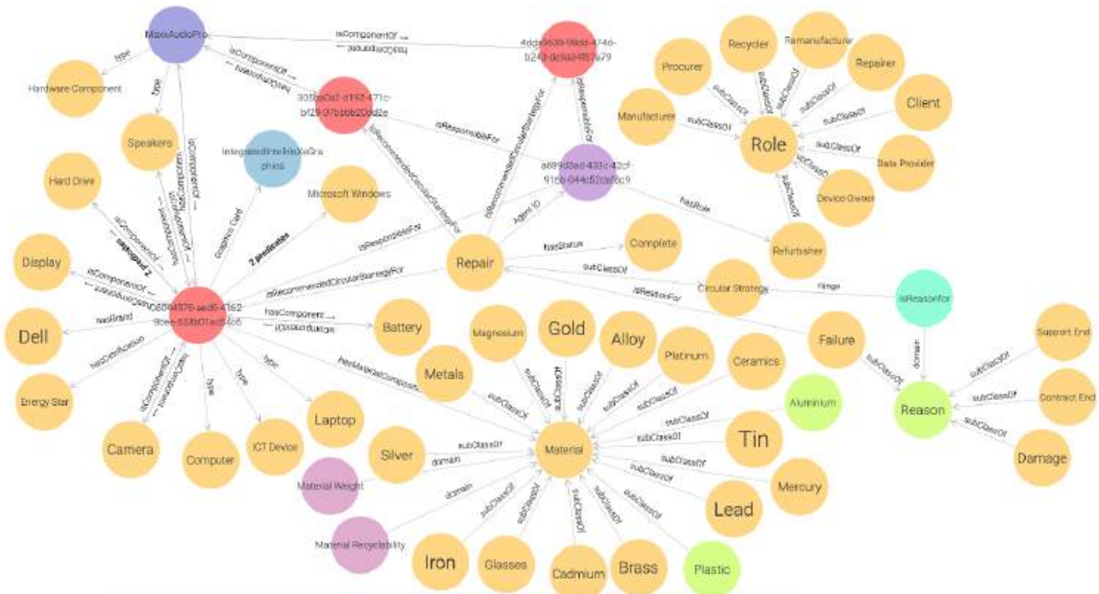


Figure 19. Visualisation (2) of a DPP from the KG



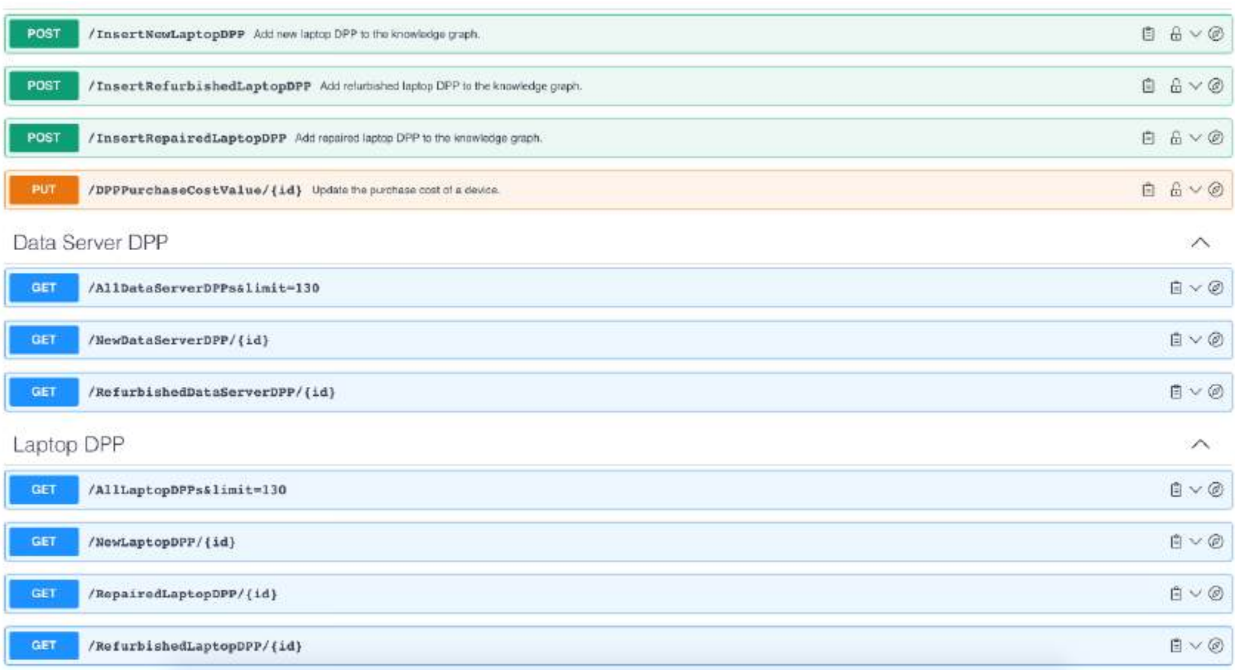
Appendix - Query 1 is a SPARQL query used to create (or insert) a DPP instance in the knowledge graph, while query 2 is an example of how to query an existing DPP from the knowledge graph.

The DPPs are currently available through several APIs (see Fig X), which have been documented according to standard with [Swagger](). DPPs of refurbished ICT devices have information on the utilised circular strategy (e.g. refurbishment), which is not present in DPPs of new ones. Based on this, separate API endpoints have been defined (e.g. NewLaptopDPP and RepairedLaptopDPP) as shown in Figure 20.

Querying DPPs is unrestricted, however, inserting new laptop DPPs can be performed by only authorised agents (based on the bearer12 authentication mechanism). Implementation details on the APIs and the knowledge graph itself (e.g., SPARQL queries, ICT device IDs for testing and DPP visualisation examples) are available in GitHub.

Currently, the knowledge graph consists of 31,776 total statements and utilises 0.40 GB of memory. For reference, on average (based on 10 runs with GraphDB's SPARQL EndPoint), inserting a laptop's DPP takes approximately 0.4s (new), and 0.6s (refurbished), while querying full DPP takes approximately 0.4s (new), and 0.8s (refurbished). Inserting and querying a refurbished laptop's DPP takes longer due to the additional information on utilised circular strategies present in it and not present in a new laptop's DPP.

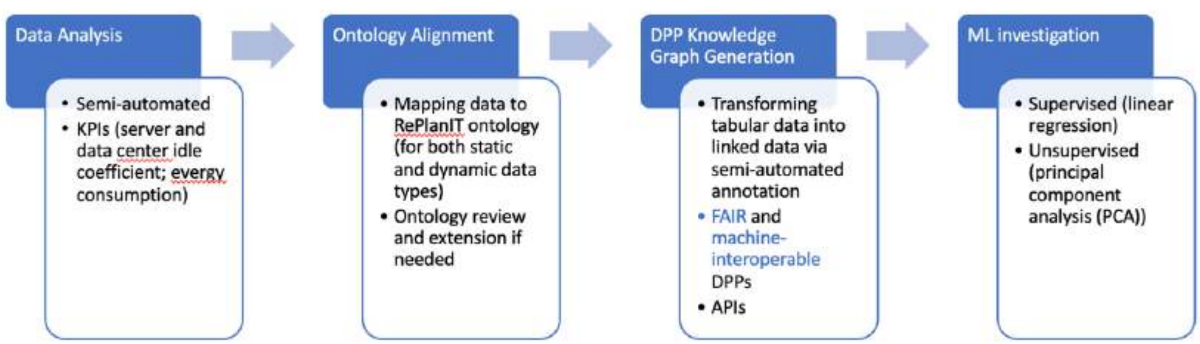
Figure 20. APIs for access to RePlanIT's knowledge graph-based DPPs



4.4.3 Utilising the DPPs for machine Learning

This section presents information on data analysis, semi-automated annotation to build DPPs at scale and machine learning implementation for both data sets. The overall methodology is presented on Figure 21 below. In summary, as a start, a dataset is analysed in terms of what types of data it contains and its's quality) if there are missing values; formatting issues etc.) During this step we also perform analytics, which have been previously annotated (details on this are presented for each data set below). This step helps the data scientists to better understand the data and in general how servers are performing over time based on the information provided. Next, during the ontology alignment stage the data is mapped to the corresponding classes and subclasses from the RePlanIT ontology. At times, data types from the provided to us datasets could not be directly mapped to an existing RePlanIT class or data property. In such cases, we either looked for synonyms or extended the RePlanIT ontology with the new concepts. Once the data is aligned with concepts from the ontology, semi-automated data annotation (i.e. assigning URIs to each data point) is performed. Future datasets that follow the structure of the RePlanIT ontology can support the full automation of the process. This process transforms the dataset from tabular to linked data format, and more specifically into a knowledge graph. As discussed in the previous sections, the DPPs are stored in the GraphDB database, which provides its own SPARQL Rest API for querying. Despite this, to ease the access and reuse to the DPPs, we also provide public APIs (see https://app.swaggerhub.com/apis-docs/RePlanIT/RePlanITLaptopDPP/1.2.0#/). Once data has been investigated and annotated to build the DPPs, the next step is its utilisation for machine learning. Both supervised and unsupervised learning were explored for each dataset.

Fig. 21 Machine Learning Process Workflow



To implement the abovementioned steps (i.e. analytics and annotations) we utilise the Python (version 3.9.7) programming language and the NumPy, matplotlib and RDFlib libraries. The implementation was done in the Visual Studio (Vscode) and Jupiter Notebook (for the ML part) environments.

Details on the analysis and use of machine learning for each dataset are presented next.

Dataset 1

Data Analysis

Dataset 1 contains performance data about 1 data center with 140 data servers, recorded every 15 min over 3 months (private dataset). The data set contains the following types of performance data per server:

Server ID, date and time, number of virtual machines running, CPU performance, memory usage, energy consumption and hardware status (e.g. red, green, yellow)

Using Python, we automate statistics such as server and data center idle coefficient (SIC and DCIC respectively), average energy usage, CPU and memory usage, total VMs and hardware runtime hours per server and data center. The SIC is *"absence of work, idleness, to indicate when server resources are not being used effectively" [https://www.rvo.nl/sites/default/files/2021/01/Rapport%20LEAP_EN_TG.pdf]*. As defined by the EDNA Annex (Electronic Devices and Networks Annex) of the 4E TCP in [https://www.iea-4e.org/wp-content/uploads/2021/10/Server-Idle-Coefficients-FINAL-1.pdf], SIC and DCIC can be calculated as follows:

$$SIC = \frac{Server\ Energy\ (Idle)}{Server\ Energy\ (total)} \times 100\% \quad DCIC = \frac{\sum Server\ Energy\ (Idle)}{\sum Server\ Energy\ (total)} \times 100\%$$

For source code of the implementation refer to the following files:

MinMax_Efficient_EnergyUsage.py
AverageServerEfficiency.py
TotalServerEfficiency.py
Status_Analysis.py

Insights:

Based on average power consumption over 3 months

- **Top 10 lowest power usage servers:**
  hostname power usage
  30373237-3132-5a43-3335-33384432564d -> 198kwHr
  30373237-3132-5a43-3335-323059323934
  31333138-3839-5a43-3237-313530363356
  30373237-3132-5a43-3335-30314c41534d
  4c4c4544-0057-4c10-8035-c6c04f545932
  4c4c4544-0037-4c10-8051-c7c04f5a5832
  4c4c4544-0050-5710-804a-c7c04f475132

4c4c4544-005a-4810-8047-b3c04f5a4732
4c4c4544-005a-4710-8046-b3c04f5a4732
4c4c4544-005a-4710-804c-b3c04f5a4732 -> 240kwHr

- **Top 10 highest power usage servers:**

hostname power usage
4c4c4544-0059-3710-804e-b1c04f325432 ->364kwHr
4c4c4544-0050-5910-8047-c7c04f475132
4c4c4544-0032-4210-8057-c7c04f505832
4c4c4544-0058-5710-804e-b1c04f325432
4c4c4544-0032-4210-8057-c6c04f505832
4c4c4544-0032-4210-8057-c3c04f505832
4c4c4544-0032-4210-8057-c8c04f505832
4c4c4544-0059-3810-8052-b1c04f325432
4c4c4544-0050-4710-8054-b9c04f4e5832 ->402kwHr

Based on server idle coefficient (SIC) for power usage over 3 months. We store all SIC values in the file "SIC_Servers.py", while a graphical visualisation is presented in "Server_CPU_Power_Plots.pdf"

- **Top 10 servers with lowest SIC:**

4c4c4544-0038-4310-8050-b7c04f345832
4c4c4544-0059-3710-8050-b1c04f325432
4c4c4544-0044-5310-8030-cac04f304432
4c4c4544-005a-4710-804c-b3c04f5a4732
4c4c4544-0032-4210-8057-b9c04f505832
4c4c4544-0059-3610-8051-b1c04f325432
35393050-3432-5a43-3239-343230423157
4c4c4544-0052-4210-8044-b3c04f5a4732
4c4c4544-0052-4410-8048-b3c04f5a4732
4c4c4544-0057-4310-8050-c8c04f374a32

- **Top 10 servers with highest SIC:**

4c4c4544-0050-5910-8047-c7c04f475132
4c4c4544-0059-3810-8050-b1c04f325432
4c4c4544-0050-5910-8046-c7c04f475132
4c4c4544-0033-4210-8057-b2c04f505832
4c4c4544-0032-4210-8057-cac04f505832
4c4c4544-0032-4210-8057-c3c04f505832
4c4c4544-0032-4210-8057-c8c04f505832
4c4c4544-0058-5710-804e-b1c04f325432
4c4c4544-0050-4710-8054-b9c04f4e5832

- **Data center SIC is 7.282101179227844e-13**
  (equals to 0.0000000000007282101179227844)

- **Top 10 servers with most green flags:**
  These also have encountered "red" and "yellow" flags

  hostname status, number of times
  4c4c4544-0059-3410-804d-b1c04f325432, green,4471
  4c4c4544-0032-4210-8057-c8c04f505832, green,4471
  4c4c4544-0051-4710-8054-b3c04f4e5832, green,4471
  4c4c4544-0039-4d10-8056-cac04f374a32, green,4471
  4c4c4544-0050-4a10-8031-b6c04f343233, green,4470
  4c4c4544-0057-3910-8057-c8c04f374a32, green,4470
  4c4c4544-0059-3810-8051-b1c04f325432, green,4470
  4c4c4544-0030-5910-804b-b3c04f363133, green,4470
  4c4c4544-0032-4210-8057-b9c04f505832, green,4470
  4c4c4544-0059-3610-8051-b1c04f325432, green,4470

  Some servers do not have "red" and "yellow" flags (see below):

  30373237-3132-5a43-3335-323059323934 -> also in top 10 servers with lowest power usage
  30373237-3132-5a43-3335-33384432564d -> also in top 10 servers with lowest power usage
  31333138-3839-5a43-3236-333730344730
  31333138-3839-5a43-3236-343130394642

- **Top 10 servers with most red flags: -> these are servers to pay more attention**

  hostname status, number of times
  4c4c4544-005a-4710-804c-b3c04f5a4732, red, 1068 -> also in top 10 lowest power usage
  4c4c4544-0050-4710-8054-c6c04f4e5832, red, 152
  30373237-3132-5a43-3335-323059323856, red, 145
  31333138-3839-5a43-3237-313530363356, red,145 -> also in top 10 lowest power usage
  35393050-3432-5a43-3239-343230423157, red, 85
  4c4c4544-0057-4610-8051-c8c04f374a32, red, 80
  4c4c4544-0057-4410-8050-c8c04f374a32, red, 80
  4c4c4544-0052-4210-8044-b3c04f5a4732, red, 44
  4c4c4544-0044-5210-8054-cac04f4d3632, red, 44
  4c4c4544-0044-5210-805a-cac04f574432, red, 44

- **Missing data for several servers** (e.g. **4c4c4544-0052-4710-804b-b3c04f5a4732)** when in red at any time, which hinders further research.

- **Day of the week with the least and most red flags:**

  (For the top 10 servers with most red flags)

Sunday (highest number of red flags is the highest)

Thursday (least number of red flags)

As prevention, on Friday (or last working day if it is Saturday) a status check of the servers can be made so Sunday "red flags" are minimised.

- **Hardware runtime hours till a red flag is encountered (for the top 10 servers with the most red flags):**

  Runtime hours till a red flag is 1st encountered (in days):

30373237-3132-5a43-3335-323059323856	88.250000
31333138-3839-5a43-3237-313530363356	64.000000
35393050-3432-5a43-3239-343230423157	0.041667
4c4c4544-0044-5210-805a-cac04f574432	140.875000
4c4c4544-0050-4710-8054-c6c04f4e5832	46.875000
4c4c4544-0052-4210-8044-b3c04f5a4732	140.916667
4c4c4544-0052-4710-804b-b3c04f5a4732	140.958333
4c4c4544-0057-4410-8050-c8c04f374a32	0.041667
4c4c4544-0057-4610-8051-c8c04f374a32	0.041667
4c4c4544-005a-4710-804c-b3c04f5a4732	0.041667

  Average runtime hours before a red flag: 62 days

- **Duration in red status for each server (in hours):**

  Duration in red:

30373237-3132-5a43-3335-323059323856	72.0
31333138-3839-5a43-3237-313530363356	72.0
35393050-3432-5a43-3239-343230423157	28.0
4c4c4544-0044-5210-805a-cac04f574432	NaN
4c4c4544-0050-4710-8054-c6c04f4e5832	NaN
4c4c4544-0052-4210-8044-b3c04f5a4732	NaN
4c4c4544-0052-4710-804b-b3c04f5a4732	NaN
4c4c4544-0057-4410-8050-c8c04f374a32	NaN
4c4c4544-0057-4610-8051-c8c04f374a32	NaN
4c4c4544-005a-4710-804c-b3c04f5a4732	1926.0 -> 80 days

  Average duration of a red: 524.5 hours (almost 22 days)

Ontology Alignment

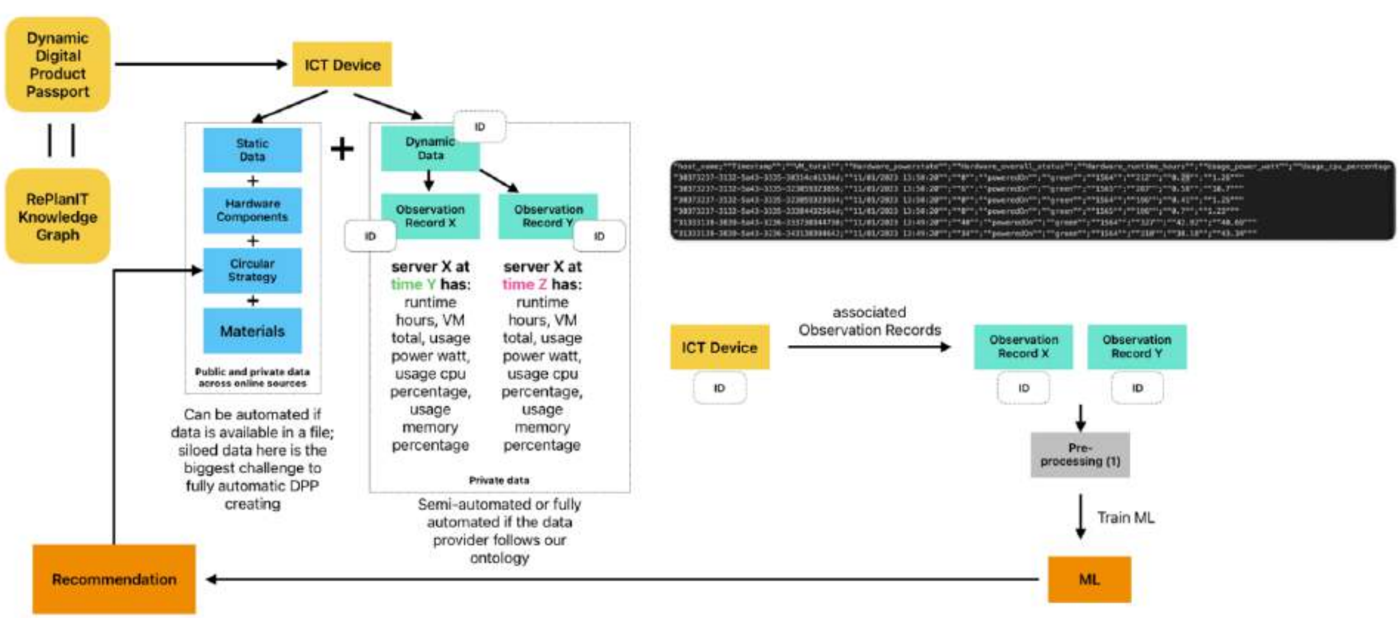
Dataset 1 introduced several new types of data that were not initially present in the RePlanIT ontology. This led to extending the ontology. More specifically, we added the following:

- **Classes**: *ObservationRecord* and *PoweredOn; PoweredOff; Unknown (all subclasses of Status)*
- **Object properties**: *associatedObservation; isObservationOf*
- **Data properties**: *VM_Total; HardwareRunTimeHours; StatusCode*

DPP Knowledge Graph Generation

As shown on Figure 22 below, a DPP of an ICT device comprises of static and dynamic data parts. The static data is found through manufacturers websites; material databases and publications and represents the functional and material characteristics of a device. The dynamic, on the other hand, comprises of real-world performance data that is highly changeable (i.e. dynamic) with time. Such types of data are energy consumption, CPU and memory utilisation, encountered errors etc. Due to the time-series type of data in dataset 1 and the ReplanIT ontology specification, we have deiced to represent the specific performance measurements per device as at a specific date and time as an individual observation record. This will allow to preserve the context in which errors occured when data is analysed and used by ML. As an example, one can say that a device has several observation records, where each record is unique and stores data about several performance observations and measurements at a specific time. This architecture has been adopted for both dataset 1 and dataset 2 (discussed later on in this section).

Fig 22. High-level architecture of the DPPs – static and dynamic data components



To transform the dataset from tabular to linked data, we utilise the the RDFlib Python library and specify the URIs (or namespaces as presented below) that should be inserted in front of each data point. The process is semi-automated as it requires a human to 1st map each column to a URI from the RePlanIT ontology.

For example, we define the namespaces for each colums as follows:

```
data_server=Namespace('http://www.semanticweb.org/RePlanIT/ICDevice/DataServer/')
timeStamp=Namespace('http://www.semanticweb.org/RePlanIT/DateTime/')
vm_total=Namespace('http://www.semanticweb.org/RePlanIT/VMTotal/')
hardware_powerstate=Namespace('http://www.semanticweb.org/RePlanIT/Status/InProgress')
hardware_overallstate=Namespace('http://www.semanticweb.org/RePlanIT/StatusCode/')
hardware_runtime_hours=Namespace('http://www.semanticweb.org/RePlanIT/HardwareRunTimeH
ours/')
usage_power_watt=Namespace('http://www.semanticweb.org/RePlanIT/EnergyConsumption/')
usage_cpu_percentage=Namespace('http://www.semanticweb.org/RePlanIT/CPULoad/')
usage_mem_percentage=Namespace('http://www.semanticweb.org/RePlanIT/MemoryUsage/')
unknownStatus=NameError('http://www.semanticweb.org/RePlanIT/Status/Unknown')
partOfObservationRecord=Namespace('http://www.semanticweb.org/RePlanIT/PartOfObservati
onRecord/')
```

And iterate over the whole dataset to insert the corresponding URIs to each data point in each column:

```
for index, row in df.iterrows():
        g.add((URIRef(observationRecord+row['uuid']), URIRef(timeStamp),
        Literal(row['Timestamp'], datatype=XSD.dateTimeStamp)))
        g.add((URIRef(data_server+row['hostname']),
        URIRef(associatedObservation),(URIRef(observationRecord+row['uuid']))))
        g.add((URIRef(observationRecord+row['uuid']), URIRef(vm_total),
        Literal(row['VMtotal'], datatype=XSD.int)))
        g.add((URIRef(URIRef(observationRecord+row['uuid'])),
        URIRef(hardware_overallstate), Literal(row['Hardwareoverallstatus'],
        datatype=XSD.string)))
        g.add((URIRef(URIRef(observationRecord+row['uuid'])),
        URIRef(hardware_runtime_hours), Literal(row['Hardwareruntimehours'],
        datatype=XSD.float)))
        g.add((URIRef(URIRef(observationRecord+row['uuid'])), URIRef(usage_power_watt),
        Literal(row['Usagepowerwatt'], datatype=XSD.float)))
        g.add((URIRef(URIRef(observationRecord+row['uuid'])),
        URIRef(usage_cpu_percentage), Literal(row['Usagecpupercentage'],
        datatype=XSD.float)))
        g.add((URIRef(URIRef(observationRecord+row['uuid'])),
        URIRef(usage_mem_percentage), Literal(row['Usagemempercentage'],
        datatype=XSD.float)))
```

The result of this is the data represented as a knowledge graph (see below).

```
<http://www.semanticweb.org/RePlanIT/ICDevice/DataServer/30373237-3132-5a43-3335-30314c41534d> replanit:associatedObservation
<http://www.semanticweb.org/RePlanIT/ObservationRecord/0013a5e1-752d-4b6f-ae1c-8004c01165>
...
```

This can be interpreted as: Data server with ID - 3**0373237-3132-5a43-3335-30314c41534d**, has observation record with ID - **006c2cdf-8e97-45ca-b847-3af1fdcc6457.** The observation record refers to the following recorded measurements (CPU load, energy consumption, memory usage etc.) at a specific date and time:

```
<http://www.semanticweb.org/RePlanIT/ObservationRecord/006c2cdf-8e97-45ca-b847-3af1fdcc6457>
<http://www.semanticweb.org/RePlanIT/CPULoad/> "1.19"^^xsd:float;
    <http://www.semanticweb.org/RePlanIT/DateTime/> "11/09/2023 
03:23:40"^^xsd:dateTimeStamp ;
    <http://www.semanticweb.org/RePlanIT/EnergyConsumption/> "214.0"^^xsd:float;
    <http://www.semanticweb.org/RePlanIT/HardwareRunTimeHours/> "1746.0"^^xsd:float;
    <http://www.semanticweb.org/RePlanIT/MemoryUsage/> "1.26"^^xsd:float;
    <http://www.semanticweb.org/RePlanIT/StatusCode/> "green"^^xsd:string;
    <http://www.semanticweb.org/RePlanIT/VMTotal/> "0"^^xsd:int .
```

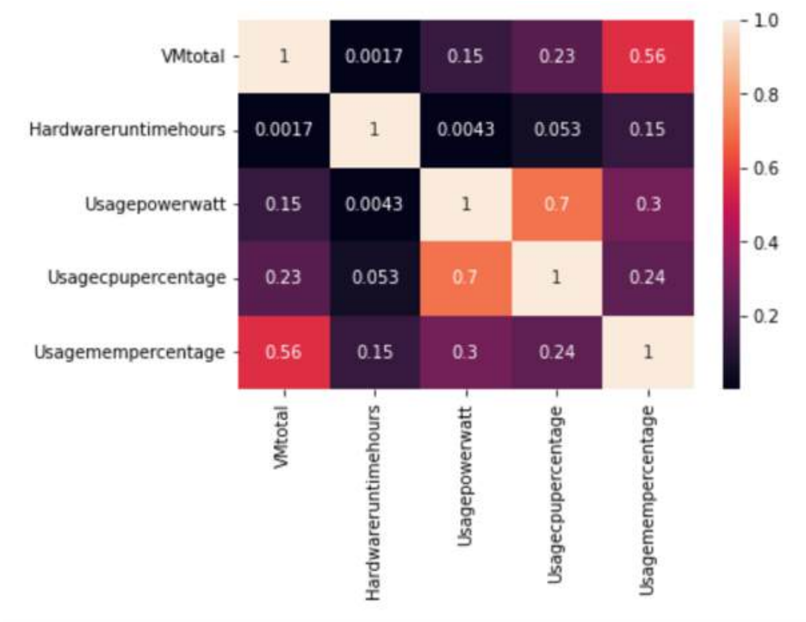
Machine Learning (ML)

Due to the limited diversity in terms of errors, lack of data on reason for errors and the volume of data (only 3 months) ML insights are limited. The experimental implementation is available in Github.

We performed both supervised and unsupervised ML to gather insights. For both, data was 1st pre-processed (correct data types were assigned to each data; conversion to numerical data; imputing of missing values etc.).

Next we performed correlation analysis. Figure 23 presents a visual of correlations between data, where a score of 1 signifies the highest correlation.

Fig. 23 Correlations between data in dataset 1



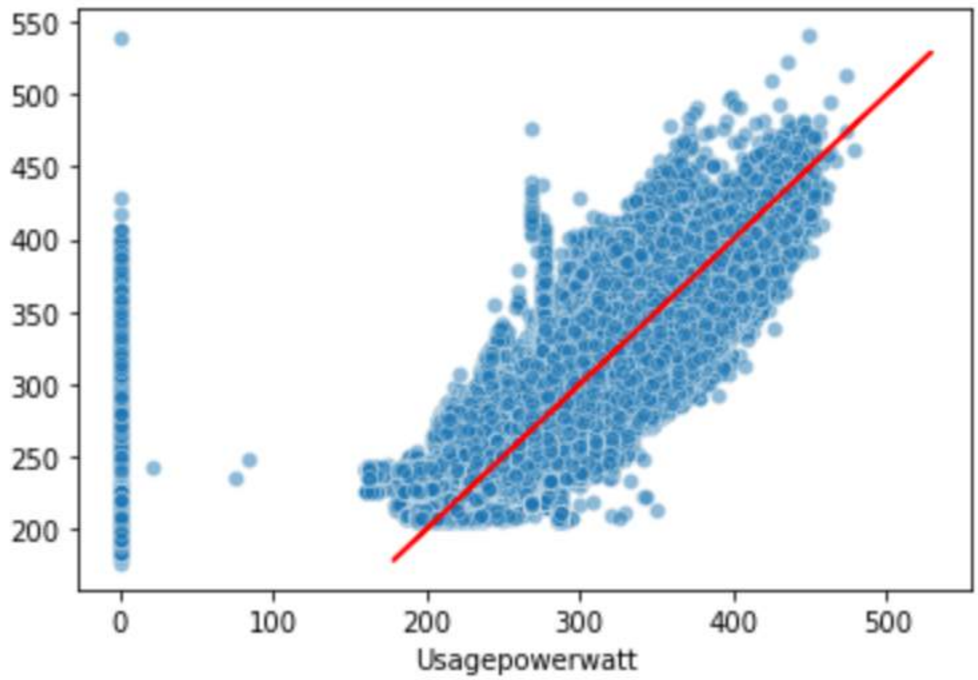
From the visual, one can note that as expected VMs are leading to higher energy usage, CPU utilisation and memory utilisation.

Next, we utilised linear regression (a supervised ML approach) to see if there will be any possible change in the energy consumption of the servers in the future. As a good practice, we follow the 80/20 rule and select 80% of the data for training, while 20% is used for testing. The data set is also divided into **x** and **y** subsets, where y is the energy usage and x are the rest of the data we use to predict it.

Results:

- Energy usage will be rising if servers used in the same manner (to up to 540 watts)
- Expected rise of the energy usage of around 100 watts (when looking at the server with lowest energy usage)

Fig. 24 Linear regression for energy usage – a rising trend



The ML model was evaluated with standard measurements - mean square error (MSE) and r-squared (R2) analysis. The ML results on the testing data (MSE - 1197.013492 and R2 - 0.547509) justify the possibility for energy rise for some servers. However, R2 score is below 0.7 (used as a good measure score) which signifies a high chance that the model can be incorrect. Based on our initial analysis, we believe that the limited diversity and insufficient volume of data can be some of the factors affecting this.

Finally, we performed principal component analysis (PCA) - a type of unsupervised machine learning that helps understand the variance of data within and dataset and the possibility of data optimization/reduction.

Results:

PCA showed an almost even distribution between the variance of the data types in dataset 1. This means that all the data recorded is almost equally valuable when analyzing the dataset and that it is not recommended to remove some of it as it could lead to information loss. As shown on figure 25, at least 7 out of the 9 types of data in our dataset are needed for ML to fully understand the dataset.

These findings and our supervised ML results show that the performance indicators we gathered for each server are meaningful, however limited in terms of volume and diversity in dataset 1.

Fig. 25 PCA results for dataset 1

Dataset 2

Data Analysis

Dataset 2 comprises of 2 subsets. We refer to them as dataset_2_1 and dataset 2_1a.

- Dataset_2_1 contains performance data about 1 server, recorded every 1 hour for the timespan of 4 months. There are 13 recorded errors in this dataset
- Dataset_2_1a contains performance data from 438 servers, recorded every 1 hour for the timespan of 1.8 months (55 days). There is no information on errors in this dataset.

Following the same approach as for dataset 1, we automate the analysis.

Insights from dataset_2_1

Implementation in "Analysis_T1server.py"

Number of servers: 1

Duration: 148 days

- Average CPU usage per server in %: 10.630002777777765
- Errors per server 13
- Total apdex score per server: 299444.37
- Most red flags on: Thursday
- Least red flags on: Friday
- Runtime hours till a red flag is 1st encountered: **30.04041666666667**
- Most common error: **network** error, followed by **database** error
- Average CPU usage (%) per server during error: 10.630002777777765
- Average energy usage per during error: 515.7932166666676
- Average CPU usage (%) per server with no error: 10.62463339838303
- Average energy usage with no error: 515.7455450236976
- Average application experience (apdex) with error: 84.15307692307692
- Average application experience (apdex) with no error: 83.17546138834702

Next, we performed a 2-sample T-test, which is inferential statistic used to determine if there is a significant difference between the means of two groups and how they are related. In our case, these two groups are one with errors and one with no errors for the server. We automatically detect and export each group into a files (see “Servers_NoError.csv” and “Servers_withError”) for easier readability and utilisation. Using Python’s scipy.stats library we perform the test. As a result (see below) the script returns two values: t-statistic and p-value.

T-statistics (or T-value) is is a way to quantify the difference between the groups means.
P-value is the two-tailed probability computed using the t distribution. It is the probability of observing a t-value of equal or greater absolute value under the null hypothesis. As a rule of thumb, if a p-value reported from a T-test is less than 0.05, then that result is said to be statistically significant. If a p-value is greater than 0.05, then the result is insignificant.

First, we test if the CPU utilisation is affected by server errors:

- Ttest_indResult(statistic=-1.950835911178899, pvalue=0.0511540922767569)

  Pvalue>0.05 thus there is no sufficient evidence if having or not having errors has different effects on the CPU usage

Next, a t-test to investigate if energy consumption is affected by server errors:

- Ttest_indResult(statistic=-2.143410787855086, pvalue=0.03214698484088907)

  Pvalue<0.05 thus there is sufficient evidence that having or not having errors have different effect on the energy usage

<u>Insights from dataset_2_1a</u>

Implementation in “Analysis_T.py”

Number of servers: 438

Duration: 55 days (1.8 months)

- **Top 10 Lowest CPU utilisation on average:**

svr76492 1.163178
svr61916 1.177605
svr80517 1.179872
svr45149 1.187349
svr72126 1.187530
svr20520 1.192929
svr41468 1.198645
svr52633 1.202779
svr68070 1.226476
svr63126 1.233931

- **Top 10 Highest CPU utilisation on average:**

svr38252	40.734172
svr88153	40.776845
svr62589	40.786616
svr82881	41.147575
svr81364	42.025693
svr25734	42.255742
svr16207	42.850941
svr26186	43.674300
svr19146	45.100836
svr72900	45.359209

- **Top 10 servers with lowest energy usage:**

svr67117	5.481356
svr35496	5.543547
svr93362	5.568802
svr37434	5.649985
svr13145	5.671114
svr12986	5.690565
svr22615	124.043849
svr77273	129.177450
svr17793	193.161316
svr25676	218.153179

- **Top 10 servers with highest energy usage:**

svr88153	531.719601
svr19605	536.210075
svr46627	536.582214
svr82881	538.974819
svr92571	539.083429
svr92332	541.663180
svr19146	541.926157
svr67299	543.550663
svr81364	547.861694
svr52801	660.323494

- **Top 10 servers with least number of errors:**

svr12805	0
svr75864	0
svr75649	0
svr75555	0
svr75357	0
svr75086	0
svr74850	0
svr74229	0

svr73845 0
svr73653 0

- **Top 10 servers with highest error number:**
svr42374 0
svr42187 0
svr41796 0
svr41673 0
svr41636 0
svr41501 0
svr41468 0
svr41432 0
svr43077 0
svr99977 0

- **Top 10 servers with lowest apdex:**
svr12805 0
svr75864 0
svr75649 0
svr75555 0
svr75357 0
svr75086 0
svr74850 0
svr74229 0
svr73845 0
svr73653 0

- **Top 10 servers with highest apdex:**
svr42374 0
svr42187 0
svr41796 0
svr41673 0
svr41636 0
svr41501 0
svr41468 0
svr41432 0
svr43077 0
svr99977 0

The analysis shows that there are no errors and no apdex scores in this dataset, which are essential for predictive maintenance type of ML which aims to predict future failures based on historical data. Finally, this can also be seen from the is can also be seen from the distributions we have plotted for each server (see source code in file Analysis_T1server.py). The graphs are available in the file "TuuringDistributions.pdf".

Ontology Alignment

Following the same approach as for dataset 1 (checking if data types from the dataset can be found in the ontology and if not define them as new ones), we defined several new namespaces in RePlanIT:

- Classes – Failure; Application_Performance_Index
- Object properties - hasFailure
- Data properties – ApplicationPerformanceIndex

DPP Knowledge Graph Generation

To transform the dataset from tabular to linked data, we utilise the the RDFlib Python library and specify the URIs (or namespaces as presented below) that should be inserted in front of each data point. The process is semi-automated as it requires a human to 1st map each column to a URI from the RePlanIT ontology.

We define the specific namespace mapping as:

```
data_server=Namespace('http://www.semanticweb.org/RePlanIT/ICDevice/DataServer/'
timeStamp=Namespace('http://www.semanticweb.org/RePlanIT/DateTime/')
hardware_model=Namespace('http://www.semanticweb.org/RePlanIT/Model/')
hardware_powerstate=Namespace('http://www.semanticweb.org/RePlanIT/Status/InProgress')
usage_cpu_percentage=Namespace('http://www.semanticweb.org/RePlanIT/CPULoad/')
usage_power_watt=Namespace('http://www.semanticweb.org/RePlanIT/EnergyConsumption/')
application_performance=Namespace('http://www.semanticweb.org/RePlanIT/HardwareRunTimeHour
s/')
enrountered_error=Namespace('http://www.semanticweb.org/RePlanIT/Failure')
error_reason=Namespace('http://www.semanticweb.org/RePlanIT/Reason')
application_experience_apdex=('http://www.semanticweb.org/RePlanIT/ApplicationPerformanceI
ndex')
unknownStatus=NameError('http://www.semanticweb.org/RePlanIT/Status/Unknown')
partOfObservationRecord=Namespace('http://www.semanticweb.org/RePlanIT/PartOfObservationRe
cord/')
observationRecord=Namespace('http://www.semanticweb.org/RePlanIT/ObservationRecord/')
isObservationOf=Namespace('http://www.semanticweb.org/RePlanIT/isObservationOf')
associatedObservation=Namespace
('http://www.semanticweb.org/RePlanIT/associatedObservation')
hasValue=Namespace('http://www.semanticweb.org/RePlanIT/value')
hasStatus=Namespace('http://www.semanticweb.org/RePlanIT/hasICDeviceStatus')
poweredOn=Namespace('http://www.semanticweb.org/RePlanIT/Status/PoweredOn')
poweredOff=Namespace('http://www.semanticweb.org/RePlanIT/Status/PoweredOff')
RePlanIT=Namespace('http://www.semanticweb.org/RePlanIT/')
```

And interate through the tabular csv file to annotate each datapoint with the following script:

```
for index, row in df.iterrows():
```

```
        g.add((URIRef(observationRecord+row['uuid']), URIRef(timeStamp),
        Literal(row['Timestamputc'], datatype=XSD.dateTimeStamp)))
        g.add((URIRef(data_server+str(row['deviceID'])),
        URIRef(associatedObservation),(URIRef(observationRecord+str(row['uuid'])))))
        g.add((URIRef(URIRef(observationRecord+row['uuid'])), URIRef(application_performance),
        Literal(row['Applicationperformancems2'], datatype=XSD.string)))
        g.add((URIRef(URIRef(observationRecord+row['uuid'])), URIRef(usage_power_watt),
        Literal(row['Usagepowerwatthour'], datatype=XSD.string)))
        g.add((URIRef(URIRef(observationRecord+row['uuid'])), URIRef(usage_cpu_percentage),
        Literal(row['Usagecpupercentage'], datatype=XSD.string)))
        g.add((URIRef(URIRef(observationRecord+row['uuid'])), URIRef(hardware_model),
        Literal(row['Hardwaredetails'], datatype=XSD.string)))
        g.add((URIRef(URIRef(observationRecord+row['uuid'])), URIRef(enrountered_error),
        Literal(row['Encountederror'], datatype=XSD.string)))
        g.add((URIRef(URIRef(observationRecord+row['uuid'])), URIRef(error_reason),
        Literal(row['Errorreason'], datatype=XSD.string)))
        g.add((URIRef(URIRef(observationRecord+row['uuid'])),
        URIRef(application_experience_apdex), Literal(row['Applicationexperienceapdex'],
        datatype=XSD.string)))

    if row['Hardwarepowerstate'] =='Balanced':
        g.add((URIRef(observationRecord+row['uuid']), URIRef(hasStatus), URIRef(poweredOn)))
        #g.add((URIRef(poweredOn), URIRef(partOfObservationRecord),
        (URIRef(observationRecord+row['uuid']))))
    elif row['Hardwarepowerstate'] =='High performance':
        g.add((URIRef(observationRecord+row['uuid']), URIRef(hasStatus), URIRef(poweredOn)))

    elif row['Hardwarepowerstate'] =='poweredOff':
        g.add((URIRef(observationRecord+row['uuid']), URIRef(hasStatus), URIRef(poweredOff)))
    else:
        print('server status info error')
    g.serialize('Tuuring_Servers_DPP.ttl',format='turtle')
```

The result of this is the data represented as a knowledge graph (see below):

```
<http://www.semanticweb.org/RePlanIT/ICDevice/DataServer/svr12805>
replanit:associatedObservation
<http://www.semanticweb.org/RePlanIT/ObservationRecord/00791348-73e2-4a46-a9d6-
5d5c31fb5108>,
        <http://www.semanticweb.org/RePlanIT/ObservationRecord/011e308b-3767-4805-b97d-
6c6995842dad>,
        <http://www.semanticweb.org/RePlanIT/ObservationRecord/0167ad49-8a92-4651-b33b-,
        <http://www.semanticweb.org/RePlanIT/ObservationRecord/034d873-98a7-4e88-9054-
0dd9543627d0>
.....
```

```
<http://www.semanticweb.org/RePlanIT/ObservationRecord/00791348-73e2-4a46-a9d6-5d5c31fb5108> replanit:ApplicationPerformanceIndex "0"^^xsd:string ;
    <http://www.semanticweb.org/RePlanIT/CPULoad/> "0,06"^^xsd:string ;
    <http://www.semanticweb.org/RePlanIT/DateTime/> "09/03/2023 13:00"^^xsd:dateTimeStamp ;
    <http://www.semanticweb.org/RePlanIT/EnergyConsumption/> "530,67"^^xsd:string ;
    replanit:Failure "0"^^xsd:string ;
    <http://www.semanticweb.org/RePlanIT/HardwareRunTimeHours/> "113,94"^^xsd:string ;
    <http://www.semanticweb.org/RePlanIT/Model/> "Dell Inc. VxRail P670F"^^xsd:string ;
    replanit:Reason "0"^^xsd:string .

    ...
```

Machine Learning

This section presents results from performing the same tests (supervised and unsupervised learning) on dataset2_1 and dataset2_1a. These two datasets are stored on a TU Delft server. We utilised a virtual machine (VM) that has 16GB of memory and 2 CPUs.

Dataset2_1

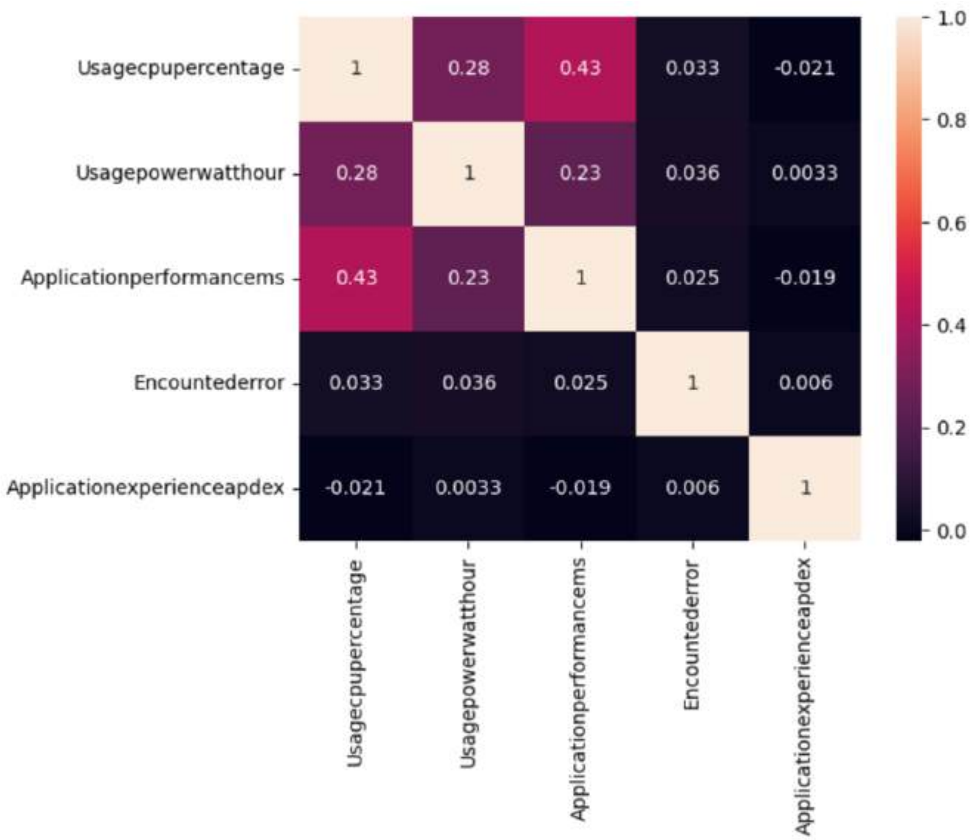
The source code ML implementation is available in the file "Dataset2_1.ipynb"

Data is 1st pre-processed (correct data types are assigned to each data; conversion to numerical data; imputing of missing values etc.).

Next, we performed a correlation analysis. Figure 26 presents a visual of correlations between data, where a score of 1 signifies the highest correlation.

CPU usage is highly correlated with the running application(s) and its runtime duration (0.43). As expected, CPU is also highly correlated with energy consumption (0.28). There is a low correlation between errors and energy consumption (0.036).

Fig 26. Correlations between data in dataset2_1.

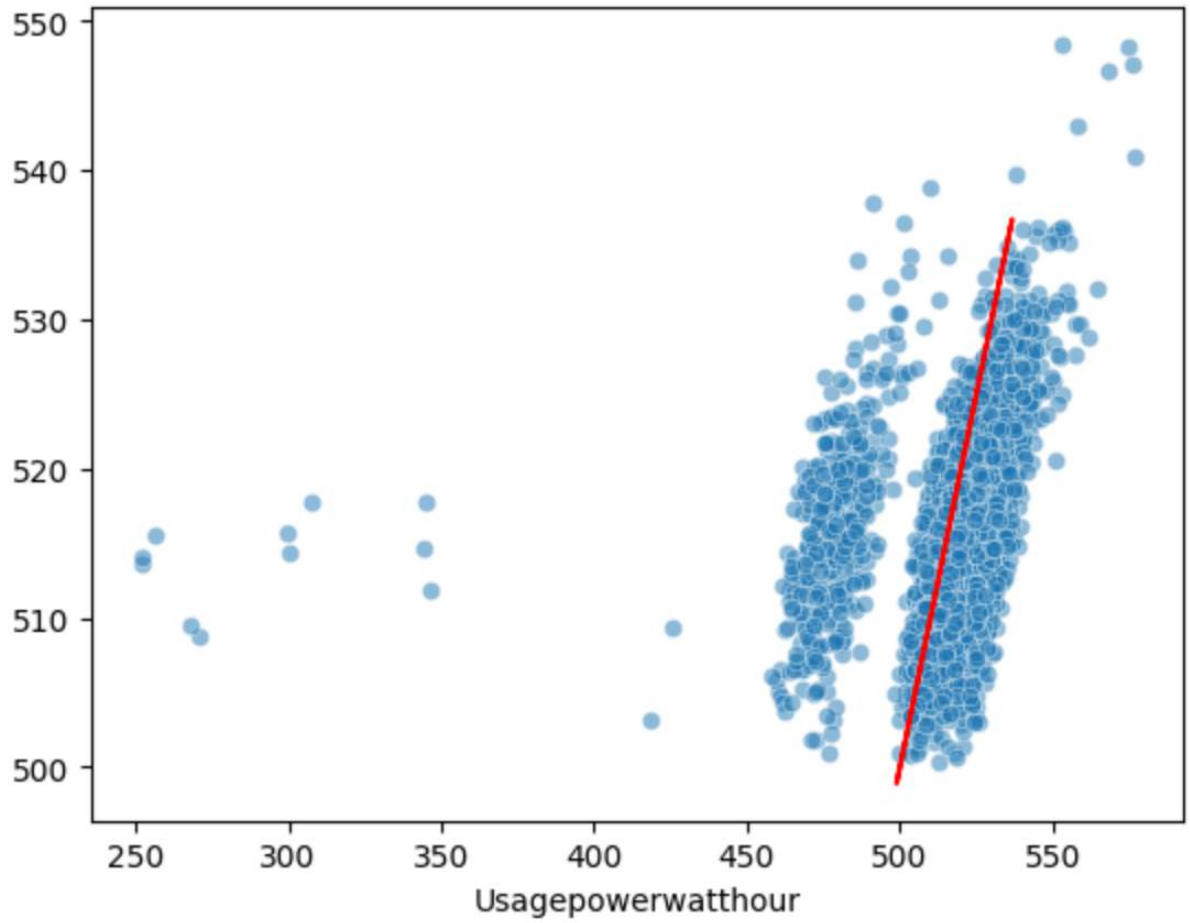


Linear regression was used to see if there will be any predicted change in the energy consumption of the server in the future. 80% of the data for was used for training, while 20% was used for testing. The data set was also divided into **x** and **y** subsets, where y is the energy usage and x are the rest of the data we use to predict it.

Results:

- The linear regression line shows a positive strong trend towards slightly rising energy consumption. The energy consumption will most probably stay in the range 498-550 kW/hr.
- Evaluating the model shows it has - mean square error (MSE) of 382.800116 and R2 score of 0.124161 on the testing data. This means that a small portion of the variance in the dependent variable is explained by the independent variables thus the model may not provide a good fit to the data and may not be useful for predictive purposes. This could be due to using label encoding when processing the data for ML. Further investigation into most appropriate encoding approach (e.g. OneHotEncoder etc.) is needed.

Fig 27. Linear regression for energy consumption in Dataset2_1.



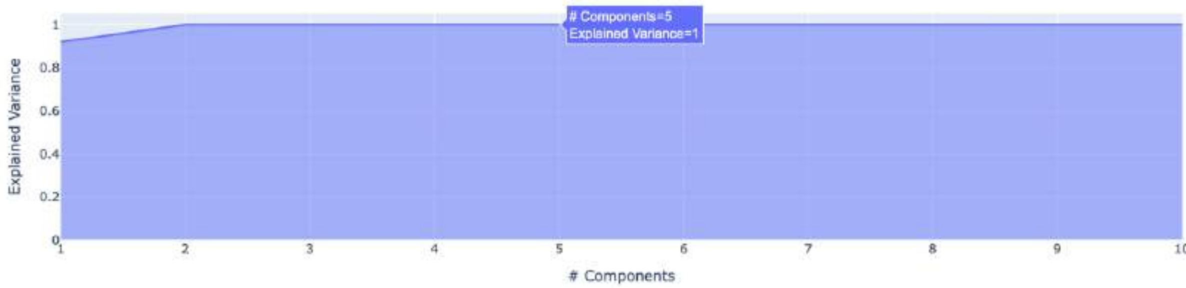
Finally, we performed principal component analysis (PCA) to investigate the variance of data within and dataset and the possibility of data optimisation/reduction.

Results:

Looking at the PCA labels and their values (in %) there is an almost even distribution between the variance of the data types in this dataset -> {'PC 1 (24.6%)', PC 2 (22.5%)', 'PC 3 (14.5%)', 'PC 4 (14.0%)'}

This means that all the data recorded is almost equally valuable when analysing the dataset and that it is not recomennded to remove some of it as it could lead to information loss. As shown on figure 28, 5 out of the 9 types of data (excluding deviceID as data type) in our dataset are needed for ML to fully understand the dataset.

Fig 28. PCA Explained Variance in Dataset2_1



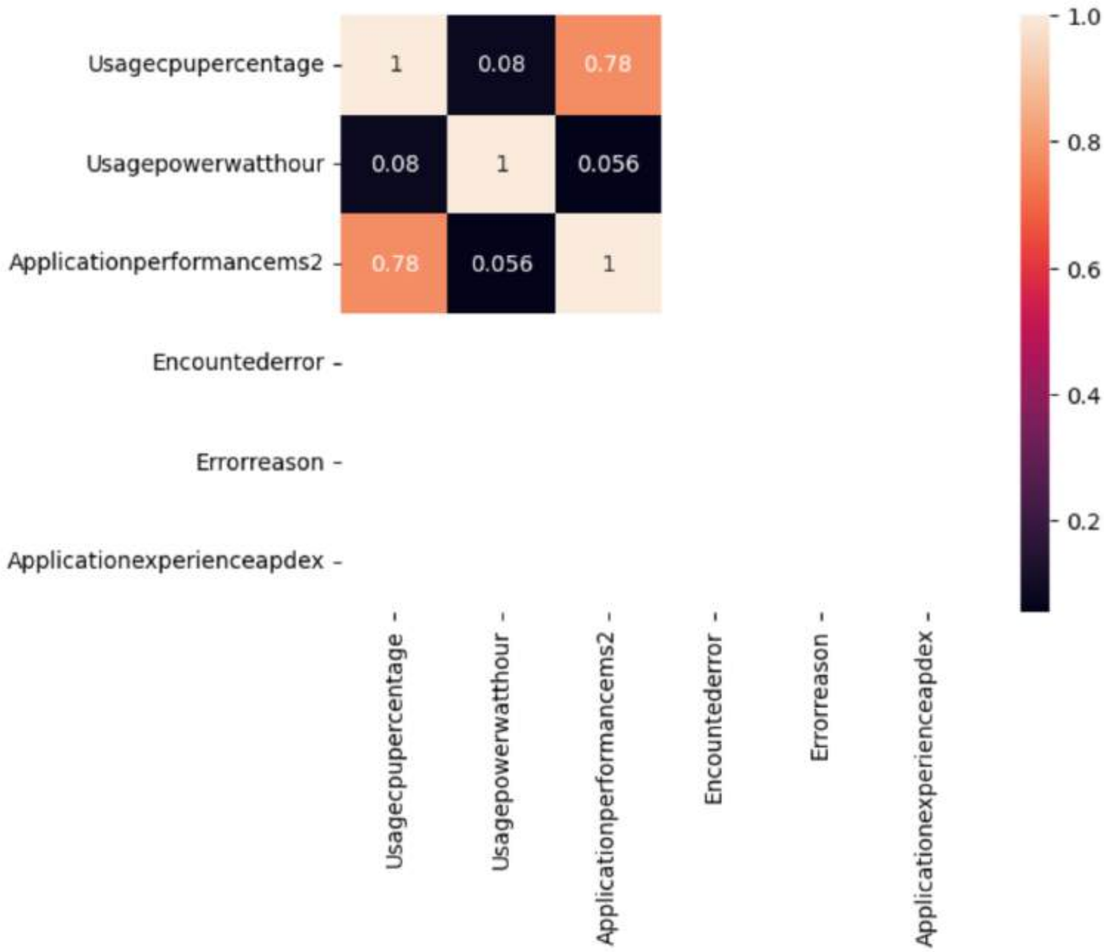
Dataset 2_1a

The source code of this ML experiment is available in the file "EnergyLR_T.ipynb".

Data is 1st exported and then pre-processed (correct data types are assigned to each data; conversion to numerical data; imputing of missing values etc.).

Next, we performed a correlatioanalysis. Figure 29 be observed that the highest correlation is between the CPU usage and application performance (in milliseconds. A significantly low correlation is observed between energy usage (per hour) and the application performance. The lack of data (in the dataset) forthe application performance index (apdex), and errors untered during the given period thus no reasons for the errors results in empty correlation matrix.

Figure 29. Correlations between data in Dataset2_1a.

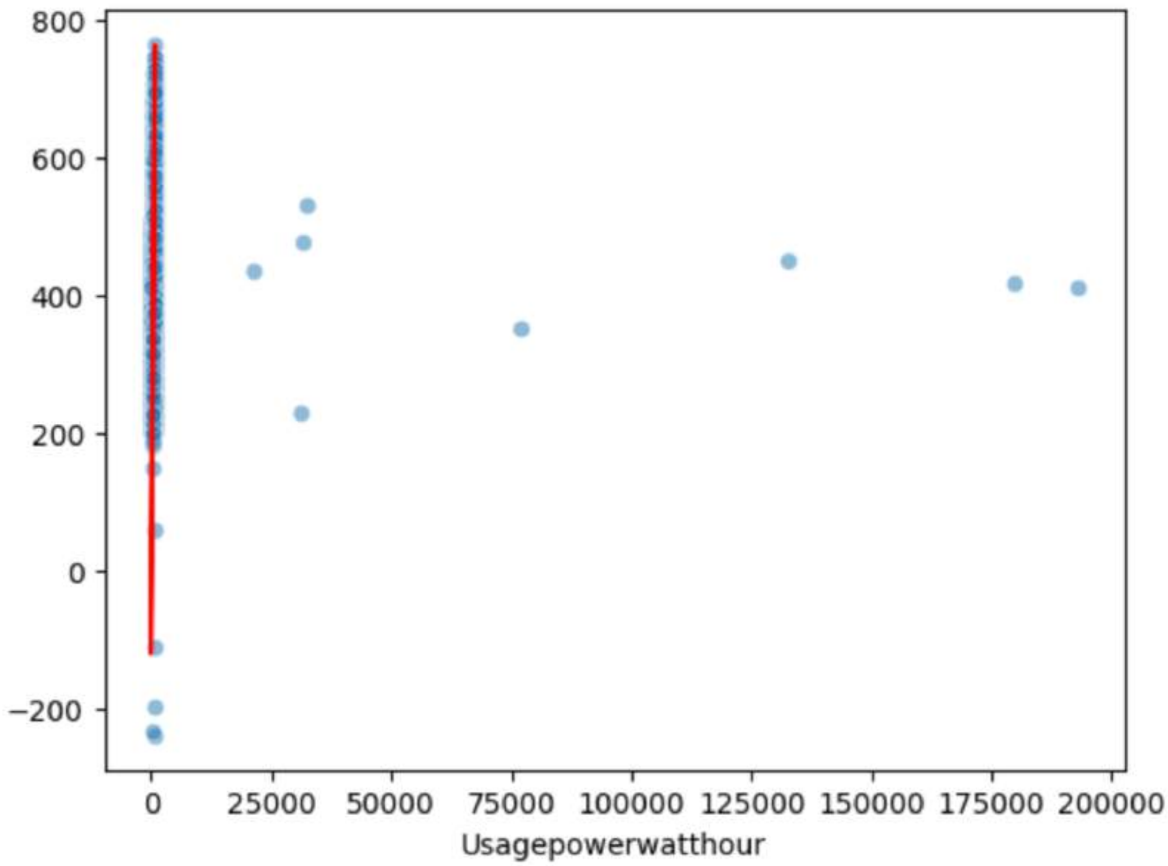


Next, we utilized linear regression to see if there will be any possible change in the energy consumption of the servers in the future. As a good practice, we follow the 80/20 rule and select 80% of the data for training, while 20% is used for testing. The data set is also divided into **x** and **y** subsets, where y is the energy usage and x are the rest of the data we use to predict it.

Results:

- No significant change in energy consumption for this dataset
- Evaluating the model shows it has - mean square error (MSE) of 227578.89242 and R2 score of 0.023357 on the testing data. This means that a small portion of the variance in the dependent variable is explained by the independent variables thus the model may not provide a good fit to the data and may not be useful for predictive purposes. Further investigation into most appropriate encoding approach (e.g. OneHotEncoder etc.) is needed.

Fig 30. Linear regression for energy usage prediction

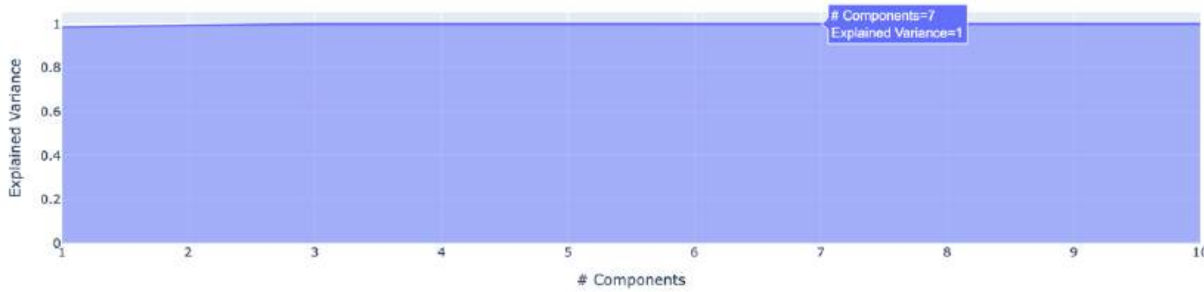


Finally, we performed principal component analysis (PCA) to investigate the variance of data within and dataset and the possibility of data optimization/reduction.

Results:

PCA shows an almost even distribution between the variance of the data types in dataset 2. This means that all the data recorded is almost equally valuable when analyzing the dataset and that it is not recommended to remove some of it as it could lead to information loss. As shown on figure 31, at 7 out of the 9 types of data in our dataset are needed for ML to fully understand the dataset.

Fig. 31 PCA Explained Variance for Dataset2_1a



4.5 Learnings from developing and testing the Dynamic Product Passports in practice

- **Laptops: main learnings from making and using the Laptop DPP's**

  Laptops comprise of numerous hardware and software components which are interconnected and affect each other thus it is important that:
  - One has expertise/knowledge of computer hardware. Having an expert on the matter who can support software developers and researchers with his knowledge in the team is needed. In our case, having such an expert from within our project consortium was highly beneficial for our work.
  - Due to the high variance and heterogeneity of the data streamed by each laptop's component (e.g. sensor) it is crucial to establish early on a vocabulary of measurement units for each measurement. In our case, we reused an existing well-established ontology focused on representing various measurement units.
  - Due to the complexity of laptops (in terms of components) and the lack of one source of truth (e.g. 1 database that comprises all the information needed for building a laptop DPP) and the lack of access to data in general, we surveyed data for each required brand and model (on different manufacturers websites; scientific papers etc.) and manually extracted and annotated the available data to build the DPPs. This is a time-consuming process that must be executed by a knowledge engineering expert. Automated data extraction via web scrapping was also not a solution as we had multiple sources of truth to investigate. The availability of ontologies such as ours and the open access to the DPPs which are provided through APIs, however, act as a standard representation of DPP device knowledge that can support future process automation at scale.
  - The RePlanIT ontology was built by following a modular approach and is flexible enough to model laptop information on both device and device component levels.
  - Providing APIs mirroring the ontology with standard public documentation (e.g. Swagger/OpenAPI) is key to support data sharing between different software components built by the different project partners.

- **Servers: main learnings from making and using the server DPP's**
  - Servers comprise of significantly less components than laptops. However, their configuration can be more flexible. Different companies can have different data server

configurations and architectures based on their supply and demand. In comparison, general purpose laptops given to staff have a more standard configuration.

- A more generic server ontology might be better in this case as it can be more easily extended when needed with new knowledge about a server and its components. Our RePlanIT ontology was flexible enough to capture such information. In some cases we utilised synonyms as well (i.e. owl:sameAs) to avoid unnecessary changes.
- As with laptops, one needs expert knowledge on when why and how servers fail that can be shared within the project to maximise output. A good way to transfer such knowledge (based on our experience in RePlanIT) is to have several dedicated sessions (e.g presentations, open discussions) between knowledge experts, researchers and software developers early in the project.
- To handle large volumes of server performance data (usually time series in csv format) for analysis and machine learning, one needs access to powerful server and database as well. In our case, we used the trial or standard versions of software such as GraphDB which comes with restrictions in terms of data query process time and amounts of data that can be stored. Investment in appropriate software subscriptions is vital for any software that aims to go beyond academic research (i.e. be used in industry).
- Machine learning requires large volumes of diverse high-quality data. In our case, having data for 3-4 months was not sufficient as there were limited errors encountered. Historic data on a device's failures and their context is essential for predictive maintenance.
- Choosing the right type of machine learning (supervised; unsupervised; semi-supervised or reinforcement), while considering the format of the data (e.g. knowledge graph) can be challenging. It is important to analyse the task at hand explore existing algorithms and evaluate their results. In our case, these were both supervised (linear regression) and unsupervised learning (principal component analysis).
- Limited (in terms of diversity and volume) data leads to limited machine learning predictions thus it is useful to have additional information on common pitfals in server's performance and strategies to deal with them within companies.

As a summary, we present below a set of the main takeaways from our work on building DPPs with ontologies and knowledge graphs and their utilisation for more sustainable ICT. We divide these into three categories – data- and technology (ontologies, knowledge graphs and machine learning) related.

<u>Data</u>

Challenges:

- Data availability (is useful and diverse and high-quality data recorded along the supply chain; is it publicly available?)
- Data accessibility, privacy and security (who, when and how can access data; data sharing conditions/contracts; legal compliance)
- Data interoperability and interpretability (FAIR data format; semantics of data in different contexts; need for domain expert)

Proposed solution:

- Set up a data collection pipeline and have documentation of the specific types of data (e.g. metadata) that are captured
- If sharing a complete data set is not possible or the data has not yet been recorded, a solution is to share metadata of the data set and a sample.
- Define data usage policies early on; automate their execution, management and monitoring
- Check for current contract conditions under which data can and cannot be shared
- Consider legal compliance (e.g. with GDPR) and current legislations on DPPs and sustainability of ICT and define a roadmap for facilitating or supporting them
- Data decentralisations a possible solution as each company and manufacturer will keep data within their systems. However, as a newer paradigm for data sharing facilitating this comes with many technical and legal challenges around identity verification, data access policies and GDPR compliance. We discuss some of these in our scientific paper [X]
- Support FAIR data principle's implementation – semantics (e.g. ontologies and knowledge graphs) are a common solution for this

Technology (ontology, knowledge graphs, machine learning)

Challenges:

- Ontology availability (most are private; limited open access; limited public documentation)
- Ontology maintenance (requires expertise and effort)
- Ontology reuse and alignment (many ontologies, what to reuse when and how)
- Knowledge graph platform support (still a new technology for industry; needs expert integration in legacy systems; lack of trust)
- Explainability of machine learning results

Proposed solution:

- Follow best practices for ontology engineering and publishing – reuse existing work when possible; make the ontology open source and provide public documentation with standard software for purposes such as WIDOCO.
- Monitor standards and update the ontology if needed as the use case and the software system develops. Scheduling times for ontology updates is useful. Notify partners/collaborators of the planned updates as this might require other software changes of components interacting with the ontology.
- Many companies have legacy systems that are not flexible to changes such as moving from a relational to a graph database. A solution is to provide APIs and translate your ontology into a JSON/JSON-LD format that is commonly supported.
- Analyse the current use case, the challenges at hand and the desired outcome and propose suitable data infrastructure. Knowledge graphs, as every technology, have their advantages and disadvantages thus it is vital to consider both in the context of the use case.
- Consider software scalability when handling large volumes of data and how the system architecture affects it.

- Machine learning results are not always straight forward to interpret thus visulisations (e.g. graphs) can help. Further, on a technology level, utilising knowledge graphs has been shown to provide context that improves predictions and a mechanism for traceability of data within the decision-making process.

4.6 Expected next steps for the Dynamic Product Passport

Having investigated current state of the art of ontologies for ICT in the circular economy, we believe that RePlanIT is by far the most detailed one that is also open access. During our survey, we discovered numerous domain-specific ontologies for laptops and materials and each has been limited by its scope. Building a new ontology for each new use case, however, is not sustainable as ontologies also need to be maintained and stored. Having a standard for what data should go into DPPS of (not only) ICT devices can help guide researchers and developers into reuse and extension of existing work. Ontology reuse is already a commonly recommended good practice for ontology engineering which we believe should be more often followed.

Having validated our RePlanIT ontology through our use cases, we believe that it can be used as a backbone of a standard for ICT DPPs. Beyond the scope of RePlanIT, we are currently investigating this within the CIRPASS-2 EU project in collaboration with multiple international research and industry organizations.

To summarize, we envision the following future directions regarding DPP work:

- Aim for European standard, where RePlanIT is one of the grounding ICT ontologies
- Ontologies as key technology in the sustainability data space; ontology alignment will be key
- Data decentralisation as possible solution to the lack of data availability and privacy concerns
- Work-group on product passports of NCDD (nederlandse coalitie duurzame digitalisering) has been started and will be looking into the possibility of using the RePlanIT ontology as starting-point

5 Results workpackage 2&3: Laptop Use Case

5.1 Customer journey re-use ICT hardware

As found in the interview analyses from Work Package 4, laid in out in section 6 of this report, there exist several barriers to the effective transfer of equipment at end of first use to new departments or organizations. A first obstacle that must be overcome is concerns for the security of sensitive personal or proprietary data on professional ICT devices. Personal information such as identifying information down to the laptop's usage behavior and performance over time is protected under the General Data Protection Regulation (GDPR). Thus, there is need for such data to be protected and processed in a GDPR-compliant manner. Furthermore, financial and other confidential information about the organization as a whole is contained in this hardware. Not only should data wiping between users be functionally able to effectively remove all data, but the process should elicit trust from the original device owner in order to avoid the owner deciding to, for example, shred hard disks or not participate in refurbishment. Access to reused or refurbished equipment that meets the performance, compatibility, bulk quantity, and specific time-framed needs of the purchasing organization is also an obstacle in practice reported by interviewed ICT decision-makers. While organizations are interested in participating in refurbishment, and some have tried, they often ran into issues meeting these particular ICT needs.

One recommended solution to these obstacles is in a product service system approach, where the supplier maintains ownership of the physical devices and the customer purchases the use and service of the equipment instead. Through use of a product service system, organizations can employ a supplier that considers these needs holistically, increasing trust and organizing the logistics of large quantity orders with reused/refurbished equipment. Furthermore, a product service system addresses another major obstacle for circularity in organizational ICT management found in our interviews: that circularity is often not perceived to be in the interest of the supplier. Through use of a product service system, it is now in the suppliers' interest to continue the long-term use and reuse of the ICT equipment they own. We found an example of this in practice by the company NEG IT Solutions' device as a service option.

5.2 Laptop Prototype of Circular Resource Planner & Circular Resource Configurator

The laptop prototype is a tool which can compare the sustainability impact of different laptop models and different purchase scenarios; for example, buying the same model laptop new, or refurbished. A prototype of the tool was built, in order to test its functionalities and the user experience. Real numbers and properties were used for the laptop models that were used in the tool. The calculations and indicators point out real outcomes. The prototype is interactive and different scenarios can be explored. The laptop models that we used in the prototype are common models at our test organiziations. After further development, the tool was tested at again.

The next series of screenshots of the design of the tool, show how a user might navigate through the tool, and what functionalities the tool offers on each page.

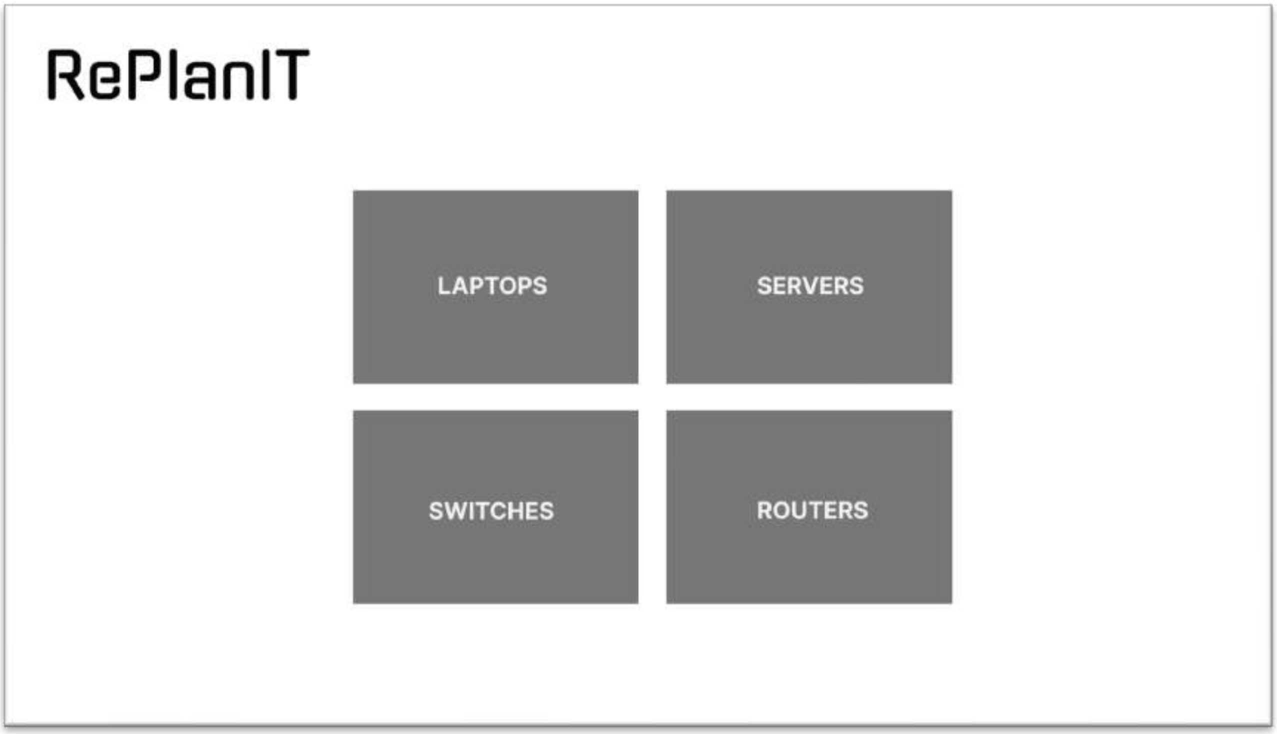


Figure 31: Landing Page

At the lading page, different ICT devices are visible to choose from. In this example, the test organization would be the user and chooses laptops.

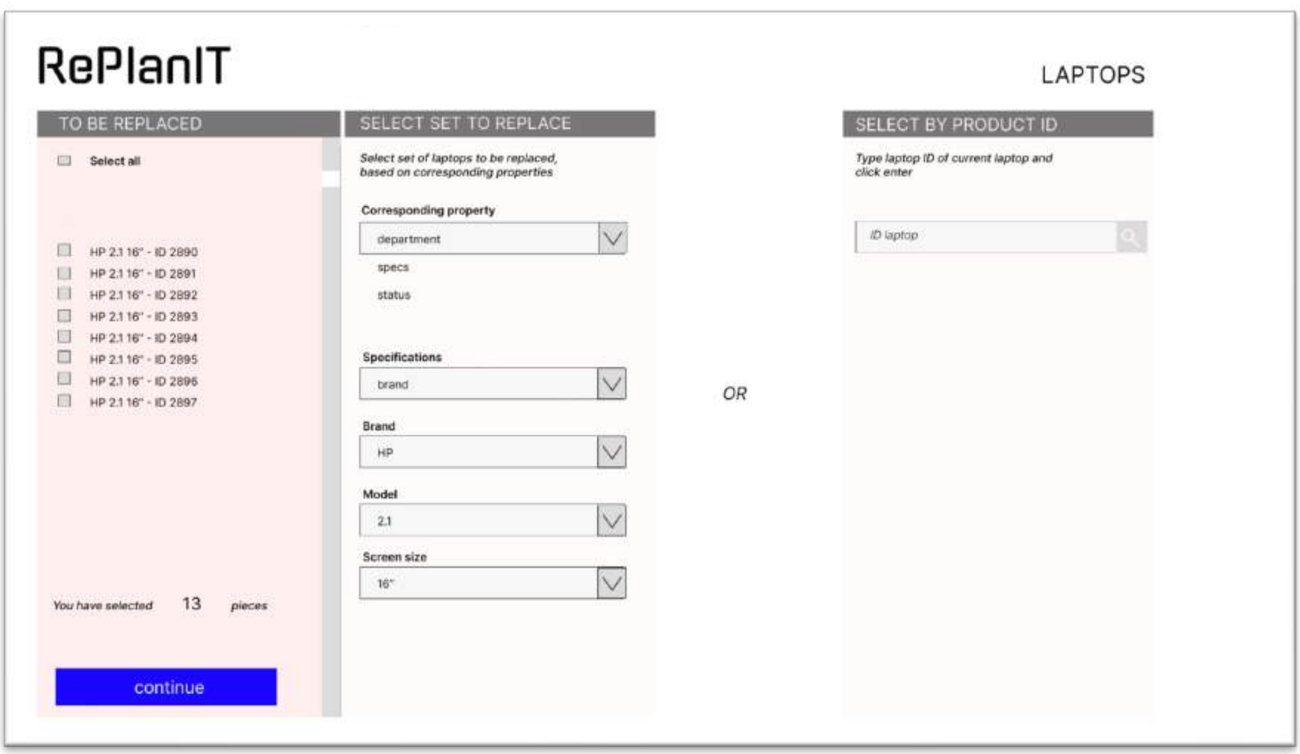


Figure 32: Selection Page

After choosing ‘laptops’, the selection page is shown. Here, different ways of selecting your (group of) laptop(s) are presented. Either by specifications or ID. These are the company laptops, that need to be replaced/upgraded.

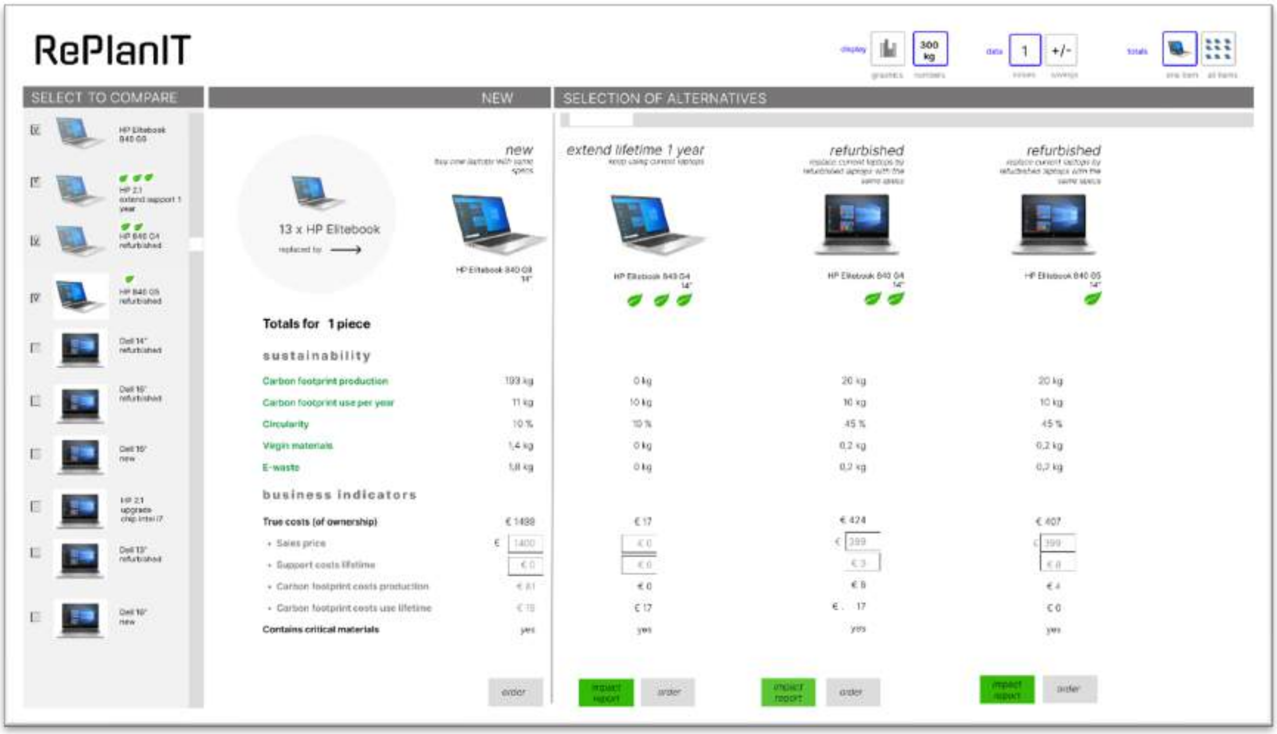


Figure 33a: Compare page

When the selection of laptops that need replacement is done, the ‘compare’ page opens. One the left side of the compare page, one can select the replacement models (the models that will replace the current laptops), to compare. As a baseline, a new generation model of the same brand is always included (middle column). In the right column, the impact of choosing a certain laptop model (and business model, like refurbished laptops) is shown. The purchase price can be filled in by the user because prices are part of a contract. Sustainability and business indicators are listed. The green leaves beneath every model, are an expression of the ‘most sustainable choice’ according to experts. The more leaves, the better the choice.
In the top part of the screen, several toggles can be clicked, to change the view to ‘savings’, ‘graphical display’ and ‘group totals’ to calculate for the total impact of a complete fleet of devices.

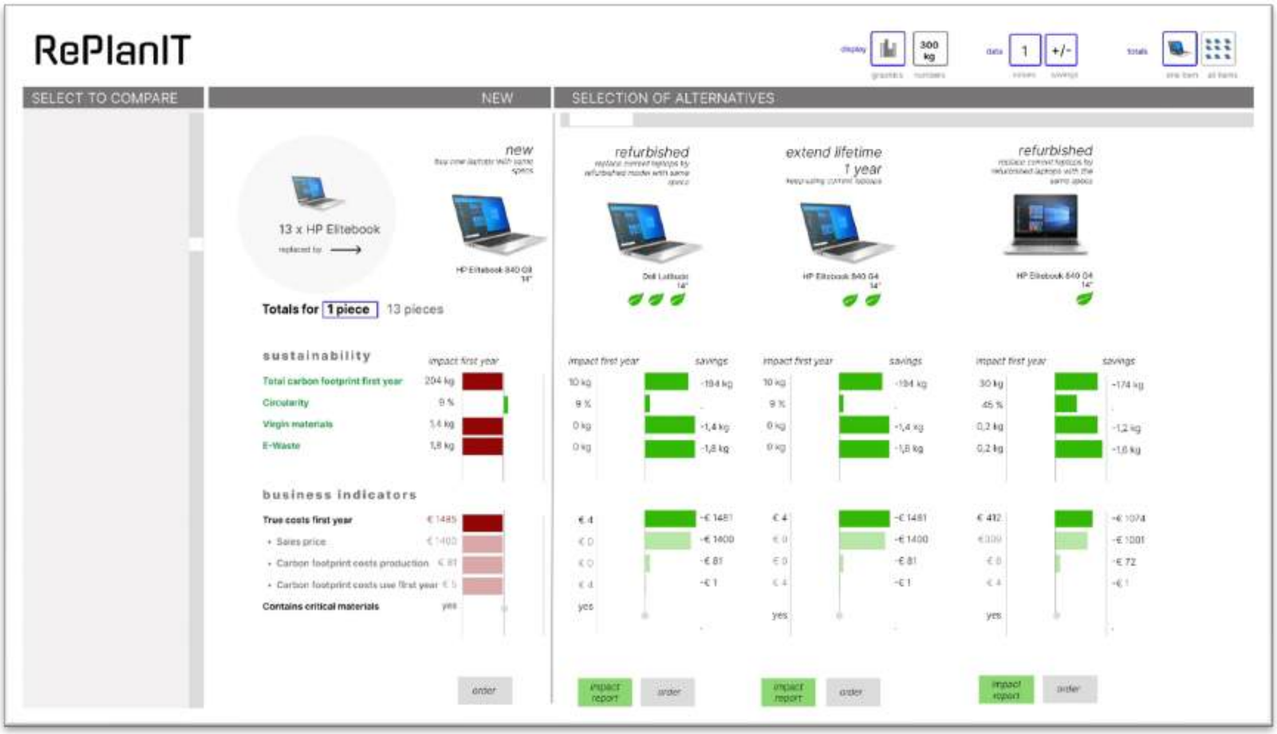


Figure 33b: Graphical view of compare page

The 'graphics' toggle shows a visual display of the impact and savings (green) or costs (red) for different laptops and scenarios, compared to the baseline scenario (to buy new laptops).

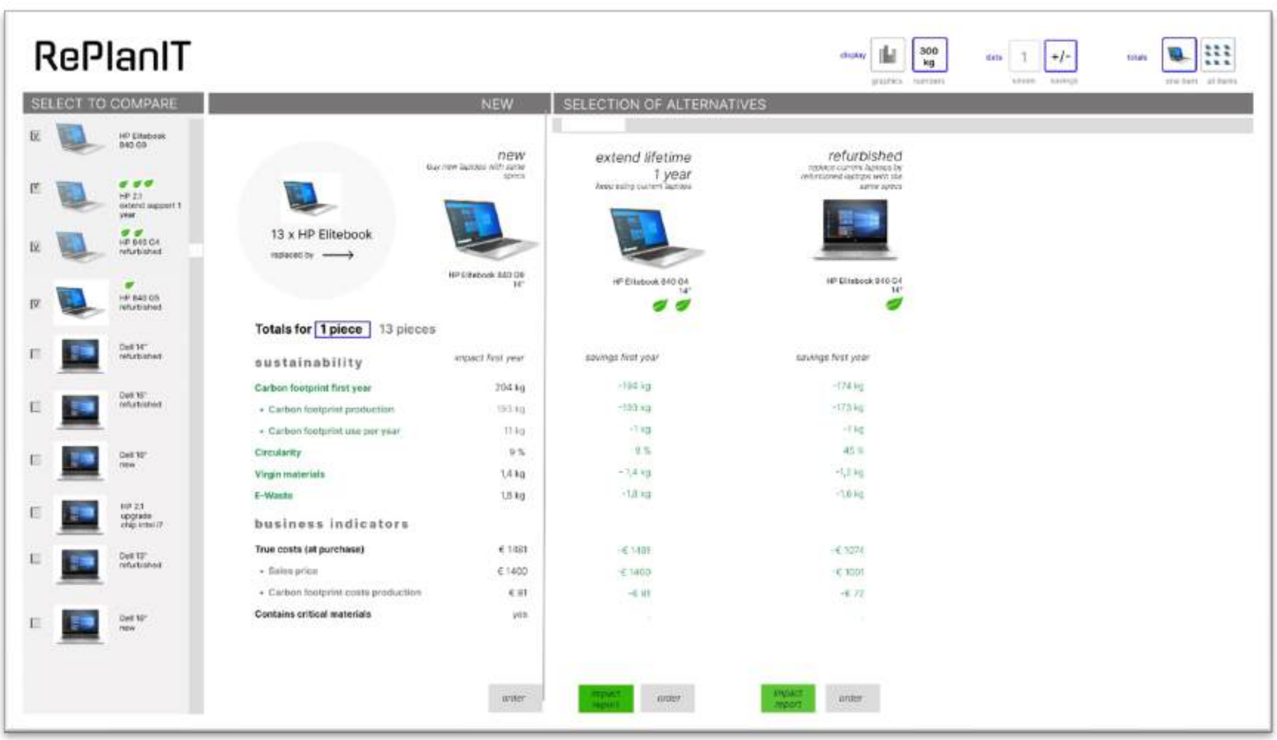


Figure 34: Savings view

When selecting the ‘Savings’ toggle, savings are shown, compared to the baseline scenario.

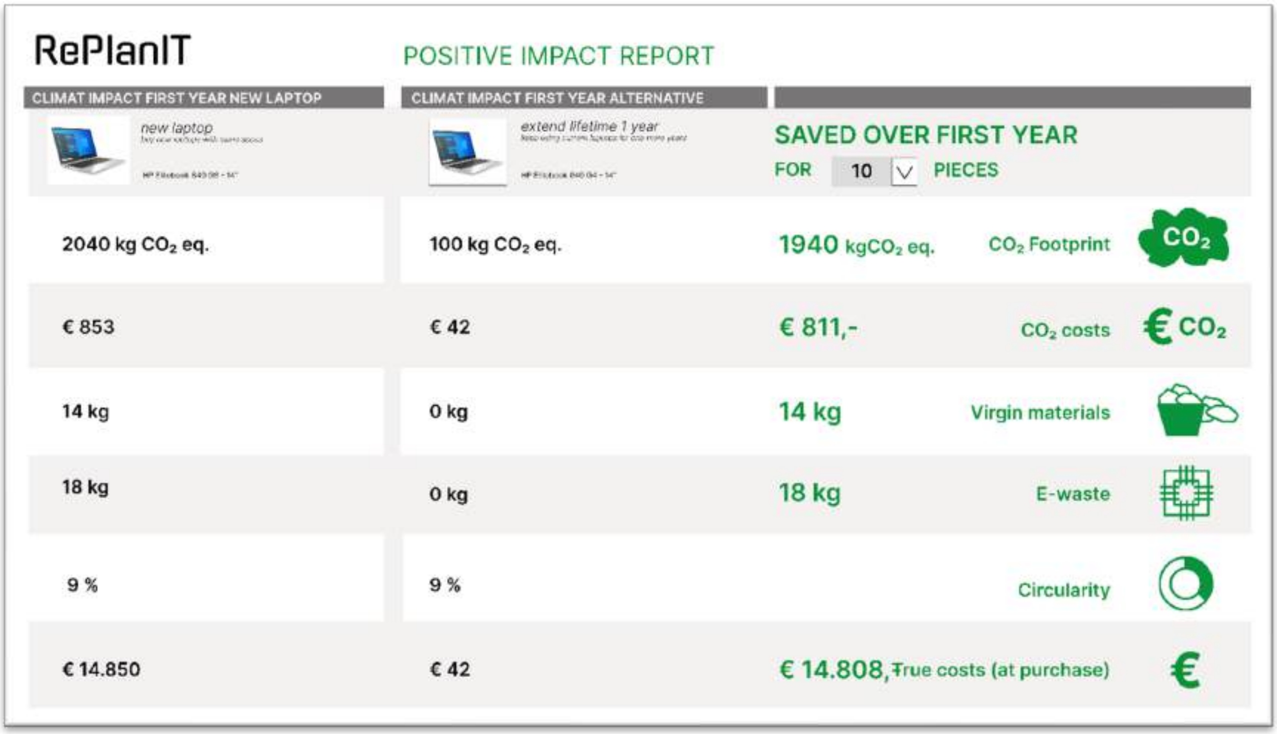


Figure 35: Report page

On the report page, an overview of all indicators is shown of the selected model laptop and business model, compared to the baseline scenario. The number of laptops can be changed.

5.3 Server & Server Park Prototype of circular resource planner & circular resource configurator

A prototype was built of a datacenter tool, which gives insight into the current performance of a selected datacenter. The tool can also advise actions to improve the effectiveness of the datacenter and show the sustainability impact of these actions. If a user wants to expand or replace servers, the tool provides impact data of different scenarios, to compare.
In the prototype, real numbers, calculations and outcomes were used. Based on data received from consortium partners. The prototype is not fully interactive, and some functionalities are shown as an example.

The next series of screenshots of the design of the tool, show how a user might navigate through the tool, and what functionalities the tool offers on each page.

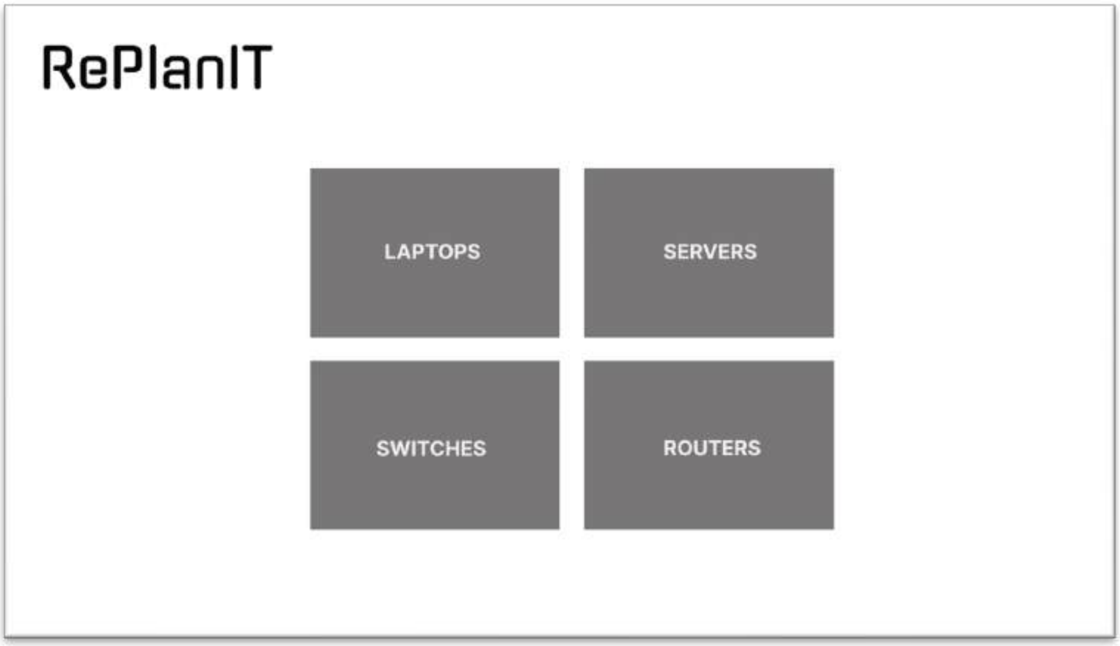


Figure 36: Landing page

At the landing page, different ICT devices are visible to choose from. In this example, the user chooses 'servers'.

Figure 37: performance page

After choosing 'servers', the selection and scanning page is shown. When a datacenter is selected, the current performance (dynamic data) can be shown:

- Memory usage (%)
- Max CPU usage (%)
- Min CPU usage (%)
- Power draw (kWatt)

On the right, the static data of the datacenter are shown.
Based on the performance, the RePlanIT tool provides advice to improve the effectiveness and efficiency of the datacenter, expressed in actions. The potential effect of these actions are direct savings of energy, CO_2 emissions and Euros.

From here, 3 pathways are possible:

1. To learn about the advised actions, click on the 'Go to actions' button. -> action page
2. If one needs to expand the capacity of the datacenter, click the "expand capacity" button -> expansion page
3. If one wants to replace servers, click the "replace servers" button -> replacement page

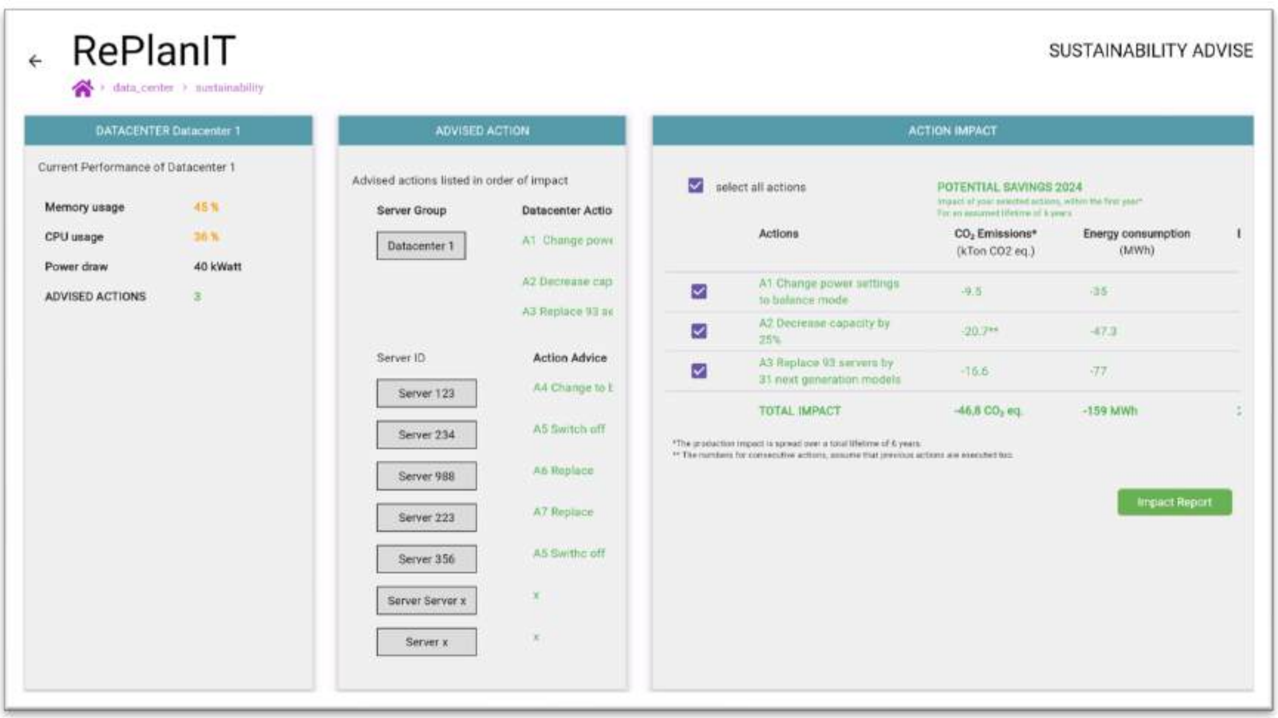


Figure 38: action page

On the action page, advised actions per server are listed, as well as actions that count for the complete fleet of servers. On the right side, a summary of the sustainability impact of the first year is shown (potential savings) per action: CO_2 emissions, energy consumption and created E-waste. From here, an impact report can be printed, of the selected actions. -> Impact report page

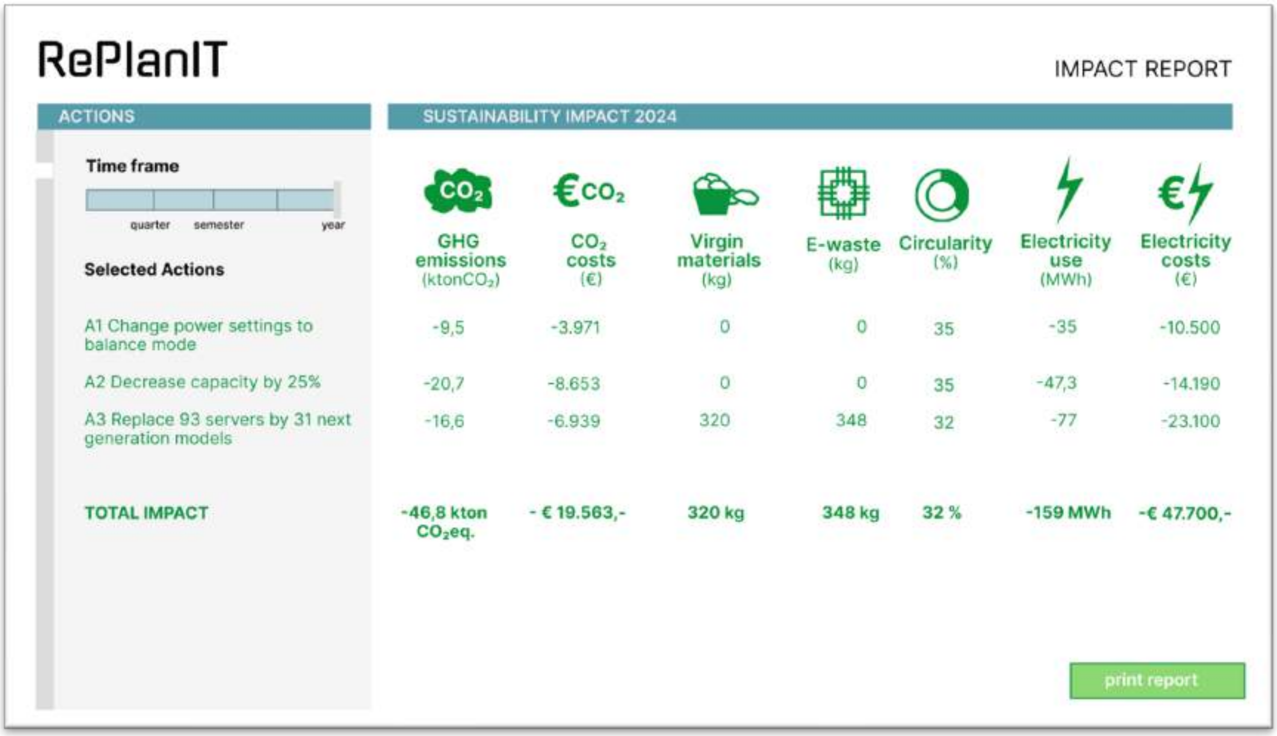


Figure 39: Impact Report

This page shows the full impact of the advised actions or scenarios, expressed in the following indicators:

- Green House Gas emissions (kgCO_2 equivalents)
- CO2 costs (€), (unit price determined by user)
- Use of virgin materials (kg)
- Produced E-waste (kg)
- Circularity of the datacenter (%)
- Electricity use (kWh)
- Electricity costs (€)

A timeframe provides the possibility to calculate the impact for different periods of time.
The report page can be printed or saved as a PDF, together with the previous input pages.

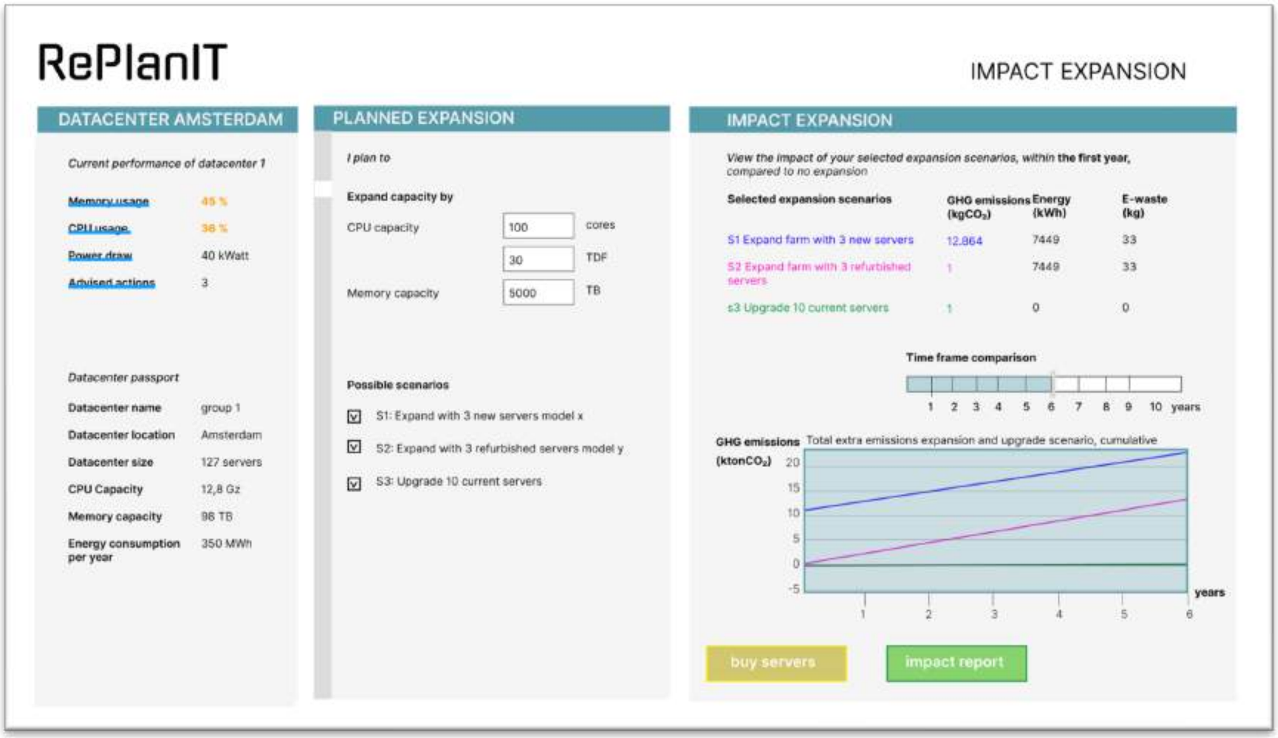


Figure 40: Expansion page

On the expansion page, the planned expansion can be entered, expressed in memory or CPU capacity. RePlanIT then suggests possible expansion scenarios to compare. The sustainability impact of the selected scenarios is displayed in numbers and graphicly. The graph shows the cumulative impact over time. The number of years is adjustable. The results can be printed into a report again. The “buy servers” button, redirects to a marketplace of a third party.

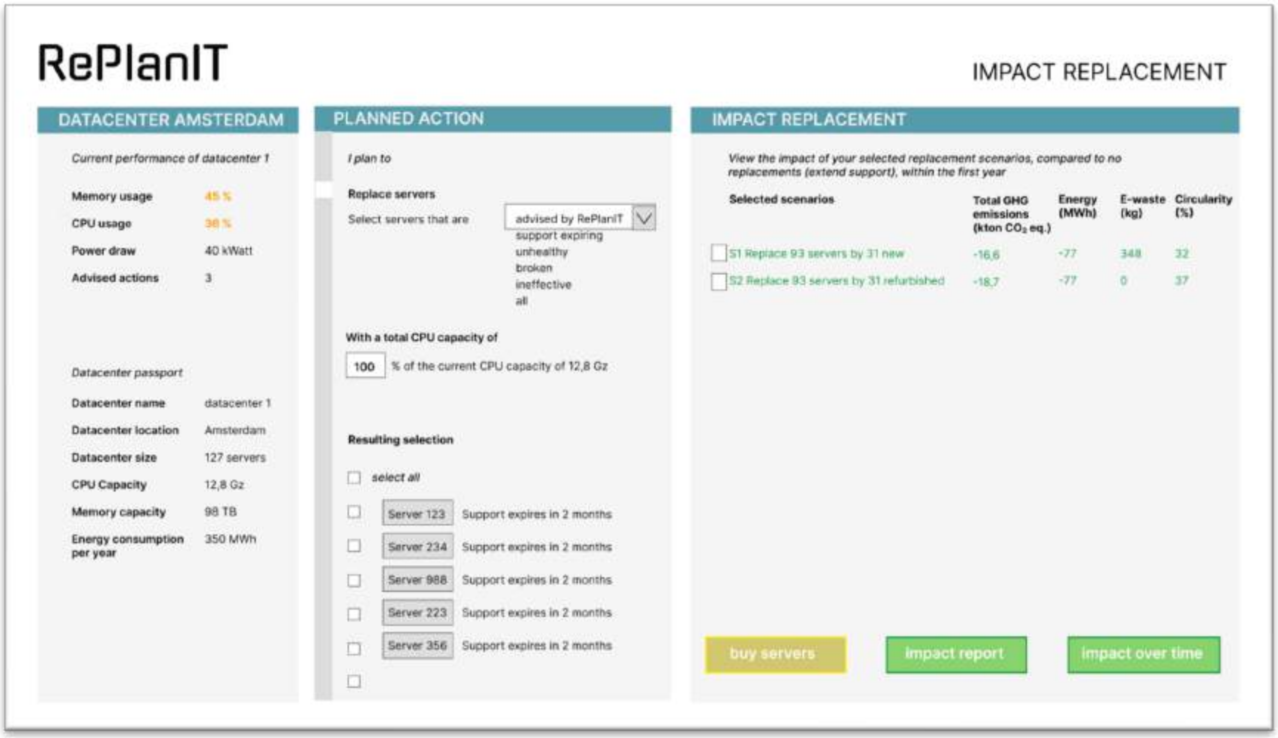


Figure 41: Replacement page

On the replacement page, the reason for replacing servers can be selected. For example, based on malfunctioning, expiring support or advised by the RePlanIT tool. Based on the given input, different replacement scenarios are suggested by the tool. Displayed with their potential impact for the first year. After selecting the preferred scenario, one can navigate towards a more extensive impact page (-> impact over time) or the impact report page (-> report page).

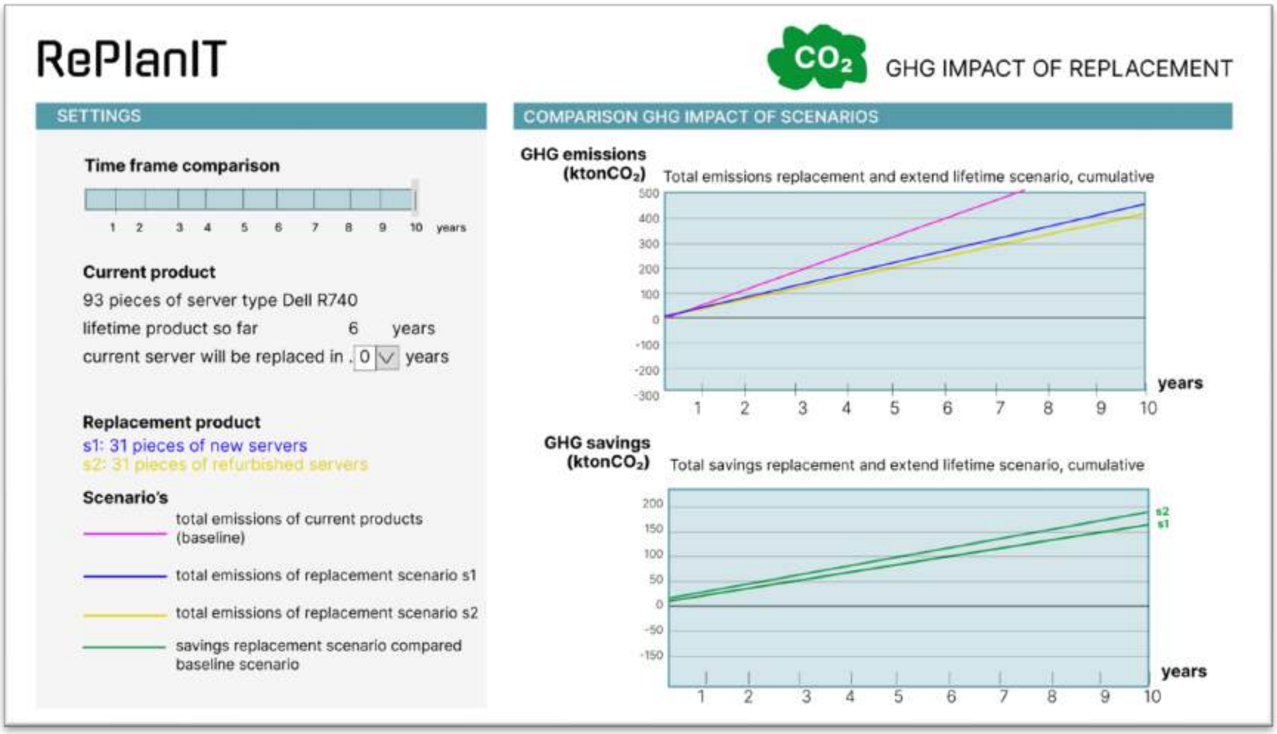


Figure 42: GHG impact of replacement page

On this page, the impact of the selected replacement scenarios is graphicly displayed, expressed in GHG emissions over time. The time frame can be adjusted. Different replacement scenarios can be compared, compared to the current emissions. The second graph shows the savings of a more sustainable scenario (suggested by RePlanIT) in comparison with a standard baseline scenario.

Assumptions server tool

- no full Bill of Materials was available from the servers in the prototype, therefore fictional data is used, based on incomplete data from a Dell LCA
- packaging of server excluded
- collection rate at end-of-life is estimated
- recyled content estimated based on industry averages
- recycling rates are from Dell LCA study
- collected steel & aluminium are 100% recycled (open loop)

5.4 Learnings from user tests and field labs

5.4.1 Laptop Use Case

On June 6th 2023 and July 20th 2023, user tests were conducted. On November 21st 2023, a 2nd user test was conducted after further development of the tool.

Participants June 6th:

- Advisor Sustainable Sourcing
- Advisor Sustainable IT (Adviseur Duurzaamheid IT)

Participants July 20th:

- Contract manager for IT Services, including laptop hardware
- Senior manager of department that manages contracts

Participants November 21th:

- Infrastructure manager work place

Test set-up

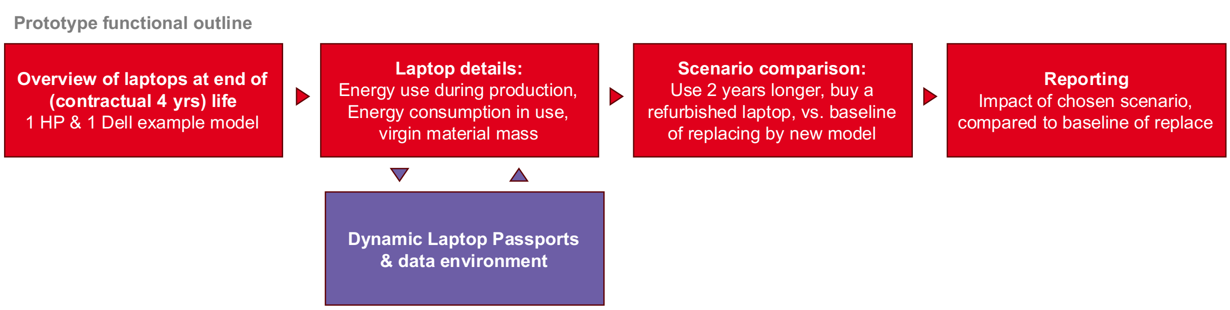


Figure 43: test set-up functional prototype outline

1. Assignment: "you are planning to replace four laptops, model HP 840 g4. They are to be replaced by the new model, HP 840 g9. Use the tool to evaluate the impact of this plan and to see which alternative strategies there are available."
2. Evaluate user experience: functionalities, ease-of-use, understandable
3. Evaluate the user test: what was the conclusion of using the tool and seeing th message and alternative scenarios? What insights did this give? What next steps will you take now if any?

Learnings on user experience

- Some features were added after first test:
  - Ability to change purchasing price
  - Ability to add yearly costs of support
- Several small design changes were made after each test

Learnings of the user test 1

- Good amount of information presented in an easy and usable way in the scenarios
- Interesting key message: 194kg CO_2 emissions reduced for every year that you use the HP laptop longer than planned, as well as 33% costs saving on equipment purchasing
- Decision makers showed reluctance at first, warning for cost pressure. Clear benefits did invoke a determination to talk to the IT supplier to see what's possible within the contract

Direct impact of user test 1

- RePlanIT Laptop tool is not used after the user test. No part or data from the tool is used structurally within the processes
- The data from RePlanIT can be used as source of inspiration: it the organization insight in the effectiveness of policy interventions, e.g. sourcing refurbished hardware or extending lifetime. This makes it possible to substantiate the need to make certain choices with data.
- More specifically: RePlanIT has quantified the environmental impact of life-extention for one type of laptop, and found out that several suppliers are able to give support and security updates for 6 years.

Learnings of the user test 2

After further development, the laptop prototype was tested again, following the same protocol as was used for test 1. Test subject was responsible for the workplace employees, including their laptop. In this role, he supplies the requirements for laptops to the buying/procurement department. In these specification, they specify the life-time of the laptops for users.

- **Roadblocks that prevent extended use of laptops**

1. *Security (main driver concerning workplace hardware)*
    - The HP Elitebooks G4 can't run Windows11, because of a chipset vulnerability
    - The interviewee expects that such unpatchable chip vulnerabilities will be found again in the future, making life extension impossible each time.
2. *New equipment is essential for hiring and retaining talent*
    - New laptops have better performance for users: e.g. faster screen update
    - Test subject indicates that an old laptop may be a reason not to join or even to leave
3. *Old laptops may not look professional*
    - Over time, dents and damages make the laptop look unprofessional

- **To what level does the prototype solve the roadblock?**

1. *Security*
    - "The tool does not help, it does not show what software is supported" according to the test subject. **Note:** we did investigate this within the project, and found that this data is publicly available and could be integrated in a future version.
    - Device as a service is not something the test subject would consider at this moment
2. *New equipment is essential for hiring and retaining talent*
    - "Tool does not solve this concern – the information on environmental benefits would not be enough to counter the preference for new hardware". **Note:** this contradicts finding from interviews with laptop users. RePlanIT team is still convinced that the tool

can successfully contribute to employee satisfaction and retention by providing insight in impact of their hardware use and their acceptance of refurbished hardware.

3. *Old laptops may not look professional*
    - "Tool doesn't solve that, although refurbishment may solve that for a bit". **Note**: RePlanIT insights may however change the perception of what is "professional" by showing the negative impact of using new hardware when old still works.
    - "Batteries would most probable need to be replaced after 4 years". **Note:** according to a refubisher, this is often the case but not always – replacement is based on test results.

Direct impact of user test 2:

Up to now, the user test 2 did not have direct impact:

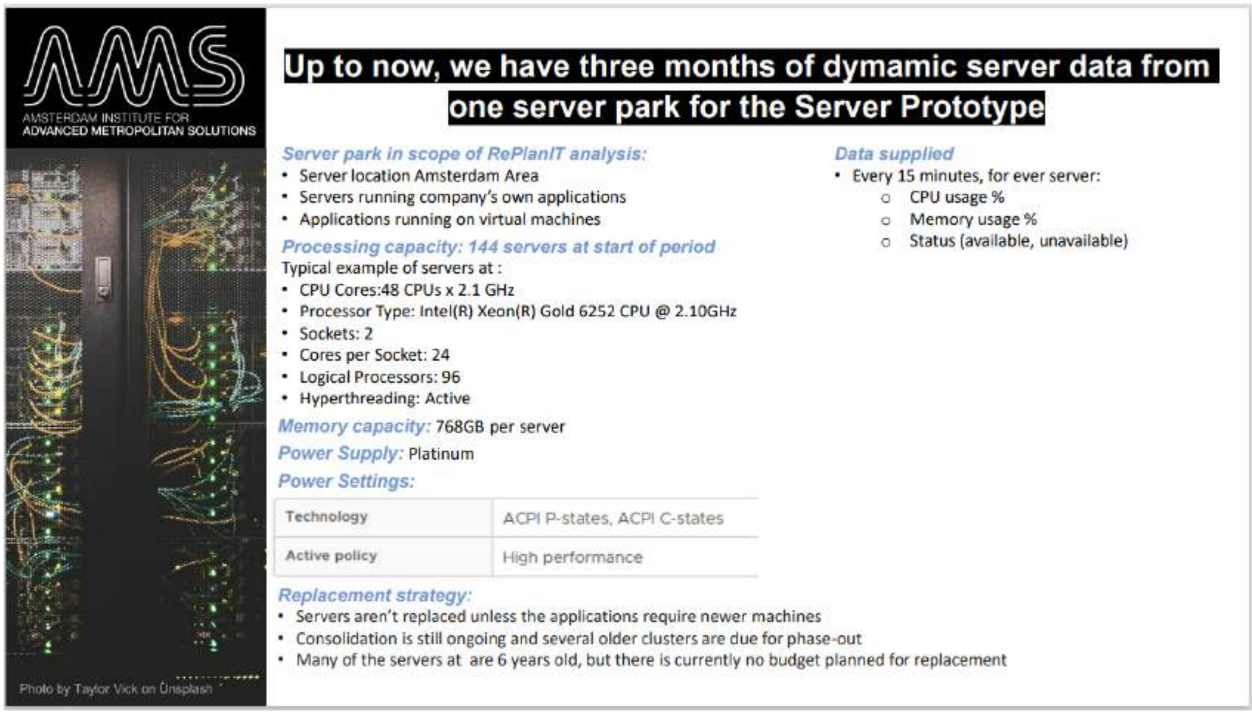
- Sustainability of laptops is managed in procurement phase, through procurement specifications – strict criteria for energy star rating for instance.
- Based on gov't criteria, but even stricter on some points (e.g. the power conversion in the adapter)
    - Company ambitions and goals on sustainability are translated into the procurement specifications by test subject
    - When two or more offers pass the criteria, the cheapest option is chosen. In that step, sustainability has not played a role in the decision up to now.
    - There is no monetary value for CO_2 and therefore that doesn't contribute to the "cheapest option"
- test subject indicates that if he would be certain that a specific model has a much longer lifetime than another model, he'd go for the longer life-time model
- test subject does not have specific targets or goals that he needs to reach, like reduction e-waste or GHG emissions related to ICT Hardware, only the global goals that are translated in procurement specifications
- test subject would not be able to change the laptop specifications to "must be supported 6 years" without alignment with ICT helpdesk/support procurement, because helpdesk may get more requests for repairs / replacements; this type of support is not part of the same procurement package.

5.4.2 Server Use Case – tested at the data center that supplied the data

User test

We conducted user testing. The findings for one server park were presented to ICT managers, decision makers and fleet owners, showing a huge potential for optimization, as can be found in the following figures:

Figure 44-52 Management presentation based on RePlanIT analysis of one server park



Finding 1: Applying more energy efficient energy settings for the servers is expected to save ~10% on energy consumption

As determined in the LEAP project, 'balanced mode' will save about 10% on energy consumption – and 's servers are currently in 'high performance mode'

- Validated in LEAP project
- No regret move
- Can be implemented directly
- Specific low-used servers could even be set to energy saving mode, but this is not taken into account in the 10% estimate

10% energy reduction would amount to 35 MWh per year for the server park in scope

- Current average total power usage is 40k Watt (total for 127 servers in scope)
- Servers run 24 hrs for 365 days per year, i.e. At 8760 hours per year
- Energy consumed = 40kW x 8760 hr = 350 MWh per year

35 MWh energy reduction = the electricity consumption of 13 Dutch households

- Average electricity consumption of a Dutch household 2640 kWh (2022)
- Source: CBS https://www.cbs.nl/en-gb/figures/detail/81528ENG

This is for just one server location of 144 servers

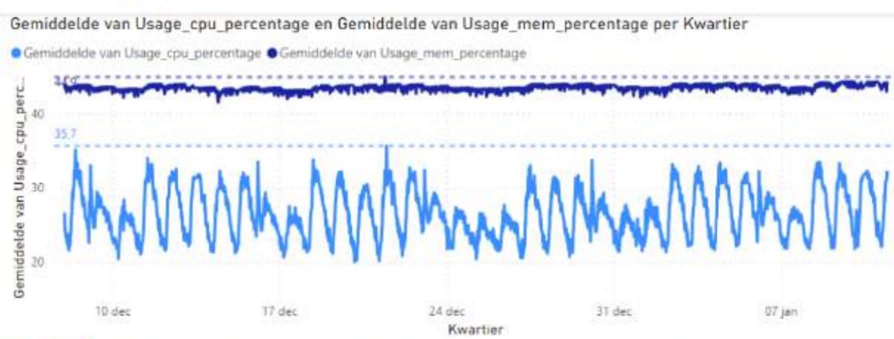
Finding 2: 50% of installed server hardware capacity is currently unused, when we compare it to expert and industry benchmarks

Current usage of the servers is low

- At start of 2024, there are 134 servers in use, of which there are 7 that run on low usage for specific reasons. For the other 127:
- Maximum CPU usage of 36%
- Maximum Memory 45%

According to our experts and industry publications, max usage can be 90% during peaks without performance issues

- If we would be able to host all applications on 50% of the servers, with half CPU and memory available, the usage would be:
- Maximum CPU usage of 72%
- Maximum Memory usage of 90%



Key question: what is possible in practice within the complexity of so many applications running on virtual machines?

AMSTERDAM INSTITUTE FOR ADVANCED METROPOLITAN SOLUTIONS

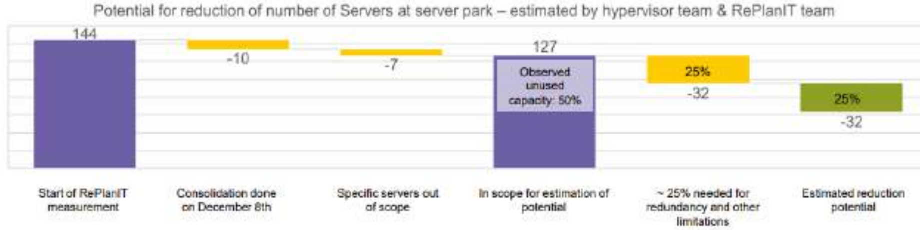
Photo by Taylor Vick on Unsplash

Finding 2: Out of this 50%, ~25% of servers could actually be reduced if optimizes the core use of applications on VM's

In a meeting with RePlanIT team, the server park hypervisor team estimated that 25% of capacity could potentially be phased out, if is able to optimize the number of CPU-cores allocated to applications that run on virtual machines:

1. Consolidation of servers is still ongoing
   - Within the data set provided to RePlanIT, there are 10 servers that were phased out during the measurement period (around December 8th)
   - Further consolidation is planned
2. Significant part of the underused capacity can not be avoided, estimated 25%
   - For business continuity, servers need to be able to take over critical tasks in case of server failure. requires ~25% redundancy server capacity
   - Some applications have expensive licenses that need to be limited to specific machines
   - Some applications need to run alternating on two physically separated locations which cause temporary underusage
3. There may still be potential for reduction of up to 25% of servers, if can optimize the applications on virtual machines
   - Hypervisor team indicates that many applications do not utilize the number of cores that they request – this could potentially free up server capacity
   - Team estimates that optimizing this could reduce up to 25% of the servers
   - At the moment, 's internal application owner specifies the number of cores, often based on vendor advice
   - In practice, this specified capacity is not used – while adding cores when use of application grows is easily done
   - According to literature, additional optimization may be possible by dynamically allocating virtual servers to physical server within clusters

Potential for reduction of number of Servers at server park – estimated by hypervisor team & RePlanIT team



AMSTERDAM INSTITUTE FOR ADVANCED METROPOLITAN SOLUTIONS

Photo by Taylor Vick on Unsplash

Finding 2: Reduction of 32 would directly lead to a saving of about 47 MWh electricity per year

25% less servers would save a bit less than 25% because the remaining servers need to work harder

- Conservative expert estimate is that total energy consumption would drop by 15% with 25% reduction of servers
- Estimate is made by our server expert Dirk Harryvan based energy consumption tests on other servers

15% energy reduction would amount to 47 MWh per year for the server park in scope (assumed already in Balanced Mode)

- Current average total power usage is 40k Watt (total for 127 servers in scope)
- Servers run 24 hrs for 365 days per year, i.e. At 8760 hours per year
- Energy consumed = 40kW x 8760 hr = 350 MWh per year

47 MWh energy per year = the electricity consumption of ~ 18 Dutch households

- Average electricity consumption of a Dutch household 2640 kWh (2022)
- Source: CBS https://www.cbs.nl/en-gb/figures/detail/81528ENG

This is for just one server location of 144 servers

AMS
AMSTERDAM INSTITUTE FOR ADVANCED METROPOLITAN SOLUTIONS

Photo by Taylor Vick on Unsplash

Finding 2: Additionally, not replacing 25% of servers at end of life would save additional emissions from production phase

Actual LCA data for 's servers is (as of yet) not available, for reference we're using a Dell server

- Dell R740 (Stanfort LCA)
- Manufacturing emissions: 4288 kg CO_2 equivalent

We calculated that 3 current servers could be replaced by 1 new model with same computing power

- Current servers (excluding 7 special purpose severs): 127
- 25% would not have to be replaced: 32 servers
- These 32 servers would require 11 new servers to replace 3 for 1

Estimated annual kg CO_2 equivalent reduction from not producing replacement servers: 47 ton CO_2 equivalent

- 11 servers not made x 4288 kg CO_2 impact = 47 ton CO_2 equivalent (one time saving)

Plus a prevention of ~121 kg of e-waste when those new servers would be decommissioned at end-of-life

- 1 Dell R740 weighs ~11kg excluding chassis

Thought experiment: what if we hadn't bought those 32 servers in the first place?

- 32 servers
- Manufacturing emissions: 4288 kg CO_2 equivalent
- Estimated total: 32 x 4288 kg = 137 ton CO_2 equivalent
- Estimated total: 352 kg of e-waste prevented

AMS
AMSTERDAM INSTITUTE FOR ADVANCED METROPOLITAN SOLUTIONS

Photo by Taylor Vick on Unsplash

Finding 3: When looking at the carbon emission only, it seems that replacing the 6 year old servers may be interesting already

Energy efficiency for the same calculation power of new server is significantly better

- New servers have roughly three times the computing power, with roughly two times the power usage

We calculated that 3 current servers could be replaced by 1 new model with same computing power

- Removing 3 servers for one would reduce the energy consumption of 1 server
- In total, the 127 servers use 350 MWh per year
- Per server: 2,76 MWh per year (average)

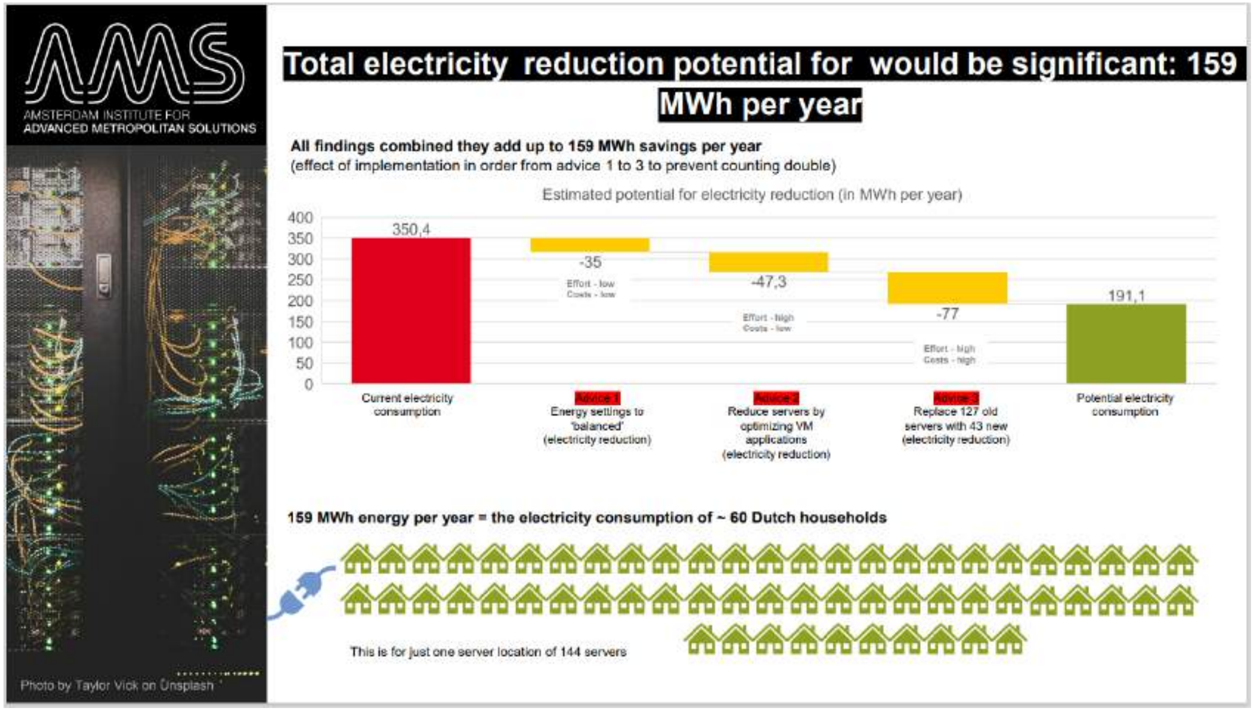
CO_2 emissions savings: 1490 kg per year

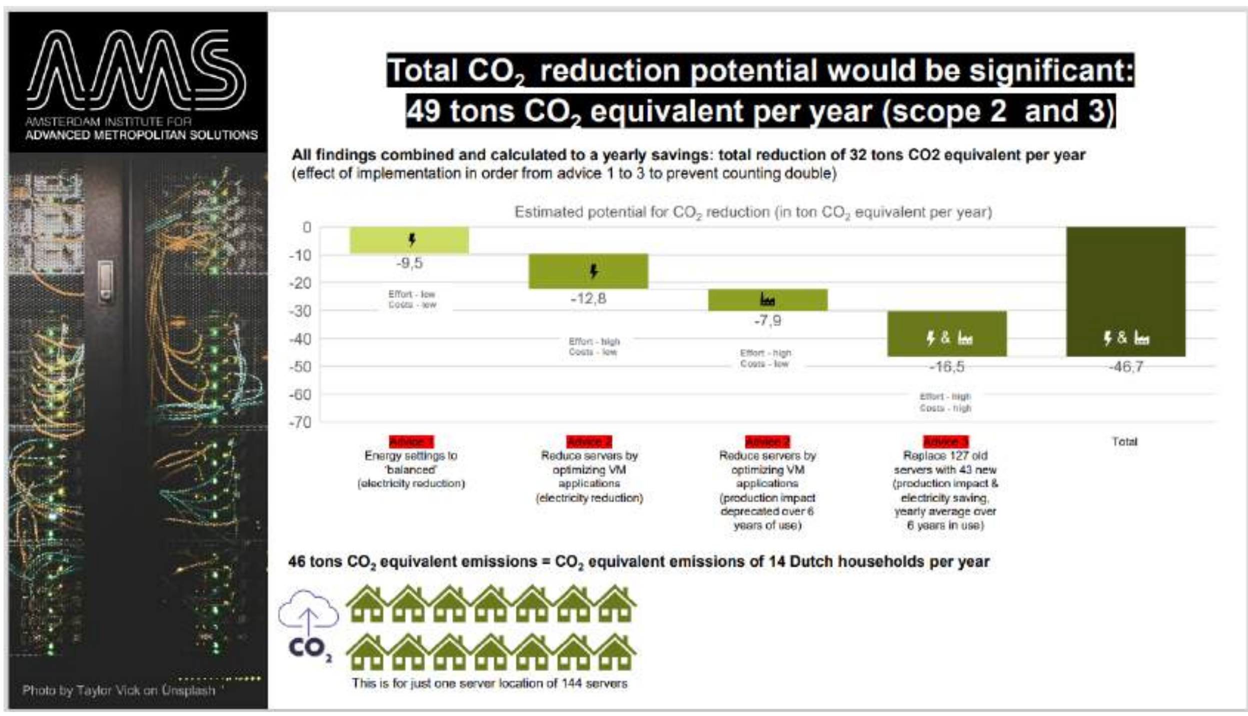
- Annal energy savings from replacing 3 servers by 1 new model saves annual energy consumption of ~33%
- Annual energy savings: 5518 kWh per year
- CO_2 emissions from Dutch electricity energy mix: 0,270 kg/kWh
  - Bron: klimaatmonitor databank Rijksoverheid, 2022
- CO_2 emission savings from energy savings: 1490kg per year

CO_2 emissions costs from production: est. 816 kg CO_2

- Typical CO_2 equivalent emissions from producing one server is 4288 kg CO_2 equivalent; Reference model: Dell R740
- For replacement, we included
  - Mainboard (CPU, RAM): 175.3 kg CO_2 equivalent
  - Fans: 11.1 kg CO_2 equivalent
  - Packaging: 1.9 kg CO_2 equivalent
  - PSU: 31.3 kg CO_2 equivalent
  - PWB Mixed: 591.8 kg CO_2 equivalent
- For replacement, we excluded:
  - 3.84TB Solid State Drives: 3373.5 kg CO_2 equivalent
  - 400GB Solid State Drives: 64.1 kg CO_2 equivalent
  - Chassis: 34.1 kg CO_2 equivalent

CO_2 emissions 'pay-back time' for replacing servers with new models: < 1,5 years
(not including Solid State Drives and chassis)





This lead to starting up conversations with OEM/Vendors, aimed at starting joint testing of the energy efficiency settings advice from RePlanIT. This testing is still ongoing and no results were shared yet.

No further user test was conducted with the circular server. Instead, the tool was shown to demonstrate its purpose and working, on two events:

- Nationale Conferentie Circulaire Economie – Nijmegen, April 14 2024
- AMS Institute Scientific Conference – May 25 2024

5.5 Expected next steps for Laptops

After a year of being part of the project, Aliter joined the Circular IT group (CITg), sparking increased interest in the project's findings. As CITg focuses on various IT products, the ReplanIT tool development lead to two realized products aimed at assisting CITg's customers. One tool, developed with IDEAL&CO, has been integrated into CITg's website (https://circularitgroup.com/impact-calculator/). This platform enables users to assess and quantify the impact of using refurbished laptops or extending the lifetime of laptops with different business models. The number of laptop models included in the tool is limited to the laptops that CITg currently offers. In addition, manufacturers need to offer – at least- EPD-datasheets, in order to be able to quantify the required sustainability data. So far, only a limited number of laptop manufacturers do so. The following figures show a few screenshots of the tool and reporting view:

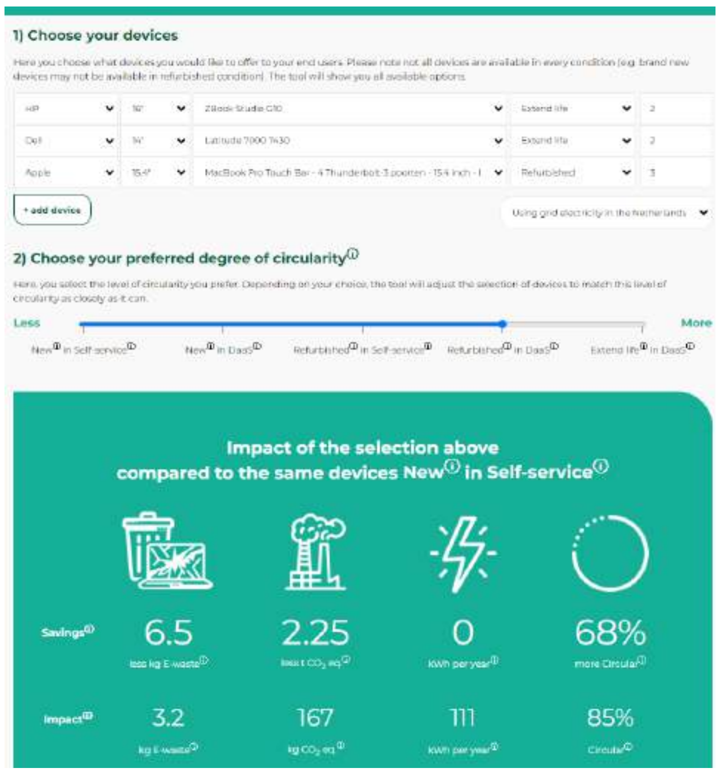


Figure 53: CITg impact calculator

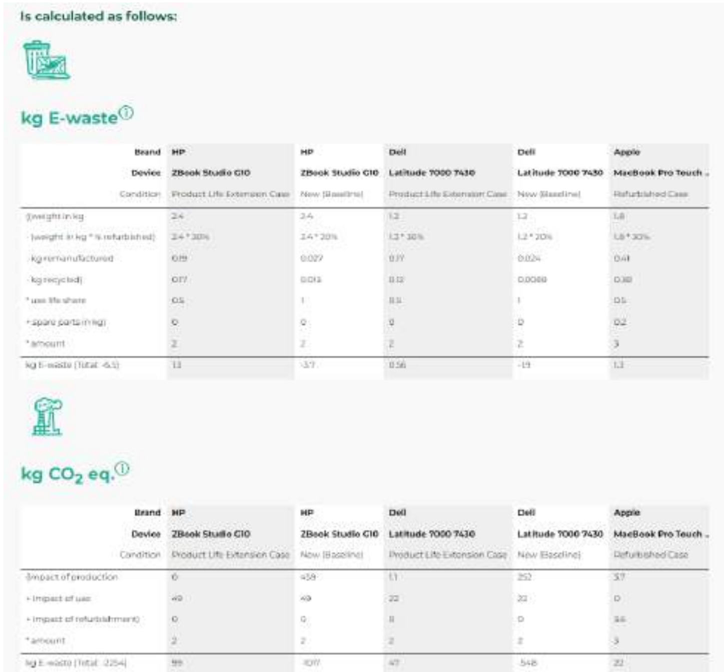


Figure 54: CITg platform based on Px3 -1

A second commercial product & service based on ReplanIT tool is the platform developed in collaboration with British researcher and creator of Px3 platform Dr. Justin Sutton – Parker. The platform will be used by CITg for tenders and to give valuable information which can be used in CSRD reports by our customers and help them to choose the option which suits their company sustainability ambitions. The app allows users to calculate impact of different IT hardware items:

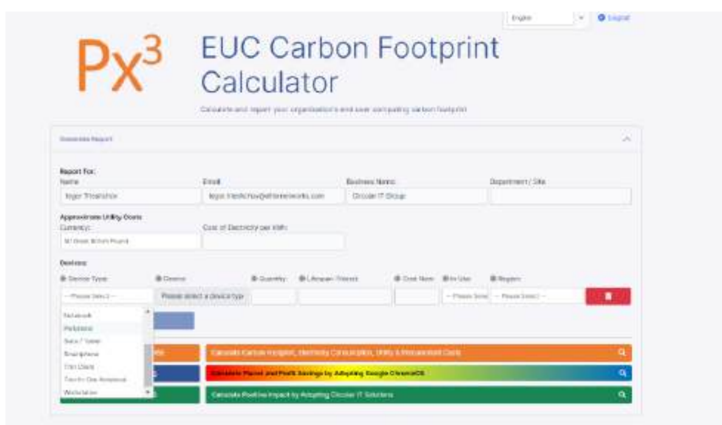


Figure55: CITg platform based on Px3 -2

Figure 56: CITg platform based on Px3 -3

To see carbon footprint of new or refurbished by CITg laptop:

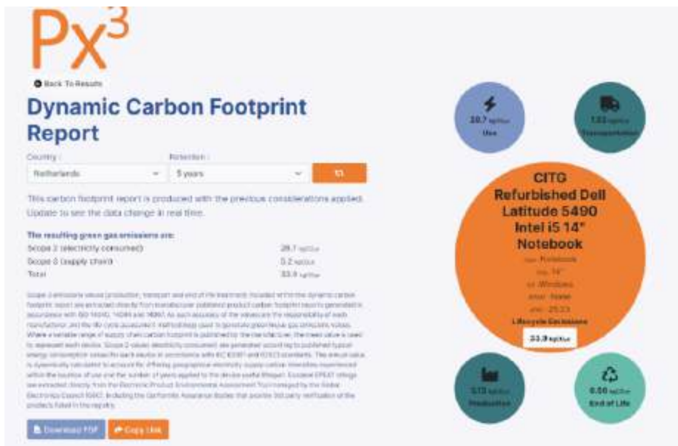


Figure 57: CITg platform based on Px3 -4

Compare new vs refurbished by CITg or new to new:

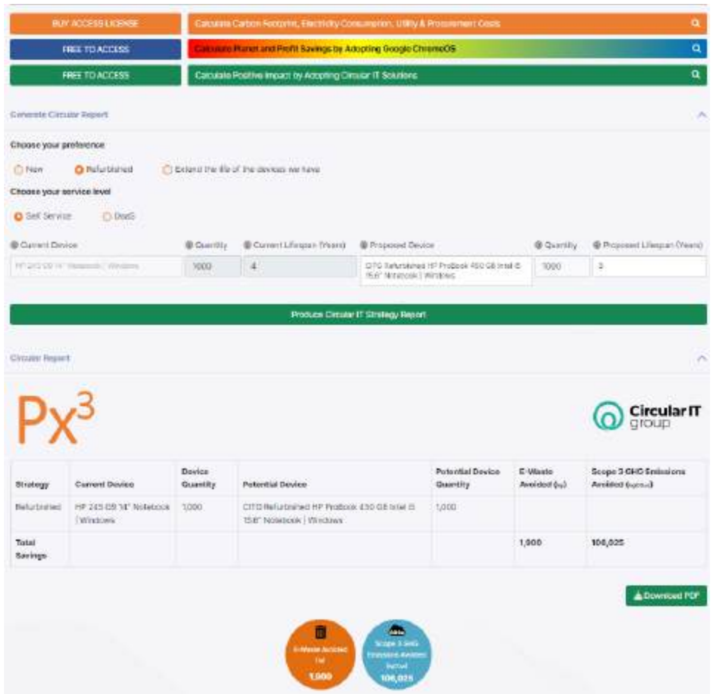


Figure 58: CITg platform based on Px3 -5

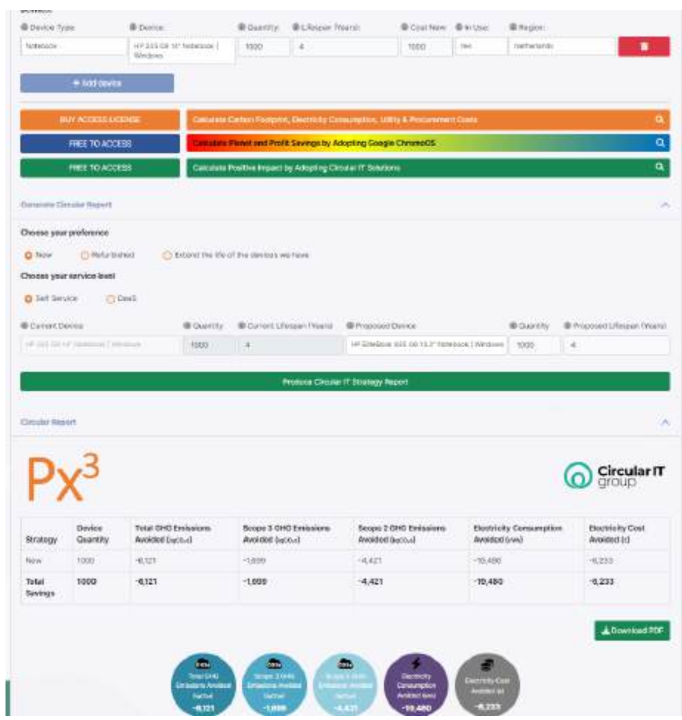


Figure 59: CITg platform based on Px3 -6

CITg plans to add to more devices these platforms and update the data regularly.

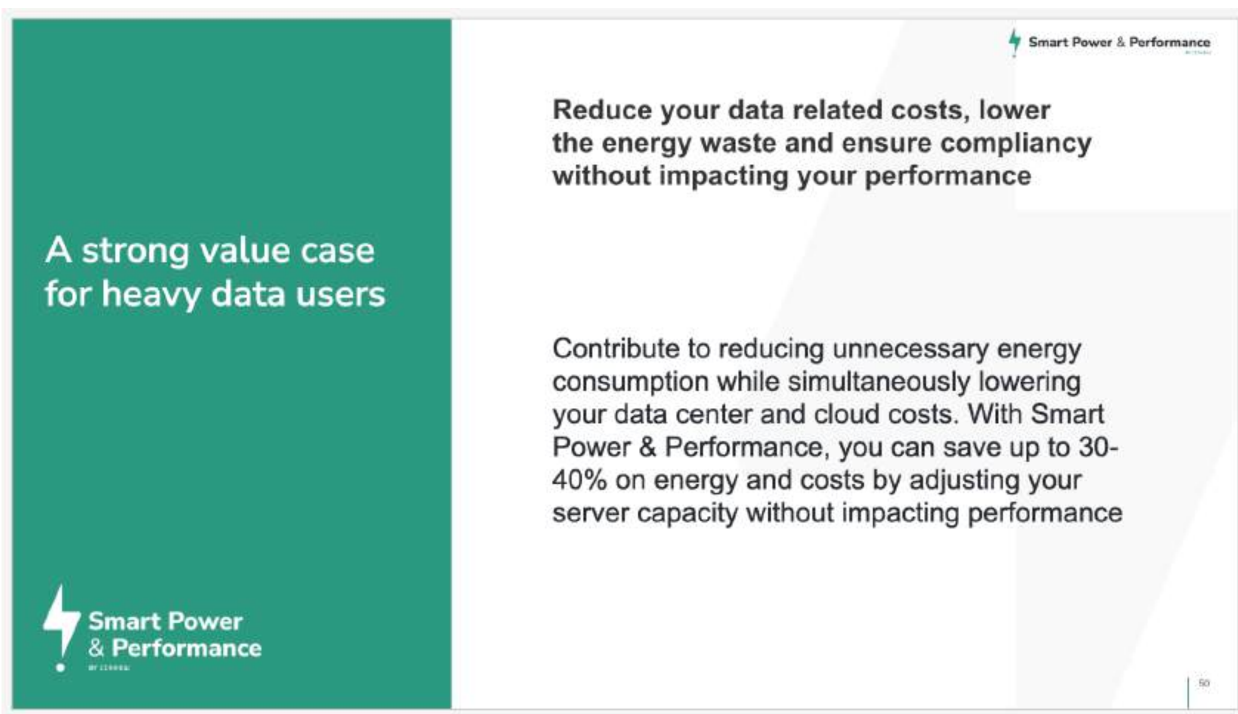
5.6 Expected next steps for Servers &Server Parks

(Partially) based on and inspired by the research and findings for servers & Server parks, RePlanIT partner WCoolIT started a new venture together with Tuuring (who provided data for RePlanIT) and another partner. Together, they started Zirrow, a company aimed at monetizing the huge potential for data-driven optimization of server parks.

The relation to RePlanIT is as follows:

- WCoolIT and Tuuring had already spotted the potential for optimization of energy settings and a general trend of overcapacity in server parks
- RePlanIT field lab confirmed that potential for business applications running on virtual machines
- RePlanIT field lab quantified the huge untapped potential of capacity reduction by right-sizing the applications, virtual machines and the total server park
- Zirrow's proposition is directly aimed at monetizing the potential that was quantified in the RePlanIT field lab

Figure 60: Zirrow's proposition "Smart Power & Performance":



https://www.smartpowerperformance.com/

6 Behavior of decision makers & decision influencers

Organizational and individual behavior play an important role in transitions toward circularity in organizations. The success and usefulness of tools like those developed in RePlanIT depend on how the behaviors, perceptions, and functional needs of organizational ICT decision-makers interact to allow for changes and improvements to circularity to happen. In Work Package 4, we investigated the perspectives of those involved in making decisions about ICT across partnering organizations, from management to everyday laptop users. These perspectives were used to determine what prevents the adoption of circular ICT solutions within the business market and how this can be increased by means of the intended RePlanIT system. The following sections share the results of interviews with employees in both ICT-related positions as well as ICT users.

6.1 Drivers & blocks – what hinders the use of more circular strategies?

6.1.1 Interviews with ICT decision-makers

The following results were shared at the Product Lifetimes and the Environment conference in Espoo, Finland, on June 1st 2023[1], and the Innovation and Product Development Management Conference in Lecco, Italy, on June 9th 2023[2]. The results were further developed for publication in the journal Resources Conservation and Recycling in a journal article in *Resources, Conservation, and Recycling*:

McMahon, K., Mugge, R. and Hultink, E.J., 2024. Overcoming barriers to circularity for internal ICT management in organizations: A change management approach. Resources, Conservation and Recycling, 205, p.107568.

Through interviews with 11 on-the-ground ICT decision makers across 5, we identified 13 barriers to the acceptance, development, and implementation of circularity-related changes in organizational ICT management. We determined that the barriers relate to several important themes to be considered in the development of the RePlanIT tools, namely, information and knowledge transfer, access to circular equipment, finances and contracts, and prioritization over circularity.

Identified barriers to the acceptance, development, and implementation of circularity-related changes in organizational ICT management at the decision-maker level (from McMahon et al. 2023):

1. **A lack of awareness** – Organizational decision-makers often lack awareness of circularity's importance and benefits, which is necessary to effectively initiate circular activities within organizations.
2. **A lack of knowledge** – In addition to not being aware of why circularity is important for their organizations, decision-makers often have a limited understanding of how to incorporate circularity and how circularity fits into existing processes. This lack of knowledge results in fewer and less effective circular initiatives, even when awareness and acknowledgement of their importance is present.
3. **Limitations to the flow of needed information** – The knowledge needed to address the previous lack of knowledge often meets roadblocks in its pathway from device production to use. Both producers and user organizations have information that would be beneficial to circularity but have difficulty passing information to each other through bridging stakeholders.

Table from our paper McMahon et al. 2023
Types of Circular ICT Device Information Requested by Interviewed ICT Decision-Makers
• Realistic and accurate expected product lifetimes
• Energy consumption in production
• Energy consumption in the use phase
• Recycled material content
• Accurate recyclability of the device and components including actual returns with current technology)
• Repair and performance history (device tracking)
• Information on financial costs and trade-offs of equipment with a high circularity standard
• A comparative assessment of circular impact of different choices and devices

4. **Difficulty assessing true impacts** – A lack of previous baseline measurements, difficulty tracking measurements over large quantities of equipment, frequently changing eco-standards, and potential misrepresentations of the actual circular impacts of services (greenwashing) contribute to confusion over what decision will have the greatest positive impact on the environment, society, and organizational finances.
5. **Access to circular ICT devices and spare parts** – Organizations need to be able to obtain specific devices and components to transition to circular ICT. Changing circumstances such as supply chain issues (e.g., chip shortages) limit availability. It can also be difficult to obtain spare parts for repair or to store these parts in bulk.
6. **Limitations to incorporating refurbishment** – the availability of refurbished equipment at the needed time is low (dependent on incoming equipment, what is already in stock, and processing time). There are also limited (or no) support contracts for refurbished equipment.
7. **Repair-related costs and limitations** – Effects on whether a device will be repaired included time to conduct the repair, need for specified tools, and the weighing of costs against current values of devices. When costs are considered too high, repair is not done.
8. **Financial barriers to circular ICT** – Existing budgets not considering circularity, potential higher initial costs of circular equipment, and costs of extending support contracts affect decisions to purchase longer lifetime equipment or to extend lifetimes of existing equipment.
9. **Limited supplier interest in lifetime extension** – Lifetime extension is often not perceived by suppliers to be to their benefit, limiting the availability and participation of suppliers in ICT lifetime extension.
10. **Limits to existing or available contracts** – Circularity may not be incorporated into existing or on-offer contracts. These contracts have limited service-period lengths, after which equipment would be unsupported.
11. **Concerns for data security** – There is often hesitancy about the completeness of data wiping, leading to non-circular activities like shredding hard disks. Older equipment may have outdated software or hardware compliance, risking data security.
12. **Low priority of circularity in ICT** – Basic needs, changing circumstances (e.g., Covid-19-related switches to laptops), energy costs, low-cost equipment that meets performance goals,

standardized orders, and existing sustainability initiatives often have greater priority than ICT circularity.

13. **Lack of accountability and initiative** – The lack of a dedicated position or person to take accountability for circular choices and a lack of support or requirement from upper management to make circular decisions results in less action. Even when the importance of circularity for the organization is acknowledged, actions are not taken.

Despite these barriers, organizations express desire to participate in circularity. The following drivers express why organizations would like to overcome these barriers and improve their circularity:

Table from our paper McMahon et al. 2023

Table 2. Drivers and motivators for organizational adoption of circularity in ICT.

Driver/Motivator	Illustrative Quote
Public image	"It's good for our promotion, our name." (P3)
Cost savings	"Interestingly, extending the life of equipment in [type of organization] is driven more by the austerity tasks at hand than the sustainability aspects." (P8)
Environmental impacts	"We are a large organization, so already you can make a big impact just by reducing your own footprint." (P7)
Legislative requirements	"There is legislation coming... to prove what you've done regarding sustainability criteria." (P6)
Stakeholder pressure	"Investors ask us where we are on sustainability, so the score is becoming more and more important to attract the right finance instruments." (P7)
Talent attraction and retention	[Employees] "find it really important to work at a company that... is working a lot on sustainability, so they identify with it and it's also a way to retain and attract talent." (P2)
Personal employee interest	"Many of these kinds of initiatives... really happen because of an intrinsic motivation of an employee." (P9)

6.1.2 Interviews with everyday laptop users

The results of this subsection were shared at the AMS Institute's Reinventing the City conference in Amsterdam, the Netherlands on April 25th, 2024, and are in further development for publication in the form of a journal article.

Interviews focused on two main research questions:

1. What influences decisions employees make about how to **choose** a work laptop, when to **repair** a laptop, and when to **replace** a work laptop?
2. What influences whether or not an employee would **accept more circular choices** for their work laptop?
   - (e.g., using a refurbished laptop, choosing a laptop with more appropriate/lowered specifications, repairing a laptop rather than replacing it, or using a laptop for longer)

Through interviews with 20 everyday employees across 8 large Dutch organizations who use company-owned laptops for their professional work, we identified 6 main themes relating to user perspectives on choice and acceptance of circularity with their work laptops:

1. Physical laptop features impact willingness to accept refurbished or long-term use devices.
    a. Preferences for physical features like **screen size**, **weight & portability**, and **specific components** like USB or HDMI ports are often static regardless of circularity.
    b. The physical condition, like **cleanliness**, **scratches**, and other "**evidence of the previous user**" affects willingness to accept refurbished laptops, or to use their own laptops longer.
2. Circular laptops should deliver expected technical performance.
    a. Decreases in laptop **speed**, technical **compatibility** with programs and security software, and **battery capacity** decrease willingness to use older computers.
    b. Concerns for **performance reliability** can make employees wary of refurbished and long-term use devices, especially **repeated failures**.
    c. Assurances like **guarantees** for servicing and replacement, if necessary, **encourage acceptance**.
3. Employees feel good about contributing to sustainability and circularity.
    a. Employees were generally **aware** of and **concerned** about sustainability and circularity, but it was **not their first consideration**.
    b. Topics like **CO2 emissions** and the importance of **resource efficiency** were familiar to employees.
    c. Employees were **concerned** about **impacts on society**, especially marginalized communities, from non-circular practices.
4. Employees bring their personal experience to their decisions about work laptops.
    a. Personal **concerns**, **experiences**, and **habits** shape how an employee chooses a work laptop and what circular practices they are likely to accept.
    b. The influence of **friends**, **family**, and **societal norms** also shape decisions.
5. Employees feel less ownership and attachment to work laptops.
    a. **Lack of ownership and attachment** can make employees more likely to request or accept **replacement** and **shorter laptop lifetimes**.
    b. Employees count on the **guarantee** that they will always be able to get another **functioning laptop.**
    c. **However**, employees often **feel responsible** to **spend money wisely**, even if it is not theirs, and especially if it is the taxpayers'.
6. The company can also influence how employees make decisions internally.
    a. Employees preferred to **trust** that their companies will:
    - provide a **suitable laptop**,
    - make **competent repairs**,
    - and make **sustainable/circular** decisions.
    b. A **company culture** that **prioritizes sustainability** and circularity means employees put it 'front of mind.'

6.2 Evaluation of user experiences of Prototypes

The research into drivers and barriers confirms and provides further support for two types of findings from the user experiences of the prototypes. First, the prototypes specifically address the barrier that users (ICT decision makers) have a limited understanding of how to incorporate circularity and how circularity fits into existing processes. The user test 1 clearly showed that the prototype conveyed knowledge in a manner that suits the potential users, that the tool was able to remove a preconception about increased cost, and that it sparked action towards more circular solutions. The research confirms that cost savings and environmental impact, which are expressed in the prototypes as key performance indicators, are indeed drivers for the adoption of circularity in ICT.

Second, the research shows other barriers, outside the scope of this project, especially organizational and behavior-change barriers that are of key importance for implementing more circular solutions. For example, one participant in the user test provided input that seemed to combine low priority for sustainability and reluctance to change. Another important barrier, 'limits to existing contracts', that also emerged in the user tests, is that organizations need to integrate circular strategies in their procurement contracts to be able to offer more circular solutions, such as refurbished laptops, extended service & repair. Especially, concerns for data security need to be addressed. Finally, the project showed that, although the companies involved in the project have clear and ambitious sustainability and circular targets, these have yet to be transferred into targets for ICT decision makers. Without targets, other KPI for which targets are set (such as cost) may well be prioritized, even when a knowledge tool is available. This links to the barriers low priority and lack of accountability.

7 Impact estimation

7.1 Laptop Use Case

New Business development as a follow up result of the prototypes

The ReplanIT project has provided CITg with the opportunity to develop additional platforms, enhancing competitiveness in the market. These platforms, built upon the foundation of ReplanIT, serve as powerful decision support tools as well as marketing tools, attracting environmentally conscious customers who prioritize sustainability. Consequently, this has led to the creation of new business opportunities. Moreover, these platforms have played a pivotal role in securing tenders where sustainability scores carry significant weight, further solidifying the organization's position in the market.

Through the development of new products rooted in the ReplanIT framework, CITg has not only advanced its own initiatives but also provided support to businesses operating within the sustainability sector. This effort has resulted in the creation of job opportunities within the realms of sustainability and circularity. Additionally, CITg has fostered international connections, exemplified by collaborations such as the development of the Px3 platform alongside British scientist Dr. Justin Sutton-Parker.

A simplified version of the RePlanIT laptop prototype has been rebuild into a web-tool that is available on the website of Circular IT Group:
https://circularitgroup.com/impact-calculator/

For IDEAL&CO, the project has expanded their network, generated a follow-up assignment for CITg (development of the impact calculator), generated knowledge and expertise about the circularity and sustainability of electronic products, and provided a reference project they can use for acquisition.

7.2 Server & Server Park Use Case

New Business development as a follow up result of the prototypes

The Server & Server Use Case has lead to a new venture, Zirrow (www.zirrow.nl) . This venture uses the same approach as the RePlanIT Prototype to analyse and quantify the impact potential of server park optimization (electricity consumption and over-capacity reduction). Two of the three founding partners have been partner in or closely involved in the RePlanIT consortium: WCoolIT, (M. Verzijl) a core partner in the development of the prototype. This venture is doing successful business with already several launching customers in Financial Services and Hospital industries.

8 Knowledge dissemination

Media attention:

- 29-5-2023 Project RePlanIT krijgt subsidie KIA-CE circulaire-it.nl
- 8-6-2023 Project RePlanIT krijgt subsidie KIA-CE datacenterworks.nl
- 08-05-2024 RePlanIT maakt circulaire opties voor laptops en servers inzichtelijk

Kate McMahon's publications and appearances:

- McMahon, K., Hultink, E.J., and Mugge, R. Identifying barriers and enablers for circular ICT practices: An exploratory study. Product Lifetimes and the Environment (conference). Espoo, Finland, June 2023.
- McMahon, K., Mugge, R., and Hultink, E.J. Exploring the transition to circular ICT in businesses. Innovation and Product Development Management Conference. Lecco, Italy, June 2023.
- McMahon, K., Mugge, R., and Hultink, E.J. A change management approach for circular transitions of organizational ICT management. Resources, Conservation, and Recycling.
- On Friday, September 29, AMS institute and Delft University of Technology hosted an interactive session on extending the life of ICT hardware during as part of the ECP-NCDD* event 'Environmental Impact of the Digital System. Menno van Dijk, project manager at AMS institute and Kate McMahon, postdoc researcher at TU Delft, presented the RePlanIT project's findings on what's blocking decision makers in business from using ICT hardware longer.
- Kate McMahon presented RePlanIT during one of TU Delft's Design, Organization and Strategy Department meetings

Anelia Kurteva's publications and appearances:

Peer-reviewed scientific publications

- Kurteva, A., McMahon, K., Bozzon, A., & Balkenende, R. (2023). Semantic Web and its Role in Facilitating ICT Data Sharing for the Circular Economy: An Ontology Survey. Semantic Web journal (In Review)
- Kurteva, A., & Pandit, H. J. (2023). Relevant Research Questions For Decentralised (Personal) Data Governance. Trusting Decentralised Knowledge Graphs and Web Data (TrusDeKW) Workshop at Extended Semantic Web Conference 2023
- Kurteva, A., van der Valk, C., McMahon, K., Bozzon, A., Balkenende, R. (2024). RePlanIT Ontology for FAIR Digital Product Passports of ICT: Laptops and Data Servers. Semantic Web journal (In Review).
- Chirvasuta, T., Kurteva, A., Hofman, W., Rukanova, B., Tan, Y.H., Aligning the FEDeRATED Upper Ontology with Battery and Electronics Ontologies to Aid Circular Economy Monitoring in Practice (2024), SEMANTiCs conference (In review)

Presentations:

- Kurteva, A., M. van Dijk, McMahon, K., (2024), How to Lower the Footprint of IT Using Digital Product Passports: From Research to Practice, AMS Scientific Conference

- Kurteva, A. (2024). Knowledge Graphs for More Sustainable ICT: A Digital Product Passport Case, Wageningen Data Competence Center Meet Up on Sustainability, Data sharing and Knowledge Graphs, Available at https://www.researchgate.net/publication/379154609_Knowledge_Graphs_for_More_Sustainable_ICT_A_Digital_Product_Passport_Case
- Kurteva, A. (2023). What can Knowledge Graphs do for the Circular Economy?, NODES by Neo4j, ML and AI track, Available at https://www.researchgate.net/publication/374998414_What_can_Knowledge_Graphs_do_for_the_Circular_Economy
- Kurteva, A. (2023). Towards FAIR ICT Data Sharing in the Circular Economy with Knowledge Graphs, ICT Open, Available at https://www.researchgate.net/publication/370106721_Towards_FAIR_ICT_Data_Sharing_in_the_Circular_Economy_with_Knowledge_Graphs
- Kurteva, A. (2023) Building FAIR Digital Product Passports for ICT, Circular Industries Talks. Available at https://www.centre-for-sustainability.nl/news/digital-product-passports-with-t-oberhauser-circularise-b-rukanova-y-tan-j-ubacht-and-a

Iegor Trieshchov, Aliter Networks/Circular IT Group

17.10.23 Presenting ReplanIT project to Circular economy club of Amsterdam at Aliters office in Amsterdam

Figure 61: photo of event

15.3.24 The National Circular Economy Conference, together with M. van Dijk of AMS Intitute

Figure 62: photo of event

And, multiple mentioning of the RePlanIT project on the social media of Aliter and CITg.

Appendix

1. SPARQL query - Create a DPP

```
PREFIX : <http://www.semanticweb.org/RePlanIT/>

PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

PREFIX unit: <https://qudt.org/2.1/vocab/unit/>

PREFIX om-2:<http://www.ontology-of-units-of-measure.org/resource/om-2/>

PREFIX dpv: <http://www.w3.org/ns/dpv#>

PREFIX prov: <http://www.w3.org/ns/prov#>

PREFIX owl: <http://www.w3.org/2002/07/owl#>

PREFIX obo: <http://purl.obolibrary.org/obo/>

INSERT DATA{

  :f5056b45-3736-44d2-9df5-fed8a334948f a :Laptop;

                    :AssemblyNumber "d82f130f-f011-441c-989d-1a931257982a"^^xsd:string;

                    :hasBrand :HP;

                    :Model "EliteBook 840 G4"^^xsd:string;

                    :ModelYear "2008"^^xsd:integer;

                    :hasStatus :New;

                    :DeliveryTime ""^^xsd:double;

                    :ICTDeviceWeight "1.48"^^xsd:double;

                    :hasCertification _:blankNode;

                    :hasDeclarationType :EnvironmentalProductDeclaration;

                                                              :DeclarationDate "2009-09-
24"^^xsd:dateTime;

                    :PurchaseCostValue "1.309"^^xsd:double;

                    :CurrentCostValue "1.309"^^xsd:double;

                    :MaintenanceCycles "0"^^xsd:double;

                    :hasSupport _:blankNode;

                    :SupportCostValue ""^^xsd:double;

                    :hasOperatingSystem :MicrosoftWindows;

                    :hasSecuritySoftware :HPClientSecurity;

                    :hasSecuritySoftware :TrustedPlatformModule;

                    :WarrantyDuration "3"^^xsd:double;

                    :Image "https://support.hp.com/doc-images/391/c05349578.jpg"^^xsd:anyURI;

                    :Temperature ""^^xsd:double;

                    :hasComponent :HPBIOSphere;
```

```
:hasComponent :HPSureStartGen3;
:DisplayResolution "1920x1080"^^xsd:string;
:ScreenSize "14"^^xsd:double;
:hasGraphicsCardProcessor :IntelHDGraphics620;
:ClockRate "300"^^xsd:double;
:hasComponent :Webcam;
:CameraPixels "720"^^xsd:double;
:hasComponent :HPPremiumKeyboard;
:hasComponent :BangOlufsen;
:hasMemory :DDR4;
:hasComponent :SSD;
:RAMSize "8"^^xsd:integer;
:ROMSize "256"^^xsd:integer;
:hasComponent :DisplayPort;
:hasComponent :DockingStationPort;
:hasComponent :HDMI;
:hasComponent :VGA;
:hasComponent :USB-C;
:hasComponent :SDCardReader;
:hasComponent :HPLongLife3Cell;
:BatteryCapacity "51"^^xsd:double;
:BatteryLifetime "12.15"^^xsd:double;
:BatteryWeight   "200"^^xsd:double;
:hasComponent :IntelCorei7;
:hasCPUSeries :IntelCorei77200U;
:CPULoad ""^^xsd:double;
:CPUSpeed "2.8"^^xsd:double;
:hasComponent :CoolingSystem;
:hasComponent :HPCoolingFan;
:hasSensor :FingerprintReader;
:CarbonFootprintUse ""^^xsd:double;
:CarbonFootprintDistribution ""^^xsd:double;
:CarbonFootprintErrorratio ""^^xsd:double;
:CarbonFootprintEoL ""^^xsd:double;
:CarbonFootprintManufacturing ""^^xsd:double;
```

```
:CarbonFootprint_kg_Use "40"^^xsd:double;
:CarbonFootprint_kg_Distribution "30"^^xsd:double;
:CarbonFootprint_kg_EoL "0"^^xsd:double;
:CarbonFootprint_kg_Manufacturing "185"^^xsd:double;
:CircularActivityCost ""^^xsd:double;
:DeviceCarbonFootprint "255"^^xsd:double;
:DeviceCarbonFootprintErrorRatio ""^^xsd:double;
:EnergyConsumption ""^^xsd:double;
:EPDAvailability  "true"^^xsd:boolean;
:SourceHash ""^^xsd:string;
:EPDSource ""^^xsd:anyURI;
:EPDDeviceLifetime "4"^^xsd:double;
:EPDDeviceWeight "1.7"^^xsd:double;
:EPDUseLocation "Worldwide"^^xsd:string;
:EPDFinalManufacturingLocation "China"^^xsd:string;
:EPDUseEnergyDemand "18.98"^^xsd:double;
:GHGCostProduction ""^^xsd:double;
:GHGCostUse ""^^xsd:double;
:CarbonFootprintSource ""^^xsd:anyURI;
:ProductSpecificationSource "https://support.hp.com/us-en/product/hp-elitebook-840-g4-notebook-pc/11122291/document/c05349510"^^xsd:anyURI;
:ProductSpecificationSource "https://nl.hardware.info/laptops.18/hp-elitebook-840-g4-99678165.423992 "^^xsd:anyURI;
:MaterialCompositionSource  "https://www.nature.com/articles/s41597-020-0573-9"^^xsd:anyURI;
:MaterialRecyclability ""^^xsd:boolean;

:AluminiumWeight "559.10"^^xsd:double;
:CopperWeight "72.80"^^xsd:double;
:SteelWeight "356.00"^^xsd:double;
:PlasticWeight "765.20"^^xsd:double;
:PCBWeight "368.60"^^xsd:double;
:GlassesWeight "315.00"^^xsd:double;
:OtherMaterialsWeight "24.50"^^xsd:double;
:OtherMetalsWeight "493.70"^^xsd:double;
:Waste ""^^xsd:double;
:RecycledContent  ""^^xsd:integer;
```

```
:AluminiumRecycledContent ""^^xsd:double;
:BatteryRecycledContent ""^^xsd:double;
:CopperRecycledContent ""^^xsd:double;
:SteelRecycledContent ""^^xsd:double;
:PCBRecycledContent ""^^xsd:double;
:GlassesRecycledContent ""^^xsd:double;
:OtherMetalsRecycledContent ""^^xsd:double;
:OtherMaterialsRecycledContent ""^^xsd:double;

:CollectionRateValue ""^^xsd:double;
:EoLRefurbishmentRate ""^^xsd:double;

:EoLRemanufacturingAluminium ""^^xsd:double;
:EoLRemanufacturingCopper ""^^xsd:double;
:EoLRemanufacturingSteel ""^^xsd:double;
:EoLRemanufacturingBattery ""^^xsd:double;
:EoLRemanufacturingPCB ""^^xsd:double;
:EoLRemanufacturingPlastic ""^^xsd:double;
:EoLRemanufacturingGlasses ""^^xsd:double;
:EoLRemanufacturingOtherMaterials ""^^xsd:double;
:EoLRemanufacturingOtherMetals ""^^xsd:double;

:EoLRecycledCLAluminium ""^^xsd:double;
:EoLRecycledCLCopper ""^^xsd:double;
:EoLRecycledCLSteel ""^^xsd:double;
:EoLRecycledCLBattery ""^^xsd:double;
:EoLRecycledCLGlasses ""^^xsd:double;
:EoLRecycledCLPCB ""^^xsd:double;
:EoLRecycledCLPlastic ""^^xsd:double;
:EoLRecycledCLOtherMetals ""^^xsd:double;
:EoLRecycledCLOtherMaterials ""^^xsd:double;

:EoLRecycledOLAluminium ""^^xsd:double;
:EoLRecycledOLCopper ""^^xsd:double;
:EoLRecycledOLSteel ""^^xsd:double;
```

```
                    :EoLRecycledOLBattery ""^^xsd:double;
                    :EoLRecycledOLGlasses ""^^xsd:double;
                    :EoLRecycledOLPCB ""^^xsd:double;
                    :EoLRecycledOLPlastic ""^^xsd:double;
                    :EoLRecycledOLOtherMetals ""^^xsd:double;
                    :EoLRecycledOLOtherMaterials ""^^xsd:double.


:c762119e-58a4-4e46-8e4a-880cc8aaa18a a prov:Agent;
                     a prov:Organization;
                     dpv:hasRole :Manufacturer;
                     :Email "john.doe@gmail.com"^^xsd:string;
                     :TelephoneNumber "0337899020932"^^xsd:string;
                     :worksFor :HP;
                     :isResponsibleFor :b82f1s0f-f011-441c-989d-1a931257982a.


:HPClientSecurity a :SecuritySoftware.
:TrustedPlatformModule a :SecuritySoftware.
:HPBIOSpehere a :BasicInputOutputChip.
:HPSureStartGen3 a :BasicInputOutputChip.
:IntelHDGraphics620 a :GraphicsCardProcessor.
:WebCam a obo:NCIT_C49858.
:HPPremiumKeyboard a :Keyboard.
:BangOlufsen a :Speakers.
:DDR4 a :Memory.
:SSD a :HardDrive.
:DisplayPort  a :Port.
:DockingStationPort a :Port.
:HDMI a :Slot.
:VGA a :Slot.
:USB-C a :Slot.
:SDCardReader a :Slot.
```

```
:HPLongLife3Cell a obo:NCIT_C49839.

:IntelCorei7 a :CPU.

:IntelCorei77200U a :CPUSeries.

:HPCoolingFan a :Fan.

:HP a prov:Organization;

        :OrganizationWebsite "https://www.hp.com/gb-en/home.html"^^xsd:anyURI.


:c33a11b2-1631-41a7-a2e2-635l6223cc3 a :HardwareComponent;

                                                        a :Display;

            :isComponentOf :f5056b45-3736-44d2-9df5-fed8a334948f;

            :CarbonFootprintManufacturing ""^^xsd:double.


:c23a11b3-1631-41v7-a2e2-6310102ccl35 a :HardwareComponent;

                                                        a :PCB;

            :isComponentOf :f5056b45-3736-44d2-9df5-fed8a334948f;

            :CarbonFootprintManufacturing ""^^xsd:double.


:c23a112w-1131-41d7-a2d2-635065l3c3ld a :HardwareComponent;

                                                        a :Cables;

            :isComponentOf :f5056b45-3736-44d2-9df5-fed8a334948f;

            :CarbonFootprintManufacturing ""^^xsd:double.


:c23a13bw-1631-41s7-a2e2-635l10s3c13c a :HardwareComponent;

                                                                    a :Chassis;

            :isComponentOf :f5056b45-3736-44d2-9df5-fed8a334948f;

            :CarbonFootprintManufacturing ""^^xsd:double.


:c23211bw-2631-4vc7-a2e2-6o206523c2c7 a :HardwareComponent;

            a obo:NCIT_C49839;

            :isComponentOf :f5056b45-3736-44d2-9df5-fed8a334948f;

            :CarbonFootprintManufacturing ""^^xsd:double.


:c21a11bw-1631-41f7-a2d2-6350602sv3c1 a :HardwareComponent;

            a :HardDrive;

            :isComponentOf :f5056b45-3736-44d2-9df5-fed8a334948f;
```

```
:CarbonFootprintManufacturing ""^^xsd:double.

:c22a11bw-1631-p1q5-a2w2-aa506023c31c a :HardwareComponent;
        a :Packaging;
        :isPackagingFor :f5056b45-3736-44d2-9df5-fed8a334948f;
        :CarbonFootprintManufacturing ""^^xsd:double.

:c22a11bw-1621-41c7-a2q2-635dd5p3c31c a :HardwareComponent;
        a :OtherHardwareComponent;
        :isComponentOf :f5056b45-3736-44d2-9df5-fed8a334948f;
        :CarbonFootprintManufacturing ""^^xsd:double.

:f5056b45-3736-44d2-9df5-fed8a334948f :hasIndicator :PurchaseCost;
        :hasIndicator :CurrentCost;
        :hasIndicator :TrueCost;
        :hasIndicator :Circular_Activity_Cost;
        :hasIndicator :Delivery_Time;
        :hasIndicator :ICT_Device_Weight;
        :hasIndicator :MaterialWeight;
        :hasIndicator :Clock_Rate;
        :hasIndicator :Camera_Pixels;
        :hasIndicator :CPU_Load;
        :hasIndicator :CPU_Speed;
        :hasIndicator :Battery_Capacity;
        :hasIndicator :Battery_Lifetime;
        :hasIndicator :Battery_Weight;
        :hasIndicator :Memory;
        :hasIndicator :Screen_Size;
        :hasIndicator :GreenHouseGasCost;
        :hasIndicator
:GreenHouseGasCostProduction;
        :hasIndicator :CarbonFootprintUse;
        :hasIndicator :CarbonFootprintDistribution;
        :hasIndicator :CarbonFootprintEoL;
        :hasIndicator :CarbonFootprintErrorRatio;
```

```
:hasIndicator :CarbonFootprintManufacturing;
:hasIndicator :Warranty_Duration;
:hasIndicator :Energy_Consumption;
:hasIndicator :GreenHouseGasEmissions;
:hasIndicator :MaterialCircularity;
:hasIndicator :UseEnergyDemand;
:hasIndicator :Waste;
:hasIndicator :CollectionRate;
:hasIndicator :EoLRecycledCL;
:hasIndicator :EoLRecycledOL;
:hasIndicator :EoLRemanufacturing.

}
```

2. Query 2- SPARQL Select

SPARQL query to get a DPP of a device (e.g. a laptop):

```
PREFIX : <http://www.semanticweb.org/RePlanIT/>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
select * where {
    ?ICTDeviceID a :Laptop; //replace ?ICTDeviceID with the device ID-> :ksdlqwdqliflq
            :hasBrand ?Brand;
            :Model ?Model;
            :ModelYear ?ModelYear;
            :hasStatus :New;
            :ICTDeviceAge ?DeviceAge;
            :AssemblyNumber ?AssemblyNumber;
            :hasCetrification ?Certification;
            :PurchaseCost ?PurchaseCost;
            :CurrentCost ?CurrentCost;
            :YearOfPurchase ?YearOfPurchase;
            :ScreenSize ?ScreenSize;
            :DisplayResolution ?DisplayResolution;
```

```
            :GraphicsCard ?GraphicsCard;
            :hasGraphicsCardProcessor ?GraphicsCardProcessor;
            :RAMSize ?RAMSize;
            :ROMSize ?ROMSize;
            :hasOperatingSystem ?OperatingSystem;
            :hasSecuritySoftware ?SecuritySoftware;
            :Keyboard ?Keyboard;
            :BatteryCapacity ?BatteryCapacity;
            :Port ?Port;
            :Slot ?Slot;
            :CameraPixels ?CameraPixels;
            :Copper  ?Copper;
            :Aluminium ?Aluminim;
            :Steel ?Steel;
            :Plastic ?Plastic;
            :Glasses ?Glasses;
            :Metals ?OtherMetals.
}
```

3. Example of a DPP (of a RefurbishedLaptop) in a machine-readable RDF format


```
<?xml version="1.0" encoding="UTF-8"?>
<rdf:RDF
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#">


<rdf:Description rdf:about="http://www.semanticweb.org/RePlanIT/872b262c-9d69-4bb2-be09-7fd8c570f95v">
<AluminiumRecycledContent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></AluminiumRecycledContent>
<AluminiumWeight xmlns="http://www.semanticweb.org/RePlanIT/" rdf:datatype="http://www.w3.org/2001/XMLSchema#double">1024.50</AluminiumWeight>
<AssemblyNumber xmlns="http://www.semanticweb.org/RePlanIT/">p2vfafdb-b2b5-4680-a3ab-2512df2kk111</AssemblyNumber>
<BatteryCapacity xmlns="http://www.semanticweb.org/RePlanIT/" rdf:datatype="http://www.w3.org/2001/XMLSchema#double">70</BatteryCapacity>
<BatteryLifetime xmlns="http://www.semanticweb.org/RePlanIT/" rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></BatteryLifetime>
<BatteryRecycledContent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></BatteryRecycledContent>
<BatteryWeight xmlns="http://www.semanticweb.org/RePlanIT/" rdf:datatype="http://www.w3.org/2001/XMLSchema#double">240</BatteryWeight>
```

```xml
<CPULoad xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></CPULoad>

<CPUSpeed xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">3.6</CPUSpeed>

<CameraPixels xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">1080</CameraPixels>

<CarbonFootprintDistribution xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></CarbonFootprintDistribution>

<CarbonFootprintEoL xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></CarbonFootprintEoL>

<CarbonFootprintErrorratio xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></CarbonFootprintErrorratio>

<CarbonFootprintManufacturing xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></CarbonFootprintManufacturing>

<CarbonFootprintSource xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#anyURI"></CarbonFootprintSource>

<CarbonFootprintUse xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></CarbonFootprintUse>

<CarbonFootprint_kg_Distribution xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></CarbonFootprint_kg_Distribution>

<CarbonFootprint_kg_EoL xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></CarbonFootprint_kg_EoL>

<CarbonFootprint_kg_Manufacturing xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></CarbonFootprint_kg_Manufacturing>

<CarbonFootprint_kg_Use xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></CarbonFootprint_kg_Use>

<CircularActivityCost xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">249</CircularActivityCost>

<ClockRate xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></ClockRate>

<CollectionRateValue xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></CollectionRateValue>

<CopperRecycledContent xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></CopperRecycledContent>

<CopperWeight xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">34.50</CopperWeight>

<CurrentCostValue xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">2200</CurrentCostValue>

<DeclarationDate xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#dateTime"></DeclarationDate>

<DeliveryTime xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></DeliveryTime>

<DeviceCarbonFootprint xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></DeviceCarbonFootprint>

<DeviceCarbonFootprintErrorRatio xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></DeviceCarbonFootprintErrorRatio>

<DisplayResolution xmlns="http://www.semanticweb.org/RePlanIT/">3024x1964</DisplayResolution>
```

```
<EPDAvailability xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">false</EPDAvailability>

<EPDDeviceLifetime xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EPDDeviceLifetime>

<EPDDeviceWeight xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EPDDeviceWeight>

<EPDFinalManufacturingLocation
xmlns="http://www.semanticweb.org/RePlanIT/"></EPDFinalManufacturingLocation>

<EPDSource xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#anyURI"></EPDSource>

<EPDUseEnergyDemand xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EPDUseEnergyDemand>

<EPDUseLocation xmlns="http://www.semanticweb.org/RePlanIT/">EU</EPDUseLocation>

<EnergyConsumption xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EnergyConsumption>

<EoLRecycledCLAluminium xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledCLAluminium>

<EoLRecycledCLBattery xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledCLBattery>

<EoLRecycledCLCopper xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledCLCopper>

<EoLRecycledCLGlasses xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledCLGlasses>

<EoLRecycledCLOtherMaterials xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledCLOtherMaterials>

<EoLRecycledCLOtherMetals xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledCLOtherMetals>

<EoLRecycledCLPCB xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledCLPCB>

<EoLRecycledCLPlastic xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledCLPlastic>

<EoLRecycledCLSteel xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledCLSteel>

<EoLRecycledOLAluminium xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledOLAluminium>

<EoLRecycledOLBattery xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledOLBattery>

<EoLRecycledOLCopper xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledOLCopper>

<EoLRecycledOLGlasses xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledOLGlasses>

<EoLRecycledOLOtherMaterials xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledOLOtherMaterials>

<EoLRecycledOLOtherMetals xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledOLOtherMetals>

<EoLRecycledOLPCB xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledOLPCB>
```

```
<EoLRecycledOLPlastic xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledOLPlastic>

<EoLRecycledOLSteel xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRecycledOLSteel>

<EoLRefurbishmentRate xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRefurbishmentRate>

<EoLRemanufacturingAluminium xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRemanufacturingAluminium>

<EoLRemanufacturingBattery xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRemanufacturingBattery>

<EoLRemanufacturingCopper xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRemanufacturingCopper>

<EoLRemanufacturingGlasses xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRemanufacturingGlasses>

<EoLRemanufacturingOtherMaterials xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRemanufacturingOtherMaterials>

<EoLRemanufacturingOtherMetals xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRemanufacturingOtherMetals>

<EoLRemanufacturingPCB xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRemanufacturingPCB>

<EoLRemanufacturingPlastic xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRemanufacturingPlastic>

<EoLRemanufacturingSteel xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></EoLRemanufacturingSteel>

<GHGCostProduction xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></GHGCostProduction>

<GHGCostUse xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></GHGCostUse>

<GlassesRecycledContent xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></GlassesRecycledContent>

<GlassesWeight xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">219</GlassesWeight>

<ICTDeviceWeight xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">1.6</ICTDeviceWeight>

<Image xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#anyURI">https://store.storeimages.cdn-
apple.com/4668/as-images.apple.com/is/mbp14-spacegray-select-
202301?wid=904&amp;hei=840&amp;fmt=jpeg&amp;qlt=90&amp;.v=1671304673229</Image>

<MaintenanceCycles xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">1</MaintenanceCycles>

<MaterialCompositionSource xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#anyURI">https://www.nature.com/articles/s41597-
020-0573-9</MaterialCompositionSource>

<MaterialRecyclability xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean"></MaterialRecyclability>

<Model xmlns="http://www.semanticweb.org/RePlanIT/">MacBook Pro</Model>

<ModelYear xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#integer">2022</ModelYear>
```

```
<OtherMaterialsRecycledContent xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></OtherMaterialsRecycledContent>

<OtherMaterialsWeight xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">10</OtherMaterialsWeight>

<OtherMetalsRecycledContent xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></OtherMetalsRecycledContent>

<OtherMetalsWeight xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></OtherMetalsWeight>

<PCBRecycledContent xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></PCBRecycledContent>

<PCBWeight xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">219</PCBWeight>

<PlasticWeight xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">280</PlasticWeight>

<ProductSpecificationSource xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#anyURI"></ProductSpecificationSource>

<ProductSpecificationSource xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#anyURI">https://www.apple.com/nl/shop/buy-
mac/macbook-pro/14%E2%80%91inch</ProductSpecificationSource>

<PurchaseCostValue xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">2449</PurchaseCostValue>

<RAMSize xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#integer">16</RAMSize>

<ROMSize xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#integer">512</ROMSize>

<RecycledContent xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#integer"></RecycledContent>

<ScreenSize xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">14</ScreenSize>

<SourceHash xmlns="http://www.semanticweb.org/RePlanIT/"></SourceHash>

<SteelRecycledContent xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></SteelRecycledContent>

<SteelWeight xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">154.70</SteelWeight>

<SupportCostValue xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></SupportCostValue>

<Temperature xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></Temperature>

<WarrantyDuration xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double">1</WarrantyDuration>

<Waste xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></Waste>

<hasBrand xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/Apple"/>

<hasCPUSeries xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/M2ProChip10C"/>
```

<hasCertification xmlns="http://www.semanticweb.org/RePlanIT/" rdf:nodeID="genid-a307fb25193844039792a36fd913b3911044155-FB31A443FFEE4566A6E25BFB6DA5AC39"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/CoolingFan"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/CoolingSystem"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/FaceTimeHD"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/HDMIPort"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/LithiumPolymerBattery"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/M2ProChip10C"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/MagSafe"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/MagicBacklitKeyboard"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/MaxxAudio"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/SDXCCardSlot"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/zadedqa0-eazd-4141-853d-fcff2f25kz75v"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/zfeeada0-eafd-4141-q53d-fcff42d5dz7v"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/zfeedsa0-eaff-4141-853d-fcf04f55z1av"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/zfeefad0-eaqd-4141-853d-fcz04fffd37v"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/zfeek7sd-eafd-4141-853d-fc20qq55d3av"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/zkeefds0-eafd-4141-853d-fz2q4f55da7v"/>

<hasComponent xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/zqee2da0-eafd-4141-853d-fcf0azk5d27v"/>

<hasDeclarationType xmlns="http://www.semanticweb.org/RePlanIT/" rdf:nodeID="genid-a307fb25193844039792a36fd913b3911044155-FB31A443FFEE4566A6E25BFB6DA5AC39"/>

<hasGraphicsCardProcessor xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/AppleM210Core"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/BatteryCapacity"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/BatteryLifetime"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/" rdf:resource="http://www.semanticweb.org/RePlanIT/BatteryWeight"/>

```
<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/CPULoad"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/CPUSpeed"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/CameraPixels"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/CarbonFootprintDistribution"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/CarbonFootprintEoL"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/CarbonFootprintErrorRatio"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/CarbonFootprintManufacturing"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/CarbonFootprintUse"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/CircularActivityCost"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/ClockRate"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/CollectionRate"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/CurrentCost"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/DeliveryTime"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/EnergyConsumption"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/EoLRecycledCL"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/EoLRecycledOL"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/EoLRemanufacturing"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/GreenHouseGasCost"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/GreenHouseGasCostProduction"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/GreenHouseGasEmissions"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/ICTDeviceWeight"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/MaterialCircularity"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/MaterialWeight"/>
```

```
<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/Memory"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/PurchaseCost"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/ScreenSize"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/TrueCost"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/UseEnergyDemand"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/WarrantyDuration"/>

<hasIndicator xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/Waste"/>

<hasMemory xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/LPDDR3"/>

<hasOperatingSystem xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/macOS"/>

<hasPackaging xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/zfeedzq0-eafd-4141-8f3d-fcf2ka55d37v"/>

<hasSecuritySoftware xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/macOSSecurity"/>

<hasSensor xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/FingerprintSensor"/>

<hasSensor xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/TouchID"/>

<hasSoftware xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/macOS"/>

<hasSoftware xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/macOSSecurity"/>

<hasStatus xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/Refurbished"/>

<hasSupport xmlns="http://www.semanticweb.org/RePlanIT/"
rdf:resource="http://www.semanticweb.org/RePlanIT/TechnicalSupport"/>

<rdf:type rdf:resource="http://elite.polito.it/ontologies/dogont.owl#Computer"/>

<rdf:type rdf:resource="http://www.semanticweb.org/RePlanIT/ICTDevice"/>

<rdf:type rdf:resource="http://www.semanticweb.org/RePlanIT/Laptop"/>

<topDataProperty xmlns="http://www.w3.org/2002/07/owl#"
rdf:datatype="http://www.w3.org/2001/XMLSchema#double"></topDataProperty>

</rdf:Description>


</rdf:RDF>
```