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MASTER THESIS

A life-cycle assessment method to assess the environmental impacts of cyber-physical systems

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Abstract

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A life-cycle assessment method to assess the environmental impacts of cyber-physical systems

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The increasing environmental footprint of the Information and Communication Technology (ICT) sector necessitates innovative strategies for emission assessment and reduction. Addressing this, the study introduces a novel Life Cycle Assessment (LCA) method tailored for Cyber-Physical Systems (CPS), filling an existing void in environmental evaluation practices.

Adopting Wieringa's design science cycle, the research unfolds through an initial Problem Investigation stage. This phase thoroughly analyses the implicit method from Cortès Cornax, Lago, and Roncancio. This method is formalised using a Process Deliverable Diagram (PDD) in an 'as-is' model to identify limitations and set the groundwork for improvements.

Progressing to the Treatment Design stage makes the shift towards an improved 'to-be' LCA method. A new PDD is designed by collecting requirements derived from the 'as-is' analysis and stakeholder input. This phase also includes the development of an online tool designed for the practical application of the LCA method.

The proposed method quantifies the environmental footprint of CPS. This comprehensive approach distinguishes itself by analysing each CPS component's environmental impact and integrating respective environmental declarations. A standout feature is its consideration of location-specific factors, particularly in electricity production, recognising that environmental impacts vary significantly based on geographical context.

The concluding Treatment Validation stage harnesses expert opinions, sourcing essential feedback on the practicality, importance, and usability of both the proposed method and the tool. The method and tool have been assessed as overall useful, and experts state their intention to use them in practice.

In conclusion, this study signifies a method development in LCA in the ICT domain, enriching the impact measuring methodology landscape. The validation from field experts emphasises the urgency for integrating such innovative, accessible solutions in addressing the environmental challenges in the field of ICT.

Keywords: Cyber Physical Systems, Life Cycle Assessment, Internet of Things, Impact Measurement, Environmental Impact, Method Engineering, Process Deliverable Diagram

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List of Abbreviations

CO2	Carbon Dioxide
CO2e	Carbon Dioxide Equivalent
CPS	Cyber Physical System
EEA	Eco-Efficiency Analysis
EPD	Environmental Product Declaration
ESEA	Ethical, Social, and Environmental Accounting
GHG	Greenhouse Gas
ICT	Internet and Communication Technology
IMM	Impact Measurement Method
IoT	Internet of Things
ISO	International Organization for Standardization
kWh	kilowatt-hour
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCC	Life Cycle Costing
LCSA	Life Cycle Sustainability Assessment
M2M	Machine to Machine
Mt	megatonne
OEF	Organisation Environmental Footprint
O-LCA	Organisational Life Cycle Assessment
PAIA	Product Attribute to Impact Algorithm
PEF	Product Environmental Footprint
PEP	Product Environmental Profile
PDD	Process Deliverable Diagram
PCR	Product Category Rules
SDG	Sustainable Development Goal

SIA Social Impact Assessment

S-LCA Social Life Cycle Assessment

SO-LCA Social Organisational Life Cycle Assessment

UML Unified Modeling Language

Chapter 1

Introduction

A Cyber Physical System (CPS) is a concept that encompasses a close integration of computational and physical resources, resulting in mature systems that link physical devices with advanced computational capabilities (Khaitan and McCalley, 2015; Lee and Seshia, 2017; Rad et al., 2015). The concept led to the creation of sophisticated systems, facilitating a wide range of applications, including smart cities, self-driving cars, telehealth, and smart homes (Singh et al., 2021). CPSs are becoming a critical and important part of our society, and the number of connected devices has been increasingly rising (Arshad et al., 2017; Cisco: San Jose, CA, USA, 2020). Whilst Cisco reported on 6.1 billion Machine to Machine (M2M) connections in 2018, it predicted that by 2023, there would be 14.7 billion . In addition, various scholars are estimating a potential global deployment of up to 200 billion interconnected devices by the year 2030 (Borgia, 2014; Statista, 2022; Strous and Cerf, 2019)

Whereas CPSs and the Internet of Things (IoT) have brought about many benefits to this world, like smart cities and homes, self-driving cars, and healthcare applications (Singh et al., 2021), there are also some concerns; these systems consume energy, contribute to toxic pollution and generate e-waste (Alsamhi et al., 2019; Cortès Cornax, Lago, and Roncancio, 2022; Crowley and Coutaz, 2015). CPS are frequently marketed as eco-friendly and energy-efficient solutions, but often without adequate consideration of their environmental consequences. The rapid growth in this field underscores the urgency of assessing the impact of CPS on the environment (Alsamhi et al., 2019; Cortès Cornax, Lago, and Roncancio, 2022; Pirson and Bol, 2021). According to Pirson and Bol (2021) predictions, the worldwide production of interconnected devices could potentially result in a carbon footprint of over 1000 megatonne (Mt)Carbon Dioxide Equivalent (CO2e)/year by 2027, in a worst-case scenario. These figures highlight the critical need to consider environmental factors (Pirson and Bol, 2021).

1.1 Problem Description

Despite the scarcity of research and development into assessing and minimising the environmental impact of CPS, some scholars have explored how accessing sustainability aspects can be improved. Cortès Cornax, Lago, and Roncancio (2022) presented the short paper: *"Cyber-physical system and Environmental Issues: A Smart Home Case Study"*. The authors' research explores how considering the Life Cycle Assessment (LCA) of CPS can facilitate designers to balance utility, performance, and environmental sustainability. They argued that due to the low cost of components and technology, companies have adopted a "more is better" approach (Freitag et al., 2021; Cortès Cornax, Lago, and Roncancio, 2022).

This approach describes that various companies have progressively implemented more electrical features like sensors and IoT devices into their products. This increase is also represented in the rising number of M2M connections. The authors criticise the development of the "more-is-better" approach adopted by the Internet and Communication Technology (ICT) industry in recent years, contending that it often fails to consider environmental aspects. Cortès Cornax, Lago, and Roncancio (2022) propose an alternative to the 'more-is better" approach, advocating a "good enough" approach. This approach suggests including only the number of devices necessary for the functionality of the CPS and avoiding unnecessary components.

In their paper, the authors present an implicit method that measures the impact of CPS with the help of LCA and the consideration of its data production (Cortès Cornax, Lago, and Roncancio, 2022). In this context, "implicit" refers to the method being incompletely described and requires additional explanation to be fully understood. Additionally, Cortès Cornax, Lago, and Roncancio (2022) raise awareness to prioritise impact assessment when designing CPS.

However, there are limitations to the implicit method they propose. Firstly, the method lacks a structural description from a computer science perspective. Furthermore, there is no modelled representation of the implicit method. The functionalities of the proposed method are also limited. For instance, multiple locations of distributed CPS are not considered when calculating the environmental footprint. Additionally, it does not accurately calculate environmental emissions due to data transfer and storage.

Furthermore, the scope of environmental impact topics lacks diversity and is limited to climate change in Carbon Dioxide (CO2) emissions alone. The implicit method overlooks other factors, such as water consumption and pollution, resource depletion or acidification. Finally, the implicit method is not yet ready to be used by CPS designers, as it lacks a tool for its practical application.

1.2 Research Objective

The main objective of this thesis is to develop and validate a comprehensive LCA method for CPS that considers the environmental impacts of these systems. Based on the limitations of the implicit method developed by Cortès Cornax, Lago, and Roncancio (2022), this thesis aims to improve it.

Additionally, as assessing the environmental impact of products and services is expensive and time-consuming (Hauschild, Rosenbaum, and Olsen, 2018), we focus on exploring how environmental impacts can be assessed cost-effectively.

The research team comprised Paula Lago from Concordia University Montreal, Canada and Mario Cortes-Cornax and Claudia Roncancio, both from Université Grenoble Alpes in France. They are the primary authors of the implicit method. Vijanti Ramautar and Sergio España serve as supervisors from Utrecht University, the Netherlands, and Felix Schöllhammer participates as a Master's student at Utrecht University.

In collaborative meetings, we develop the main deliverables of the research project. The first outcome of the collective work is the as-is method, which can then be seen as an explicit method. This explicit method is modelled in the form of a Process Deliverable Diagram (PDD), which is part of a meta-modelling technique based on Unified Modeling Language (UML) activity and class diagrams

(Weerd and Brinkkemper, 2009). This helps to give an understanding of what the current as-is method is about and to build a basis for its further improvement.

The research team gathers limitations of the as-is and requirements for the to-be method. We refer to the improved and expanded method as the to-be method. Next, we model the to-be method in the form of a PDD to the research aim of initiating it and developing a tool to execute the method efficiently and cost-effectively.

Overall, this thesis aims to contribute by modelling, improving and validating an LCA method for assessing the environmental impact of CPS. In addition, it presents a tool support to aid in the practical execution of the method.

1.3 Research Questions and Outline

To meet the objective of this research, to develop and validate an LCA method for CPS, the following research questions are addressed:

RQ1: *"What is the state of the art in life-cycle assessment in the domain of Internet and Communication Technology?"*
This research question aims to investigate the current status of LCA in the ICT domain. The aim is to understand the existing methods and techniques used to assess the environmental impact of ICT systems. Furthermore, this research question aims to identify the limitations and gaps in the current techniques and provide improvement opportunities.

RQ2: *"How can the environmental impacts of Cyber Physical System be assessed in a cost-effective manner?"*
The purpose of this research question is to develop and propose a practical and cost-effective LCA method for CPS. The aim is to create a situational method that inexperienced CPS engineers, users, and researchers can easily apply. Ensuring cost-effectiveness is crucial, both to facilitate the development of this project and to ensure its affordability and accessibility to potential users.

RQ3: *"What are the benefits and drawbacks of the proposed to-be Life Cycle Assessment method?"*
The final research question aims to validate the performance of the proposed to-be LCA method. This question will investigate the benefits and drawbacks of the method from the perspective of CPS engineers and researchers. The aim is to assess the proposed method's practicality, feasibility, and usability by gathering feedback from experts in the field to validate the method and identify any potential improvements.

The outline of this research is as follows. It consists of two parts; the first is devoted to the theoretical basis to answer **RQ1**, and the second has a practical nature to answer **RQ2** and **RQ3**.

Chapter II delves into the theoretical background of the research, providing all essential concepts and knowledge pivotal for a comprehensive understanding of the research topic. Additionally, this section presents, reviews, and discusses related LCA methods.

Chapter III focuses on pertinent work on the topic of LCA within the ICT sector.

In *Chapter IV*, a detailed overview of the scientific approach adopted for this research is provided, aiming to guide readers through the research process.

Chapter V introduces the practical aspects of this study. Initially, it presents the formalised as-is method, developed in collaboration with the initial authors Cortès Cornax, Lago, and Roncancio (2022). Subsequently, the improved method is showcased as a to-be PDD model, accompanied by the presentation of its tool support. The chapter concludes by elaborating on the validation of the proposed LCA Method and the outcomes of the expert interviews.

Chapter VI is devoted to a thorough discussion of the research undertaken and its broader implications.

Finally, *Chapter VII* encapsulates the findings and contributions of the research.

Chapter 2

Theoretical Background

This chapter serves as a theoretical foundation of the research and delves into the research's pivotal concepts. Beyond the crucial concepts illustrated in the subchapter titles, important definitions are also highlighted in ***bold/italic*** font.

2.1 Cyber-Physical System

Until now, no worldwide acknowledged definition of CPS has been established. Despite that, this section dives into the terminology and attempts to conceptualise it (Boulila, 2019). CPS is a concept that encompasses the integration of computation, communication, and physical processes. CPSs are characterised by the close integration of computational and physical resources, resulting in mature systems that link physical devices with advanced computational capabilities (Khaitan and McCalley, 2015; Lee and Seshia, 2017; Rad et al., 2015). This integration has enabled the creation of sophisticated systems, facilitating a wide range of applications, including smart cities, self-driving cars, telehealth, and smart homes (Singh, Kumar, and Choudhury, 2021). CPSs are similar to the concept of the IoT in that they share a similar architecture, but they can be distinguished. CPSs present a higher level of combination and coordination between physical and computational elements (Rad et al., 2015). The primary objective of CPS is to incorporate computational intelligence into interactions, interactive applications, and real-time control (Mišić and Mišić, 2015). However, IoT refers to a worldwide network infrastructure that connects physical and virtual objects through the use of data acquisition and communication technologies (Mišić and Mišić, 2015).

In summary, while both CPS and IoT involve integrating physical components and digital technologies, CPS systems primarily focus on real-time feedback and control. At the same time, IoT mainly centres on connectivity and communication between devices.

Moreover, Lee and Seshia (2017) distinguish CPSs from traditional general-purpose software, stating that a key distinction is that CPSs prioritise performance over correctness. In CPSs, the rapid execution of tasks is critical for the system's function. In contrast, traditional general-purpose software has different priorities and places a greater emphasis on the accuracy and correctness of its operations (Lee and Seshia, 2017).

2.2 Process Deliverable Diagram

In this research, we employ Process Deliverable Diagrams (PDDs) to articulate and refine our LCA method. We involve modelling the as-is and proposed to-be method using PDDs, facilitating a comprehensive understanding and enabling

enhancements to the implicit method.

This section delves into the modelling technique, encapsulating two intertwined Unified Modeling Language (UML) diagrams: an Activity Diagram and a Class Diagram (Weerd and Brinkkemper, 2009). Figure 2.1 provides an illustrative example of a PDD. PDDs are designed to illustrate situational methods, which can be seen as software that is specifically tailored to the requirements of a particular industry or project (Henderson-Sellers et al., 2014). PDDs help to describe situational methods in a structured manner.

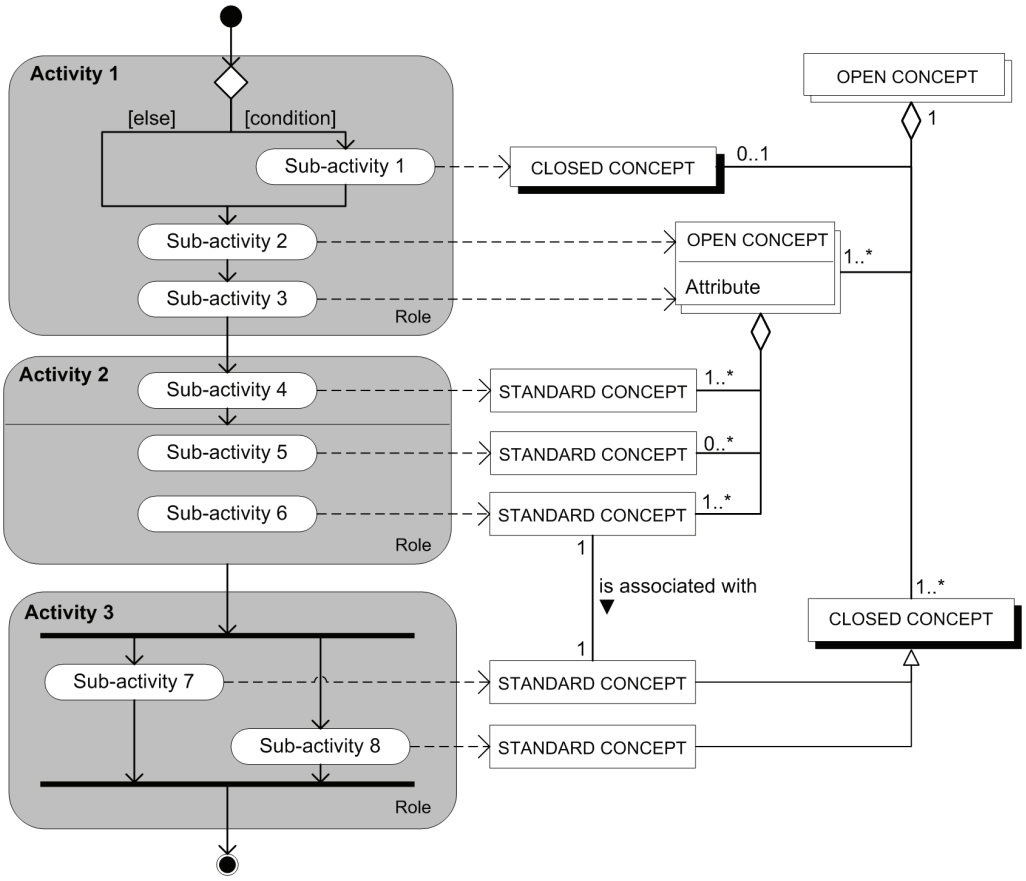


FIGURE 2.1: Example of a PDD from Weerd and Brinkkemper (2009)

The Activity Diagram on the left side of a PDD presents the sequence of activities performed in a represented method. The PDD modelling approach was established by Weerd and Brinkkemper (2009) and has two distinct types of activities in the Activity Diagram: standard and complex. A standard activity lacks sub-activities, whereas a complex activity comprises a collection of sub-activities that can be open or closed. Open activities represent a complex activity with expanded sub-activities, and closed activities represent complex activities with non-expanded sub-activities because they are unknown or irrelevant to the model.

In contrast, the UML Class Diagram on the right side showcases the outcome of the method. It also presents two types of concepts: Standard and complex. Standard concepts do not have sub-concepts. Complex concepts aggregate other concepts and are differentiated into open and closed concepts. Open concepts are constructed from other concepts, while closed concepts are constructed from concepts that are not displayed. All concepts can have assigned properties. We

use open and closed concepts in our research and its PDDs. The relationship between a general concept and a more specific concept is expressed through a generalisation. The association describes the structural relationship between concepts. Multiplicity determines the number of objects of a specific concept that can be connected through an instance of the association. An aggregation represents the relationship between a concept that incorporates other concepts (Weerd and Brinkkemper, 2009).

2.3 Impact Measurement and Life Cycle Assessment

Measuring impact is pivotal to this research, wherein we propose a novel LCA method. This chapter provides foundational knowledge essential for comprehending our approach. We understand impact measurement as identifying future consequences resulting from current or proposed actions, encompassing various methods (Becker, 2001). There are three influential ***Impact Measurement Method (IMM)***, namely ***Social Impact Assessment (SIA)***, ***Ethical, Social, and Environmental Accounting (ESEA)***, and ***Life Cycle Assessment (LCA)*** (Boog, Albrecht, and Kooistra, 2022).

First, SIA is a process of identifying and evaluating the potential positive and negative impacts of a current or proposed action on individuals, organisations, and social systems. This approach is commonly used to assess the potential consequences of policies, programs, projects, or other interventions in areas such as social welfare, environmental protection, or urban planning. For example, when an organisation wants to understand the social impact of a project, including its effects on stakeholders (Becker, 2001; Gârboan, 2006; Vanclay, 2003).

Second, ESEA goes beyond social impact and evaluates an organisation's ethical, social, and environmental performance, such as determining if it is meeting standards for transparency, gender equity, and emissions (Gray, 2006).

Last, LCA focuses on the entire life cycle of a product or service.

A LCA is a rigorous and systematic method for evaluating the impacts of a product, process, or service throughout its life cycle (Finnveden et al., 2009; Hauschild, Rosenbaum, and Olsen, 2018). LCA is occasionally also known as life cycle analysis. It is also called full LCA because it encompasses all stages of the studied subject's life cycle. Due to that, it is also called ***cradle-to-grave*** analysis because of the comprehensive study, which investigates the impacts of an object throughout its entire life cycle, from raw material extraction (cradle) to disposal (grave) (Finnveden et al., 2009; Hauschild, Rosenbaum, and Olsen, 2018; Klöpffer, 2014). In addition to the full LCA, several other variants of LCA analyse specific parts of a subject's life cycle. For example, ***cradle-to-gate*** LCA only looks at the manufacturing process. These deviations from the full LCA are discussed in more detail in the section on *Variants of Life Cycle Assessments*. In this research, when solely using the term LCA, we refer to a full cradle-to-grave LCA.

LCA methods can be broadly categorised into two primary types: Attributional LCA and Consequential LCA. The former, Attributional LCA, focuses on quantifying burdens directly associated with every stage of a product, service, or process over a defined time frame. In contrast, Consequential LCA aims at understanding and predicting the environmental consequences that arise from potential changes or decisions related to a system (Finnveden et al., 2009; Teuteberg, Hempel, and Schebek, 2019). LCA is utilised to identify areas of improvement

and opportunities to reduce environmental impacts. Since the approaches started in the 1960s and 1970s (Guinée et al., 2011), LCA has undergone constant evolution and improvement. It has adapted to new understandings and advancements and incorporates new fields of applications brought by new technology (Guinée et al., 2011; Teuteberg, Hempel, and Schebek, 2019). As regulations, business factors, and public environmental concerns grew, more organisations needed a more strategic and organised approach to environmental challenges (Ralph E Horne, Tim Grant, and Karli Verghese, 2009). Then, in 1996, the International Organization for Standardization (ISO) launched its LCA specification, signalling to organisations that the previously used unconventional environmental management was no longer acceptable (Hauschild, Rosenbaum, and Olsen, 2018).

LCA generally encompasses all stages of the studied subject's life, the extraction of raw materials, production, use, and final disposal. The generic methodology requires considering all major inputs and outputs of the processes with their whole supply chains (Hauschild, Rosenbaum, and Olsen, 2018; Ralph E Horne, Tim Grant, and Karli Verghese, 2009). The analysis can support decision-making and sustainability-oriented product development (Curran, 2006; Hauschild, Rosenbaum, and Olsen, 2018). In fact, LCA is often used because it avoids transferring impacts, meaning that a decrease in impact in one stage of the life cycle will not result in a significant increase in impact in another life cycle stage (Hauschild, Rosenbaum, and Olsen, 2018). Another benefit is that according to ISO, conducting LCAs contributes to the Sustainable Development Goals (SDGs), Responsible Consumption and Production (12), and Climate action (13) (ISO, 2006b; ISO, 2006c).

The ISO has established a set of environmental management standards known as the 14000 series, which includes widely recognised procedures for conducting LCAs. The ISO standards provide the basic principles and guidelines for conducting an LCA study and also form the foundation for the LCA method developed in this research; due to that, the standard is further elaborated on, and the structure of LCA is explained based on this ISO standard framework.

ISO 14040 is considered the foundational standard for conducting an LCA study and is essential for ensuring the credibility and reliability of LCA results.

ISO published two LCA standards:

1. **ISO 14040 (2006E)**: 'Environmental management - Life cycle assessment - Principles and framework'

2. **ISO 14044 (2006E)**: 'Environmental management - Life cycle assessment - Requirements and guidelines.'

ISO 14040 provides the 'principles and framework' of the Standard, while ISO 14044 outlines the 'requirements and guidelines' for conducting LCAs. ISO 14040 is intended for a managerial audience, while ISO 14044 is mainly for practitioners. The ISO 14000 series are not specific LCA methods but rather a set of standards that provide principles, frameworks, requirements, and guidelines for conducting an LCA. These worldwide recognised standards ensure that LCAs are carried out consistently and transparently, allowing for accurate comparisons between studied objects (Finkbeiner et al., 2006). The ISO framework and the steps are presented in *Life Cycle Assessments Framework according to ISO* in section 2.3.2.

2.3.1 Life Cycle Assessment Methods

In this section, different LCA Methods are presented and discussed. Boog, Albrecht, and Kooistra (2022) identified and analysed 13 LCA Methods based on their characteristics by conducting online surveys with LCA experts and a literature review. The presented methods are only LCA methods and, therefore, exclude Life Cycle Impact Assessment (LCIA) methods explicitly.

Eco-Efficiency Analysis (EEA) is a comprehensive method that addresses economic and ecological considerations by evaluating various options throughout a product's or service's life cycle. Initially, it was developed in 1996 by the German chemical company BASF. It uses a weighting scheme to normalise and aggregate six ecological impact categories based on LCA data. These categories include energy consumption, resource consumption, toxicity potential, land use, risk potential and emissions to air, water, and land (Dyckhoff, Quandel, and Waletzke, 2015; Saling et al., 2002; Saling and Uhlman, 2010). The combination of the data enables the determination of the total environmental impact associated with a given product or process while also compiling economic data that includes all the costs incurred during manufacturing or use. The resulting data is then used to generate the Eco-Efficiency comparisons. The Eco-Efficiency Portfolio plots the total ecological impact against the economic data to demonstrate a product or process's overall efficiency. The EEA approach compares services or products but does not provide absolute values (Dyckhoff, Quandel, and Waletzke, 2015; Saling et al., 2002; Saling and Uhlman, 2010).

Eco-Indicator 99 is the successor of Eco-Indicator 95, and it is a weighting method for LCA that was designed for product designers. Unlike the ISO 14044 recommended bottom-up approach, Eco-Indicator 99 applies a top-down approach that calculates eco-scores for products and processes (Goedkoop and Spriensma, 2001). The approach helps designers conduct an environmental evaluation of a product and compare design alternatives based on a single score for total environmental impact. The method helps to resolve two main problems of full LCA: the difficulties when interpreting results and the highly time-consuming process (Goedkoop and Spriensma, 2001; Ministry of Housing, NL, 2000). The score is calculated with predefined material information building blocks for each portion of a certain material. Three steps are required to calculate the Eco-indicator score. The three damage categories (Human Health, Ecosystem Quality and Resources) must be weighed first. Secondly, the damages caused by the flows in all processes that form the life cycle of a product must be calculated. This step follows the standard procedure in LCA and involves inventorying all relevant emissions, resource extractions and land use. Lastly, the weights and damages are combined to determine the Eco-indicator score (Goedkoop and Spriensma, 2001; Ministry of Housing, NL, 2000).

ISO 14040 and 14044 are international standards developed by the International Organization for Standardization (ISO), which guides conducting LCA of products, processes, and services. ISO 14040 provides the general principles and framework for conducting an LCA, and ISO 14044 provides more specific requirements and guidelines for each step of an LCA. Both ISO standards for conducting an LCA employ generalised terminology, allowing for broad applicability across

multiple industries (ISO, 2006b; Moretti et al., 2020; ISO, 2006c). The ISO standards leave many aspects open for the user's decision (Boog, Albrecht, and Kooistra, 2022).

The **ISO 14067 Carbon footprint** standard is the latest added standard to the ISO 14000 series. It offers principles, requirements, tools, and guidelines for quantifying and communicating the carbon footprint of products (ISO, 2018b). This approach quantifies, tracks, and reports Greenhouse Gas (GHG) consistently and transparently throughout the product's life cycle. The carbon footprint is the number of GHGs expressed in CO2e units. The standard includes several principles about coherence, avoiding double counting and fairness. Participation in communication programs like carbon footprint declarations is encouraged (Li et al., 2017; Suer, Traverso, and Ahrenhold, 2021; Wu, Xia, and Wang, 2015). Additionally, it should be acknowledged that measured GHG emissions and reductions in GHG emissions should be treated separately (Wu, Xia, and Wang, 2015).

Life Cycle Sustainability Assessment (LCSA) is an approach that involves evaluating the full range of environmental, social, and economic impacts and benefits associated with the subject of study throughout its life cycle to promote sustainability. Which is achieved by integrating traditional environmental LCA, Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) methodologies. The three pillars of sustainability - economic, social, and environmental impacts - form the foundation of this method (Ciroth et al., 2011; Finkbeiner et al., 2010; Valdivia et al., 2021). The method follows the ISO 14040 and 14044 guidelines and the ISO 26000 Social Responsibility Guidance Standard (Schwartz and Tilling, 2009). LCSA provides a comprehensive view of the potential trade-offs between the three pillars, with transparency and consideration of stakeholder perspectives. The compensation and the explicit communication of trade-offs are key principles of the approach (Ciroth et al., 2011; Finkbeiner et al., 2010; Valdivia et al., 2021).

The **MECO-Method** assesses products' environmental impact throughout their lifecycles. The method analyses environmental impacts based on specific indicators in four areas: Materials, Energy, Chemicals, and Others (MECO). Instead of conducting a detailed inventory and assessing all environmental parameters, the method uses a screening process to identify the most significant environmental impacts. The tool evaluates the agents responsible for environmental problems rather than focusing on specific environmental impact categories (Pommer and Bech, 2000; Volínová, 2011). The assessment is divided into four areas based on the underlying causes of the product's environmental impacts Volínová (2011). The MECO matrix or chart summarises the environmental impacts for each area in every life cycle stage. The method helps to get a better understanding of the environmental impacts of a product and the ability to identify areas where improvements can take place to reduce those impacts (Pommer and Bech, 2000; Volínová, 2011).

The **Organisation Environmental Footprint (OEF)** is a comprehensive, multicriteria assessment of the environmental performance of entities that offer goods and services, viewed from a life cycle perspective. These entities include corporations, public administrative organisations, territories, and other bodies (Pelletier

et al., 2014). The OEF evaluates the environmental performance of an organisation's activities as a whole from the perspective of the entire supply chain, encompassing the extraction of raw materials, use, and final waste management (Pelletier et al., 2014). Whereas other LCA methods focus on single processes or products, the OEF evaluates the environmental performance of an organisation's activities with a life cycle approach to quantify impacts, including material and energy flows, emissions, and waste streams. The method considers the whole supply chain of organisations (Pant and Zampori, 2019; Pelletier et al., 2014).

Organisational Life Cycle Assessment (O-LCA) is a holistic approach to environmental assessment that examines an entire organisation, including its upstream and downstream activities and all relevant aspects. O-LCA aims to identify and quantify the environmental impacts of an organisation's activities and supports environmental performance improvement by providing insight at the level where most decisions are made (Martínez-Blanco, Inaba, and Finkbeiner, 2015). The standard ISO/TS 14072:2014 aims to standardise O-LCA by providing regulations and frameworks (ISO, 2014; Manzardo et al., 2016). O-LCA and its set of rules are similar to traditional product-focused as they also follow a four-phase approach, including goal and scope definition, inventory, impact assessment, and interpretation. However, they differ in the scope of analysis and unit of analysis: the organisation and its portfolio (Martínez-Blanco, Finkbeiner, and Inaba, 2015). The study by Manzardo et al. (2016) showed that certain decisions that improve the environmental performance of one product could harm an organisation's overall environmental performance; therefore, they recommend using both LCA and O-LCA to improve the overall environmental performance.

The **Product Attribute to Impact Algorithm (PAIA)** is a simplified and cost-effective LCA method that estimates the carbon impact of product categories, such as notebooks, LCD monitors, and televisions (Olivetti and Kirchain, 2012). It has a main focus on ICT products. PAIA estimates the carbon impacts of a product's lifecycle by calculating in CO2e, which accounts for all GHGs (MIT, 2019). However, the streamlined LCA does not consider other impact categories, such as land use and water consumption. Additionally, PAIA's results are based on hardware characteristics based on the publication date and often do not include the specifics of production processes. The results of PAIA cannot be used to compare different products with each other (DELL Technologies, 2021). The method's main advantage is its cost-efficient, quick and simple usage (DELL Technologies, 2021).

The **Product Environmental Footprint (PEF)** is an LCA-based methodology designed to assess the environmental impact of services and goods. The method uses established techniques and international standards of the ISO 14040 series to reduce environmental impacts and was developed by the European Commission's Joint Research Centre. The PEF approach provides comprehensive guidelines for modelling the environmental impacts of a product's life cycle, from raw material extraction to the final disposal (Manfredi et al., 2012; Zampori and Pant, 2019). It considers all material and energy flows, emissions, and waste streams. The methodology includes 16 predefined environmental impact categories used in the analysis. Industry stakeholders played an essential role in the method's development, including developing Product Environmental Footprint Category Rules (PEFCRs), which form the basis of this methodology (Zampori and Pant, 2019).

Social Life Cycle Assessment (S-LCA) is an approach that can be employed to evaluate the social and socio-ecological facets of products and services and their current and prospective positive and negative impacts throughout their life cycles. S-LCA focuses explicitly on the social dimension, such as labour, working conditions, human rights and community impacts (Jørgensen et al., 2008; Lehmann et al., 2011; Wang, Hsu, and Hu, 2016). Compared to other LCA methods, the main data input type for S-LCA is subjective, for example, the information given by employees (Benoît et al., 2010). While S-LCA adheres to the ISO 14044 framework, certain aspects can differ, be amplified or condensed at different study stages (Benoît et al., 2010). S-LCA only assesses product utility, not whether to produce a product. Information on social conditions may help but rarely be enough for decision-making (Andrews et al., 2009; Valdivia et al., 2021). Nevertheless, the assessment can support sustainable development and social responsibility. It also promotes dialogue on social and socio-economic aspects of production and consumption, aiming to enhance organisational performance and stakeholder well-being (Andrews et al., 2009; Dreyer, Hauschild, and Schierbeck, 2006; Norris et al., 2020).

An **Environmental Product Declaration (EPD)** is a verified report that quantifies the environmental impact of a study's subject (process, product or service) over its entire life cycle. EPDs are principally designed to support business-to-business interactions. However, they can also serve environmentally-conscious consumers in making informed choices. The EPD methodology is a standardised process for conducting LCA and producing EPD (Allander, 2001; Del Borghi, 2013; Strazza et al., 2010). ISO has classified environmental labels into three typologies—types I, II, and III. For each type, they offer preferential principles and procedures (ISO, 2016; ISO, 2018a; ISO, 2006a). The Product Environmental Profile that we use in this research is an EPD. The chapter *Product Environmental Profile* elaborates on the different types of environmental labelling. The EPD method is a type III environmental declaration that employs quantitative environmental data to assess the life cycle of a product. The method allows comparisons between products that serve a similar function. To be used as a basis for an EPD, there are requirements for how the LCA should be performed, which are developed for different product groups by the industry and are referred to as Product Category Rules (PCR) (Allander, 2001; Del Borghi, 2013; Strazza et al., 2010). An increasing number of environmental labelling can be identified, which is why Manzini et al. (2006) have examined the usefulness of different EPD certifications.

Social Organisational Life Cycle Assessment (SO-LCA) has a growing interest as companies seek to expand the evaluation of the environmental impacts of their products, services, and processes beyond the traditional LCA with a social dimension. The methodologies of S-LCA and O-LCA have emerged to Social Organisational Life Cycle Assessment (SO-LCA) in response to this need (Martínez-Blanco et al., 2015; García-Muiña et al., 2022). SO-LCA is a comprehensive methodology used to assess the social and socioeconomic features and the positive and negative impacts of an organisation's activities (D'Eusanio, Tragnone, and Petti, 2022). The SO-LCA process involves evaluating the entire organisation or a specific segment from a life cycle perspective. Although SO-LCA and S-LCA share similar methodologies, SO-LCA focuses on the organisational approach rather than the product level. The differences between the two methods are unclear (D'Eusanio, Tragnone, and Petti, 2022). SO-LCA provides a structured approach

for organisations to effectively identify and address social and socio-economic issues (García-Muiña et al., 2022; Pant and Zampori, 2019).

2.3.2 Life Cycle Assessments Framework according to ISO

The ISO LCA framework consists of four distinct phases: Goal and Scope definition, conducting a Life Cycle Inventory (LCI), performing a Life Cycle Impact Assessment (LCIA), and Interpretation (Hauschild, Rosenbaum, and Olsen, 2018; ISO, 2006b; ISO, 2006c). Figure 2.2 graphically shows in the form of a PDD the four phases.

The to-be-developed LCA method for CPS is explained in detail in the section *Improvement of the LCA Method* and complies with ISO 14040 and ISO 14044.

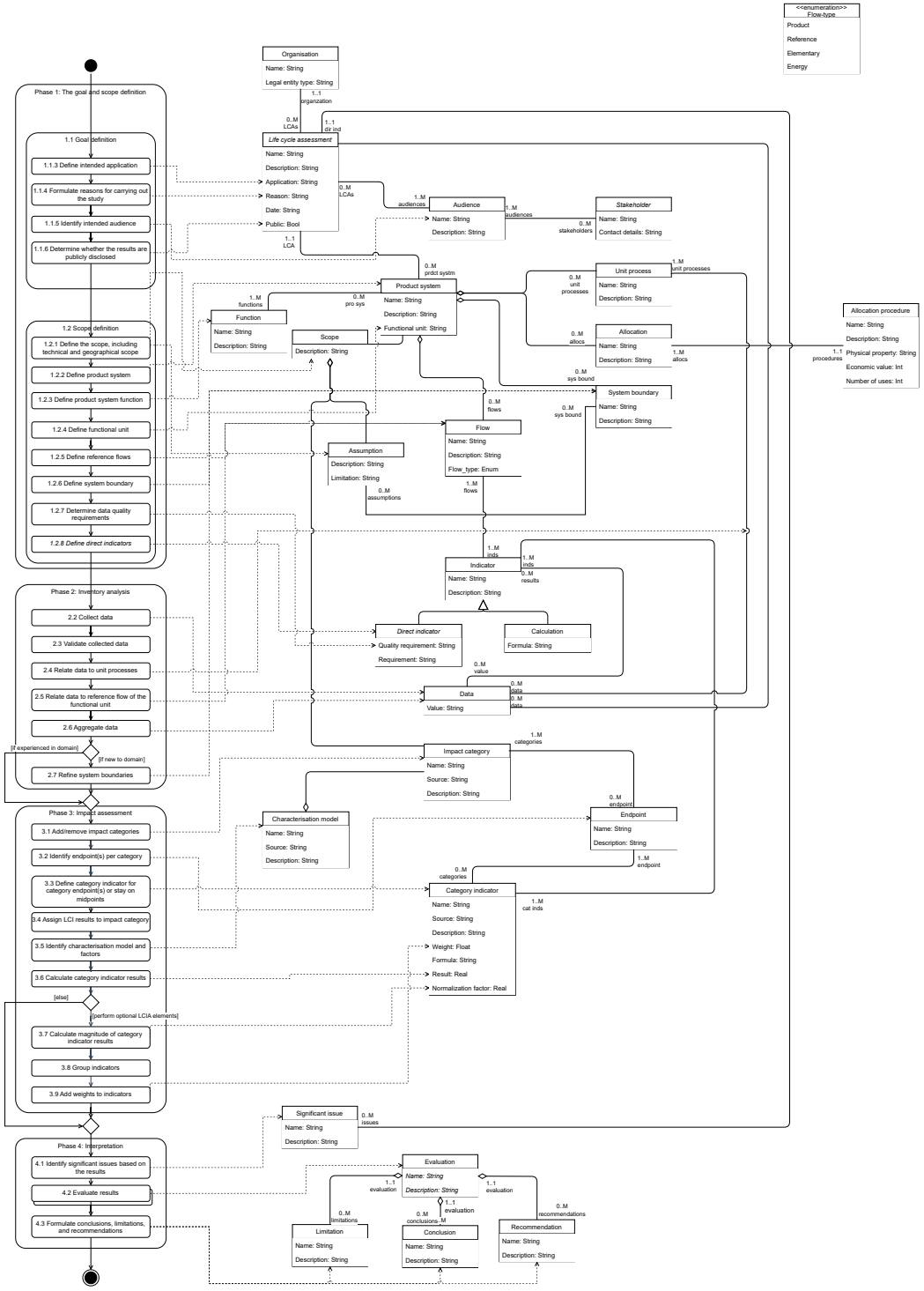


FIGURE 2.2: PDD of ISO14040 and 14044 LCA phases Boog, Albrecht, and Kooistra (2022)

According to ISO 14040 and ISO 14044, an LCA study encompasses the following four summarised phases:

1. Goal and Scope Definition – Clearly defining the goal and scope of the study (including selecting a functional unit)

2. Inventory Analysis – Compiling an inventory of relevant material and energy inputs and environmental emissions (LCI analysis)

3. Impact assessment – Evaluating the potential environmental impacts associated with identified inputs and releases (LCIA)

4. Interpretation – Interpreting the results to help decision-makers make a more informed conclusion

(Andrews et al., 2009; Curran, 2017; Hauschild, Rosenbaum, and Olsen, 2018; ISO, 2006c; Lee and Inaba, 2004).
The following explains the four distinct steps involved in an ISO LCA. Each phase is elaborated upon, including essential concepts and significant tasks.

1. Goal and Scope Definition

This is the first and most crucial step of an LCA, where the level of detail and system boundaries of the assessment are established. This step entails defining the subject that is evaluated, determining the functional unit, and selecting the life cycle stages to be included in the assessment (Hauschild, Rosenbaum, and Olsen, 2018; ISO, 2006c). This step sets the purpose and extent of the study and is its foundation.
The goal definition must specify the following aspects:

- The intended application or use of the study
- The reasons behind conducting the study
- The target audience
- Whether the findings are publicly disclosed for a comparative assertion.

(Curran, 2017; Hauschild, Rosenbaum, and Olsen, 2018; ISO, 2006c)
Defining the study's scope involves outlining the qualitative and quantitative information that are incorporated into the assessment. The following explains the concepts and terms that are relevant to LCA studies:

A **Product system** refers to a set of processes that are essential for carrying out a defined function and are confined within the study's system boundary. It includes all the processes involved in the life cycle of the object of study (ISO, 2006c; Pålsson and Riise, 2011).

The **Functional unit** accurately describes the product or process under examination. ISO refers to it as the "quantified performance of a product system for use as a reference unit" (ISO, 2006b, para. 3.20). The functional unit precisely identifies the study's focus, quantifies the system's service output, establishes a reference for related inputs and outputs, and facilitates the comparison and analysis of alternative goods or services (Grant, 2009; Ralph E Horne, Tim Grant, and Karli Verghese, 2009). A well-defined functional unit is crucial for conducting effective LCAs (Benoît et al., 2010; Curran, 2017).

The **System boundaries** delineate the processes under consideration in a product system analysis and establish the inclusion of any co-products via system expansion or allocation. The system boundary must align with the stated goal of the study (Grant, 2009; Hauschild, Rosenbaum, and Olsen, 2018; ISO, 2006b).

The **Allocation procedure** is a method used to allocate environmental impacts among different products or processes that share the same inputs or outputs. This becomes essential in manufacturing scenarios where multiple products or co-products emerge, often referred to as the multifunctionality of a product system (Curran, 2017; Hauschild, Rosenbaum, and Olsen, 2018; ISO, 2006b). To address the challenges posed by multifunctionality, ISO 14044 provides a hierarchy of solutions.

The **Data quality requirements** refer to the specifications for the type and quality of data that should be included in the LCA study. ISO provides guidelines for documenting the following data quality considerations in the study's scope: temporal coverage, geographical coverage, technological coverage, precision, completeness, and representativeness of the data, consistency and reproducibility of methods used, sources of data, and the uncertainty of information and recognised data gaps (Curran, 2017; ISO, 2006c; Pålsson and Riise, 2011). Practitioners should take all the above into account to ensure the accuracy and reliability of the used data.

The **Assumptions and limitations** refer to any decisions or assumptions made during the study that may impact the final results. Communicating these assumptions and limitations is crucial to avoid misinterpreting the findings (Curran, 2017; Pålsson and Riise, 2011). Additional assumptions and limitations may be necessary throughout the project to achieve the goals, which can be documented as needed.

2. Conducting a Life Cycle Inventory

In this second step, all the inputs and outputs of the studied subject over its entire life cycle are quantified. This includes raw material extraction, production, transportation, use, and disposal of the subject. The Life Cycle Inventory (LCI) data provides a comprehensive view of the environmental impact of the analysed unit to achieve the previously defined goals (Hauschild, Rosenbaum, and Olsen, 2018; ISO, 2006c). In detail, an LCI analysis involves compiling an inventory that documents the flows entering and leaving the product system. This process quantifies material and energy requirements, emissions, and resource use over the product's life cycle.

The creation of the **LCI model** is the main objective of an LCI, which is often a flow model. This flow model represents the inputs and output flows of the technical systems. This model is typically illustrated with a flow diagram that includes various activities within the system boundaries, including the supply chain (Finkbeiner et al., 2006; ISO, 2006c). The more detailed and the more flows are considered in this step, the more accurate and representative the study will be.

ISO 14044 prescribes a set of instructions for documenting an LCI. These instructions comprise preparing for data collection based on the study's goals and scope, collecting data, validating the data, including data from other sources, allocating data, linking data to the unit process and functional unit, and aggregating data (ISO, 2006c). Collecting primary data can be challenging, and the data may be considered copyrighted or confidential by its owner. In such cases, secondary data is an alternative, which can come from sources such as LCA databases, literature, and previous studies (Hauschild, Rosenbaum, and Olsen, 2018). When

using both primary and secondary data, it is essential to document the source, reliability, and geographical information (Curran, 2012). A compiled inventory of elementary flows from all the processes in the studied product system is an LCI output and is usually visually presented in charts and diagrams.

3. Performing a Life Cycle Impact Assessment

The third step, Life Cycle Impact Assessment (LCIA), uses the LCI data to assess the environmental impact and its potential effects on human health, ecosystem quality, and resource depletion. In this phase, impact categories and indicators are set to explain the results of the LCI (Hauschild, Rosenbaum, and Olsen, 2018; ISO, 2006b; ISO, 2006c). Selection, Classification, and Characterisation are the three obligatory tasks of LCIA.

In **Selection**, a study selects multiple environmental impacts relevant to the study's geographical region and encompasses a comprehensive set of environmental issues (Andrews et al., 2009; Curran, 2006; ISO, 2006c). This is often done by choosing an existing LCIA method.

The **Classification** task involves assigning LCI results to the chosen impact categories based on their known environmental effects. Typical impact categories comprise global warming, ozone depletion, acidification, and human toxicity (Hauschild, Rosenbaum, and Olsen, 2018).

Characterisation transforms LCI results and quantifies them within each impact category. This step involves converting all classified flows for an impact into common units that allow comparison. One common unit to quantify global warming potential is CO2e (Andrews et al., 2009; Curran, 2006; ISO, 2006c). In conducting an LCIA, each impact category is assigned an indicator representing an environmental concern, such as CO2e for global warming (Hauschild, Rosenbaum, and Olsen, 2018; ISO, 2006c). However, the units used for different impact categories vary, making it difficult to compare their relative magnitudes. Additionally, the ISO standards offer the option to incorporate two optional steps, **normalisation** and **weighting**.

The main task of **Normalisation** entails comparing the outcomes to a certain benchmark, such as the averages of an industrial sector or a country. The standardised units make it easier to compare the outcomes (Lee and Inaba, 2004).

The objective of **Weighting** is to establish the relative importance of each impact category, enabling the aggregation of impact scores into a singular indicator for comparative purposes (Curran, 2006; ISO, 2006c). This step is seen as subjective; therefore, ISO recommends not to use weighting (Finkbeiner et al., 2006; Hauschild, Rosenbaum, and Olsen, 2018).

4. Interpretation of Results

In the final step, the results of the LCA are evaluated and interpreted to determine the environmental impact of the studied subject overall. The interpretation phase summarises the inventory analysis and impact assessment results to draw conclusions and provide recommendations.

The initial step involves identifying significant issues encountered during the study, which usually have the greatest impact on the environmental performance of the product system (Curran, 2006; Hauschild, Rosenbaum, and Olsen, 2018). Another task is a sensitivity check to identify the critical processes and elementary flows that contribute the most to the overall impacts. The aim is to pinpoint areas where data quality can be improved or identify uncertainties that may be reported as study limitations (Hauschild, Rosenbaum, and Olsen, 2018; Lee and Inaba, 2004). The final step involves drawing conclusions and making recommendations based on the findings from the earlier phases.

2.3.3 Variants of Life Cycle Assessments

The described LCAs are full LCAs and take the whole life cycle into account. When conducting a full LCA, a comprehensive approach aims to encompass all the requisite processes necessary to provide the desired function, from upstream activities, such as the extraction and production of raw materials and manufacturing, to downstream activities, such as disposal (Dreyer, Hauschild, and Schierbeck, 2006; Hauschild, Rosenbaum, and Olsen, 2018). There are also alternative variants that only consider parts of the studied object's life cycle. A "cradle-to-gate" study is an example of a study that does not adopt a full life cycle perspective as the system boundary terminates at the factory gate where the product under study is manufactured (Hauschild, Rosenbaum, and Olsen, 2018; Singlitico, Goggins, and Monaghan, 2019). A gate-to-gate analysis is a partial LCA that focuses solely on a single value-added stage in the entire manufacturing process (Jiménez-González, Kim, and Overcash, 2000). In the "cradle-to-cradle" assessment, the final stage involves recycling the product, unlike the cradle-to-grave method, where the product's end-of-life is seen as the endpoint. Rather, in the cradle-to-cradle approach, the end of a product's life cycle marks the beginning of a new one (Ijassi, Rejeb, and Zwolinski, 2021; Toxopeus, de Koeijer, and Meij, 2015).

2.4 Product Environmental Profile

Despite the growing awareness and concern over the environmental impact of devices, obtaining trustworthy information for consumers remains challenging. This is mainly due to manufacturers' lack of transparency and the scarcity of standardised information that enables consumers to make accurate comparisons. However, there is a solution to this problem - the Product Environmental Profile (PEP). A PEP is a comprehensive report that provides stakeholders with information on the environmental impact of a product over its entire life cycle and guides stakeholders to make informed decisions about the environmental impact of a product based on objective data. This specific declaration is made for products in the electric, electronic, and HVAC-R (Heating, Ventilation, Air Conditioning and Refrigerating) categories (PEP Association, 2023a).

The PEP eco passport program presents transparent and rigorous procedures which allow companies to register a PEP to provide reliable data that comply with ISO standards. All PEPs undergo a validation process that the PEP Association obtains. LCAs must adhere to PEP's own PCR, designed by an external panel of recognised LCA experts (CSTB, Bureau Veritas, PWC, French Energy Agency ADEME) and to the editorial policies.

The PEP is a EPD, which is introduced in the previous section on *Life Cycle Assessment Methods*. The PEP represents an environmental labelling technique, and ISO defines the following three types of environmental labels:

Type I environmental labelling — Principles and procedures
— ISO 14024:2018 — Environmental labels and declarations

Type II environmental labelling — Environmental labels and declarations
— ISO 14021:2016 — Self-declared environmental claims

Type III environmental declarations — Principles and procedures
— ISO 14025:2006 — Environmental labels and declarations

Type I environmental labelling certifies products that meet predetermined environmental requirements. Public or private organisations can run these voluntary programs at national, regional, or international levels. The label indicates that the product is environmentally preferable within its category (ISO, 2018a).

Type II environmental labelling standards aim to ensure that all relevant aspects of a product's life cycle are considered when making environmental claims. Anyone involved in the product's distribution chain can make these self-declared environmental claims which can take various forms. Verification is necessary to ensure reliability, and the evaluation methodology should be transparent, scientifically sound, and well-documented to prevent negative market effects and unfair competition. This assures potential purchasers of the validity of the claims (ISO, 2016).

Finally, **Type III environmental declarations** provide quantified environmental information on a product's life cycle for comparison with similar products. They are based on independently verified data and developed using predetermined parameters. These declarations are intended for business-to-business communication but can also be used for business-to-consumer communication (ISO, 2006a).

The PEP adheres to the recognised ISO 14025 standard and is classified as a type III environmental declaration. This ensures that it can effectively compare similar products and is based on reliable quantified data obtained through LCA. The PEP eco passport program is part of the French PEP association, which certifies the created PEPs. The PEP association is open to various stakeholders, like institutions, industry, users and professional associations. All certified PEPs are publicly available on the PEP eco passport website, which maintains a comprehensive declarations database. As of October 2023, the database listed 2549 products (PEP Association, 2023b), making it a valuable resource for companies, researchers, and consumers to obtain environmental information about various products. Due to the reliability, consistent setup and high quantity of existing PEPs, this research leans on the PEP to get environmental information about CPS components. Moreover, the centre of this study, which is the improvement of the LCA method proposed by Cortès Cornax, Lago, and Roncancio (2022), relies on the data provided by the PEP association to evaluate the environmental impact of CPS.

2.5 Carbon Intensity of Electricity Production

Carbon intensity refers to the amount of CO2 emissions produced per unit of something. Therefore, carbon intensity of electricity production refers to the amount of CO2 emissions produced per unit of energy generated. It is a crucial metric in understanding the environmental impact of a nation's electricity production.

While the electricity mix (also termed the power generation mix) focuses solely on the sources used for electricity generation, it is distinct from the energy mix. The latter encapsulates all primary energy sources a region utilises, from electricity to heating and transportation. Both include fossil fuels, nuclear, and renewable sources (Ritchie, Roser, and Rosado, 2022). In essence, the electricity mix is a subset of the broader energy mix (Ritchie, Roser, and Rosado, 2022; TotalEnergies, 2023).

Regions dominated by coal-fired power plants usually have higher CO2 emission rates per kilowatt-hour (kWh). Conversely, areas incorporating a significant proportion of renewable sources like wind and solar tend to have lower carbon intensities. Figure 2.3 shows a simplified representation of the carbon intensity of energy production (Electricitymaps, 2023).

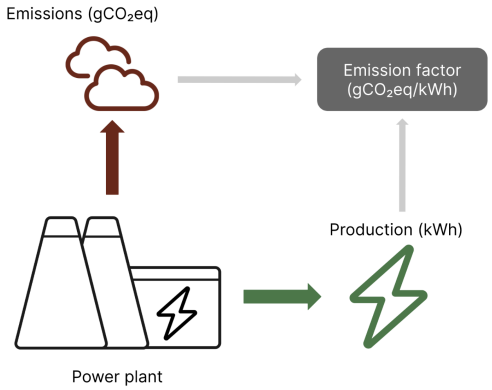


FIGURE 2.3: Schematic representation of emission factors (Electricitymaps, 2023)

As components of a CPS consume electricity, the carbon footprint of a CPS is intrinsically linked to the electricity mix of the location where its components operate. Thus, the CO2 footprint of a CPS is influenced not just by its design and operations but also by the electricity mix of its geographical location.

Numerous institutions, including Our World in Data, Ember, and Electricitymaps, aim to calculate and communicate carbon intensities for electricity generation. Such institutions offer insights into the carbon intensities of electricity production. For a robust understanding of GHG emissions associated with different energy sources, Electricitymaps and Ember rely on the data of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. This report provides information on GHG emissions for selected energy supply technologies such as coal, gas, wind and solar (Schlömer et al., 2014). Furthermore, these institutions employ an LCA approach, which comprehensively evaluates emissions over the entire life cycle of power plants. There are many prominent ways of showcasing the electricity mix of different countries. One way is in the form of an electricity map.

It visually depicts the electricity grid, illustrating information about the energy sources and the resulting GHG of specific areas, typically measured in CO2e. These emissions indicate the GHGs released due to electricity production, enabling comparisons of different GHGs based on their global warming potential relative to CO2 (Krey et al., 2014). The data from Our World in Data, Ember, and Electricitymaps is critical to our research project, as calculations in the proposed method rely on this data.

This concludes the chapter *Theoretical Background*, which offers the foundation pertinent to the study. Central to this chapter is the examination of CPS, the main object of this research. Additionally, PDDs are explained. The section also offers the needed knowledge of LCA and its variants. With this foundational context established, the subsequent chapter, *Related Work*, contextualises these theoretical backgrounds within the broader scientific discourse.

Chapter 3

Related Work

Multiple researchers have already carried out literature reviews examining the environmental impacts of ICT. Verdecchia et al. (2017) reviewed studies to differentiate the environmental effects of ICT. The role of ICT and carbon emissions is two-folded: it is considered a significant contributor to CO2 emissions due to its increasing carbon footprint, but it also has the potential to reduce carbon emissions.

By applying their framework to four use cases, Pirson and Bol (2021) conducted research estimated that the worldwide carbon footprint of IoT edge devices over ten years ranges from 22 to 562 Mt CO2e/year in 2027, depending on scenarios. However, the worst-case scenario would exceed 1000 Mt CO2e/year. The study highlights the importance of environmental considerations.

The publication by Malmodin and Bergmark (2015) explores the potential of ICT to reduce GHG emissions through different ICT solutions, including smart building, smart agriculture, and smart travel. The results, depending on the scenario, indicate a GHG reduction potential of about 4-10 Gtonnes CO2e, which is 6-15% of global emissions in the year 2030.

A publication by Ballarino et al. (2017) on the topic of CPS for environmental sustainability identifies prerequisites for using CPS systems to aid in LCAs. Their research delved into the potential of CPS in promoting environmental sustainability and suggested a framework to facilitate this process. Specifically, they look at energy management in the steel sector and research how using CPS can reduce the negative environmental impacts.

Moreover, the topic of e-waste is vital when considering the environmental impacts of ICT. CPS hardware commonly contains metals like silver, copper, and aluminium, along with non-metals such as plastics and rubber (Forti et al., 2020). Semimetals, including silicon, are used in microchips, while tin, graphite, and alkaline are used in semiconductors (Yeap, 2013).

The work of Modarress Fathi, Ansari, and Ansari (2022) examines the impact of IoT devices on the volume of e-waste, which contains toxic substances and negatively impacts environmental sustainability. The paper offers actionable recommendations for developers, policymakers, and users of electronic devices to address the escalating size of e-waste and its threat to environmental sustainability. The Global E-waste Monitor 2020 aims to educate the public about the global e-waste problem, its relationship with international efforts to achieve the SDGs, and strategies for creating circular economies and sustainable societies. It reports that the global e-waste in 2019 was 53.6 Mt, with only 17.4% being declared as properly recycled. Although the recycling rate increased by 1.8 Mt since 2014, the total e-waste generation grew by 9.2 Mt, highlighting the lack of progress in recycling activities to keep up with the global e-waste growth (Forti et al., 2020).

Bieser and Hilty (2018) give structure to the topic of environmental impacts of ICT and define three categories: The first category is the direct life cycle impacts that result from the production, use, and end-of-life of ICT products, which negatively affect the environment. The second category is the indirect enabling impacts, which occur when ICT is used to optimise or substitute activities, resulting in both negative and positive environmental impacts. The third and last category is the indirect structural impacts, which affect the macroeconomic level and can lead to increased dependency on critical infrastructure and long-term rebound effects, such as the increase in overall electricity demand regardless of efficiency improvements.

Moreau et al. (2021) call for a shift in the mindset of ICT actors towards human-centred design to address social inequalities and environmental exploitation. The publication stresses that using ICT to optimise the existing techno-economic systems to overcome major environmental and social challenges is insufficient. However, only different approaches, including the circular economy (Stahel, 2016) or the open-source appropriate technology movement (Pearce, 2012), can help.

To conclude, in the *Related Work* chapter, we reviewed existing literature on the environmental impacts of ICT, including studies examining carbon emissions, the potential of ICT to reduce GHG emissions, and the issue of e-waste. We also explored three categories defining the impacts of ICT: direct life cycle impacts, indirect enabling impacts, and indirect structural impacts. Transitioning to the next chapter, *Research Design and Method*, we leverage this knowledge to conduct our investigation into LCA for CPS.

Chapter 4

Research Design and Method

The following section of the study provides a comprehensive overview of the methodology used in this research. The research addresses a design problem where the right solution for assessing the environmental impacts of CPS is yet to be defined. To address the objectives and research questions from Chapter I, we adopt the design science framework by Wieringa (2014). We have chosen this approach because Wieringa's method provides a clear and systematic way to tackle complex design problems. The framework involves iterative processes of designing and investigating. It splits the design task into three distinct tasks: problem investigation, treatment design, and treatment validation. These tasks collectively form the design cycle, part of the broader engineering cycle.

We value the design cycle of Wieringa (2014) as important and do not intend to apply the whole engineering cycle. This research follows the phases: Treatment investigation, treatment design, and validation. Figure 4.1 presents the study process overview, illustrating the relevant research design phases from the design cycle and their respective deliverables and primary tasks, which are elaborated on for the context of this research in the following sections.

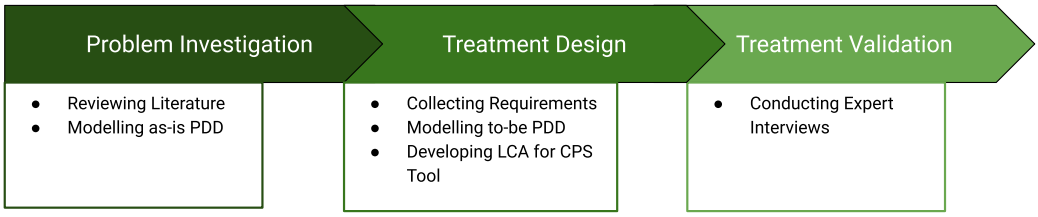


FIGURE 4.1: Research Phases with their main tasks

4.1 Problem Investigation

According to Wieringa (2014), the initial stage of the engineering process is the problem investigation phase, which involves two primary tasks: exploring the goals and stakeholders and constructing a conceptual problem framework. The problem in the context of the thesis is a need to assess the environmental impacts of CPS. The literature and research discussed extensively in the *Theoretical Background* and *Related Work* chapters form an integral part of the problem investigation phase. Central to that phase is also the formalisation and improvement of an LCA method proposed by Cortès Cornax, Lago, and Roncancio (2022) to assess the environmental impacts of CPS. An as-is method model is created to understand and identify the limitations of the implicit method. The formalised implicit method is detailed in *Formalisation of the implicit LCA Method*, *section* 5.1.

As-Is Method Model

The as-is method is the first outcome of this research, which is developed through the following steps. First, we create a PDD in collaboration with the authors of the implicit method, Paula Lago, Mario Cortes-Cornax and Claudia Roncancio. This is facilitated by conducting meetings online and in person. In sequences and multiple rounds of adjustment, the model is designed, improved, and refined until it adequately represents the current version of the initial method. UML object models are created during this process to help identify the as-is method. By fulfilling this step, the implicit method is structured. The PDD model represents the as-is method and can be seen as explicit and methodised from this step onwards. Additionally, associated with the model, the concept and activity table explain the steps of the PDD model in detail. The as-is PDD serves as the starting point to identify its limitations. We gather the limitations in shared sheets. Additionally, in the subsequent steps, the as-is method is utilised to identify requirements for the to-be method. The method has several stakeholders like designers of CPS, LCA experts and researchers, CPS manufacturers, and end users of CPS that would like to assess the environmental impact of their systems.

4.2 Treatment Design

Wieringa (2014) defined treatment as an artefact interacting with a problem context. The treatment design phase encompasses the treatment's application to the problem context, which involves defining problem requirements and context assumptions and designing appropriate treatments. In the present study, developing an improved method to calculate the environmental impacts of CPS is considered a treatment for the previously investigated problem. The treatment design consists of the engineering of the to-be method and the collection of requirements for it. The results of that phase are outlined in *Improvement of the LCA Method*, *section 5.2*.

To-Be Method Model

The next step involves engineering a to-be method modelled as a PDD, which is built on the preliminary findings of this research. We refer to the improved and expanded method as the to-be method and its PDD as the to-be model. The method is an improved and expanded version of the as-is method. The research team collaborates to gather indicators and formulas for calculating environmental footprints and establish requirements for the to-be method. We take the before-established limitations into account for developing the requirements. In addition to the ISO 14000 standards, requirements also originate from other LCA methods outlined in the *Theoretical Background* section.

All requirements are formulated in user stories and epics and stored in a shared sheet. Epics and user stories are terms used in agile software development to describe two different levels of requirements. User stories are lightweight requirements phrased in a way that focuses on the end user and the desired outcome. Epics are a larger collection of user stories of the same topic (Lucassen et al., 2016). The collection of requirements has accompanying information about each user story and epic, including description, status, prioritisation, source category, creation date, and requirement status. Prioritisation provides information about the importance of a user story to make decisions about its implementation. Source

category indicates whether the user story originated from the research team or literature. Requirement status specifies whether a user's input is mandatory or optional, and the status indicates the status and whether a user story is implemented in the PDD model or tool. Each epic and user story has a unique ID. We model the user stories sequentially, and increments are reviewed and verified with the research team during collaborative meetings.

Additionally, we implement the developed-to-be method, which entails the development of the tool support to enable the execution of the to-be method. With this, the before-created user stories give guidance. We are opting for Google Sheets, which offers a user-friendly interface familiar to many users, while the integrated JavaScript functions extend the capabilities beyond conventional spreadsheet functionalities. Additionally, we selected Google Sheets as the platform of choice due to its cost-effectiveness, efficiency in development time, and uncomplicated online access.

We use an agile development approach by doing multiple sequential phases through the design science cycle. Each round addresses a number of requirements. One approximate cycle takes two weeks (Wieringa, 2014). The two obtained PDDs can be analysed to understand how the developed method grew (Weerd and Brinkkemper, 2009). The evolution from the as-is to the to-be model is seen as improvements and extensions of the initial method.

4.3 Treatment Validation

According to Wieringa (2014), it is crucial to differentiate validation from evaluation. The goal of validation is to predict how an artefact will interact with its context without a necessary implementation. This experimental research uses methods such as modelling, simulation, and testing. However, evaluation research investigates how implemented artefacts interact with their real-world context after implementation using field research methods such as statistical surveys and observational case studies (Wieringa, 2014). This treatment validation is the last step of the research approach and is presented in *Validation of the improved LCA Method*, *section 5.4*. We validate and discuss the developed to-be method and its tool with experts in the field. By doing so, we assess the method's usefulness. We have chosen expert interviews due to their ability to delve in-depth into the insights, views, and opinions of the interviewees. Furthermore, interviews offer the advantage of immediate responses to questions and the flexibility to adapt in real-time, ensuring that the interviewee fully grasps the method and its associated tool.

4.3.1 Interviews

We create a predefined interview protocol before conducting the interviews to facilitate the interview process. Literature by Castillo-Montoya (2016) helps design the interview protocol. During the interviews, this protocol serves as a framework, helping us keep order and minimising the risk of omitting essential elements. The interviews are conducted in a semi-structured manner, wherein the protocol is consistently applied to all participants. The interview protocol can be found in *Appendix A*. Microsoft Teams serves as the platform for conducting the video calls for the interviews. We record each interview with Microsoft Teams'

recording functionality and using its built-in live transcription program. We improved this automated transcription in a clear, verbatim style to enhance accuracy and clarity. Five interviews are held in English, and three in German. Once transcribed, the interviews undergo qualitative thematic analysis using NVivo, a software commonly used to systematically organise and categorise textual documents (Lumivero, 2023). This tool facilitates identifying and labelling concepts found in the interviews, enhancing analysis and interpretation. The identification of themes is approached deductively, through prior literature, and inductively by familiarising oneself with the transcript data. Text segments deemed relevant and informative to the research question receive appropriate codes. Quoted sections from German transcriptions are translated into English to ensure consistency and clarity. In the concluding phase of analysis, identified factors, including strengths, weaknesses, and potential improvements of the proposed LCA method, are systematically grouped under their respective themes.

Within the NVivo, 13 top-level codes are delineated, with each subcodes. The codes align with the topics from the interview guide's questions. Notably, while many codes are defined based on the interview guide questions, some emerge organically during the analysis of the interview transcripts. In total, the qualitative analysis includes 175 codes. The top-level codes derived from the interview guide are structured as follows:

1. Demographics of respondents
2. Weaknesses of the tool
3. Strengths of the tool
4. Usefulness of features
    - Usefulness of PEP extraction
    - General usefulness
    - Usefulness configurations
    - Usefulness visualisation
    - Usefulness of data calculation and its impact
5. Intention to use the tool
6. Important impact indicator
7. Influence of decision-making
8. General consideration of environmental impacts

During further analysis of the transcripts, the subsequent top-level codes are identified:

9. Tradeoffs
10. Limitations of the tool
11. Improvements of the tool
12. Important topics of Interviewees
13. Trust in tool and research

In conclusion, the *Research Design and Method* chapter outlines the research's approach, which is structured into problem investigation, treatment design, and treatment validation. The next chapter, *Results*, presents our outcomes using the structure explained.

Chapter 5

Results

In this chapter, we unveil our novel LCA method, showcased through PDDs, and introduce a dedicated tool for its practical implementation. Furthermore, we delve into validating the proposed method and assessing its effectiveness.

5.1 Formalisation of the implicit LCA Method

The following section presents the outcomes derived from this study's first problem investigation phase. The primary attention is on the as-is PDD of the initial method.

5.1.1 As-is Process Deliverable Diagram

The subsequent section presents the as-is-method PDD of the LCA for CPS method. This PDD outlines the method outlined in the work of Cortès Cornax, Lago, and Roncancio (2022). The as-is method is collaboratively developed through a series of online meetings and shared documents with the initial method developers and modelled as a PDD. Figure 5.1 depicts the PDD model of the as-is method. The as-is method contains five activities, with each multiple sub-activities and 13 concepts. The following briefly explains the main activities and deliverables of the method:

The first activity involves specifying the CPS under examination (activity A-AI 1 in Figure 5.1). The CPS has a name and a description and is aggregated of multiple configurations, each containing several components. Within this research context, a component is recognised as an individual device within the CPS, responsible for functions such as sensing, storing or processing data. The step Specify Component Type elaborates on the type of components the CPS encompasses. A component type summarises multiple components of the same kind with the same device specifications.

Secondly, the analyst needs to identify the configurations that the CPS can be comprised of (A-AI 2). Within this context, a configuration is a combination of components that together build a CPS. This activity characterises configurations and counts of components within each configuration. Subsequently, the availability of environmental declarations, specifically in the form of a PEP for the components in the configuration, is checked. From the PEP, environmental information about each component type can be derived. The environmental metrics are extracted from the PEP. This step is processed iteratively until all configurations are defined.

The third activity centres on calculating and analysing the CO2 footprint of the CPS configurations (A-AI 3). Initially, the geographical region of the CPS is determined. Subsequently, the electricity mix of the previously specified region

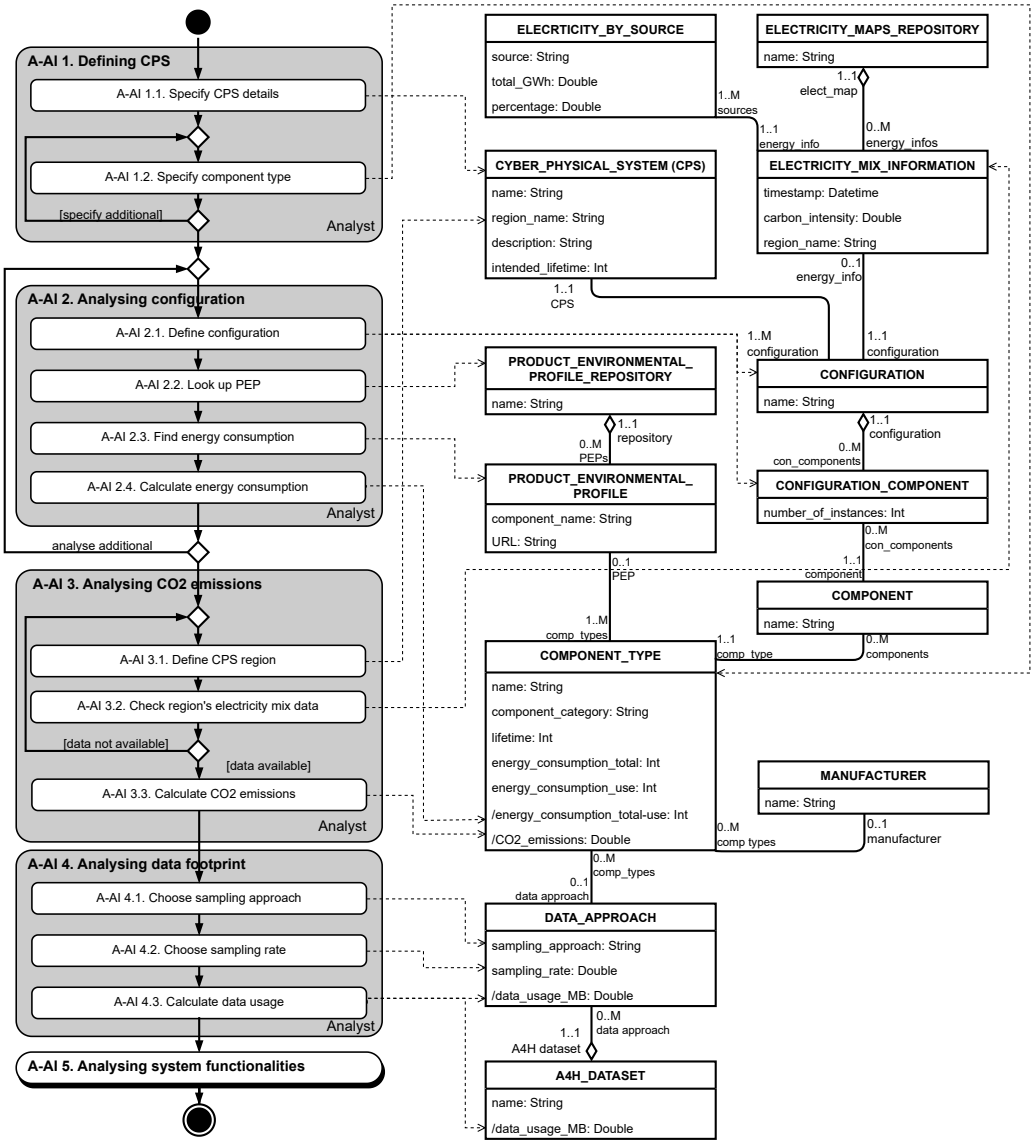


FIGURE 5.1: PDD of LCA for CPS as-is method

is obtained. This electricity mix data is retrieved from the electricity maps repository, an online accessible interactive map providing carbon intensity metrics for various countries and regions. In instances where the electricity mix information for a region is unavailable, a new region has to be defined. Conclusively, the CO2 emissions corresponding to each configuration are quantified. Fourthly, the analyst focuses on analysing and computing the data-related impact of the CPS configurations (A-AI 4). Should a component sample data, the suitable sampling approach and sampling rate are defined and results in the data_approach concept. Subsequently, the data volume is calculated. The data-related information is derived from the A4H dataset (French Research Agency, 2023).

The fifth activity is initiated to raise awareness of the significance of analysing system functionalities (A-AI 5). However, this activity remains undescribed and lacks a systematic analysis approach. Consequently, it is modelled as a closed activity whose activities are not expanded since they are unknown or irrelevant in the given context.

Appendix B presents the tables detailing the activities and concepts of the as-is model associated with the PDD, illustrated in Figure 5.1.

5.2 Improvement of the LCA Method

The subsequent section delineates the results obtained from the Treatment design phase of this study. It introduces the requirements for the to-be method, ascertained collectively by the research team and retrieved from academic literature. This is followed by exploring the to-be method, with a comparison that highlights the modifications made to the as-is method. A PDD represents the to-be method. Conclusively, the supporting tool developed for the to-be method and its specific features are elaborated.

5.2.1 Requirements and Method Comparison

We expand on the as-is method and establish detailed requirements using user stories and epics to mitigate the method's limitations. Each requirement has the following attributes:

- **ID:** A unique identifier for each requirement.
- **Description:** A short statement describing each requirement.
- **Explanation:** A more detailed explanation of the requirement, sometimes accompanied by examples.
- **Type:** Specifies whether a requirement is an epic or a user story.
- **Idea Status:** Indicates the status of the requirement idea (Brainstormed, Discussed, Agreed, Rejected)
- **Prioritisation:** Ranks the requirement's importance on a scale from 1-5, with 1 being the least important and 5 being the most important.
- **Implementation status:** Indicates the current state of the implementation of the requirements in the tool (backlogged, under implementation, partially implemented, implemented, validated).

- **Source category:** Distinguishes whether the research team proposed the requirement or if it originates from literature.
- **Link:** Provides references to sources like websites or literature related to the requirement.
- **Date:** States the date when the requirement was created.
- **Comments:** Captures any additional remarks, like questions or issues to the requirement.

The team continuously reviews user stories to ensure they align with development. These requirements are designed for the upcoming to-be method, focusing on its design, the PDD representation, and its support tools. In total, 19 epics and 48 user stories are formulated. An extensive list of all requirements is presented in *Appendix D*. Due to the comprehensive nature of the requirements, Table 5.1 offers a sample from the extensive requirements list. Within it, four important epics are presented for illustrating purposes.

ID	Description	Explanation	Type
2	to specify different locations/ regions within a CPS	The method/tool should be able to track/ specify different locations/ regions of components of a CPS.	Epic
4	to analyse other environmental impact factors	The method should be able to also analyse other environmental impacts next to the CO2 footprint.	Epic
16	to be able to calculate the data footprint of CPS	The method should help calculate the data volume that a CPS generates and also calculate the data-related environmental impacts.	Epic
17	to be able to automatically fetch data from online data sources	The method /tool should be able to automatically retrieve as much data as possible from online sources. By doing so manual entries to the tool can be kept to a minimum.	Epic

TABLE 5.1: Sample of requirements only Epics

To achieve requirement 2, the user should “be able to specify different locations/regions within a CPS,” we included the possibility that the location can be specified on the component_type level, which gives the user the possibility to represent a CPS that has multiple locations.

We incorporate three additional impact factors to fulfil requirement 4; the user should “be able to analyse other environmental impact factors,” In addition to the existing primary factor, 1) CO2 and Global Warming, quantifying CO2 emissions in kilogram linked to the component type, we introduce 2) Net use of freshwater, detailing the total volume of freshwater utilised throughout a component type’s life cycle; 3) Water pollution, measuring the volume of water, in litres, polluted by component type over their life cycle; and 4) Acidification of soil and water, assessing the acidification on both soil and water systems connected to the given component type.

Requirement 16, which mandates the ability "to calculate the data footprint of CPS," is fulfilled by incorporating a data volume assessment for each component type. Users of the method are prompted to specify if a component type is generating data and then to choose a relevant sampling approach and rate. Subsequently, the method calculates the aggregate data volume and estimates the associated CO2 emissions stemming from data processing, transfer, and storage.

Meeting requirement 17 focuses on the ability "to fetch data from online sources automatically," the tool is designed to access online repositories. Environmental declarations are automatically sourced from the PEP databases, thereby reducing users’ need for manual data input.

By implementing 50 out of 67 requirements, the to-be model fundamentally differs from the as-is method. Table 5.2 shows the quantitative differences and changes from the as-is to the to-be PDD model. The to-be PDD is represented in Figure 5.2.

Quantity	Concepts	Activities	Subactivities
as-is Method	13	5	12
to-be Method	21	5	18
Changes from as-is to to-be			
New	10	4	16
Removed	2	4	10
Modified	9	1	1
Unchnaged	2	0	1

TABLE 5.2: Method Comparison

The first four modified concepts `cyber_physical_system (CPS)`, `configuration`, `component_type`, and `configuration_component`, contain a number of new attributes. Some attributes transition from one concept to another, yet the foundational idea of these three concepts remains consistent. The concept `configuration_component` is named `configuration_line` in the to-be model because that name represents its position in the tool better.

Contrastingly, the six modified concepts, `electricity_map_repository`, `electricity_mix_information`, `product_environment_profile_repository`, `product_environment_profile`, `data_approach`, differ more. The former concept `electricity_map_repository` now adopts the name `carbon_intensity_repository`. It is more general and incorporates multiple sources for carbon intensity data. `Electricity_mix_information` changes into `carbon_intensity_electricity`, incorporating the specific average carbon intensity data from its `carbon_intensity_repository`.
The `product_environment_profile_repository` of the as-is method is called `environmental_declarations_repository` in the to-be method. Similar to the earlier concept's adaptation, the modified concept incorporates multiple sources for environmental declarations, not exclusively in a PEP format. For parallel reasons, the as-is concept `product_environment_profile` is called `environmental_declarations` in the to-be method. The `data_approach` from the as-is is called `data_information` in the to-be method. The as-is concepts `A4H_dataset` and `electricity_by_source` are not needed in the to-be method and are removed. Whereas the concepts `manufacturer` and `component` remain unchanged.

To conclude, the to-be method introduces the following ten new concepts. `Location`, which describes the geographical location of configurations. It is a concept with multiple attributes. We introduced `component_type_details` to summarise the environmental details retrieved from environmental declarations. The six concepts, `component_impacts (total)`, `component_impacts (manufacturing)`, `component_impacts (distribution)`, `component_impacts (installation)`, `component_impacts (use)`, and `component_impacts (end of life)`, contain the derived environmental information for each life cycle stage. We split them into six classes to represent the individual life cycle phases and use the same

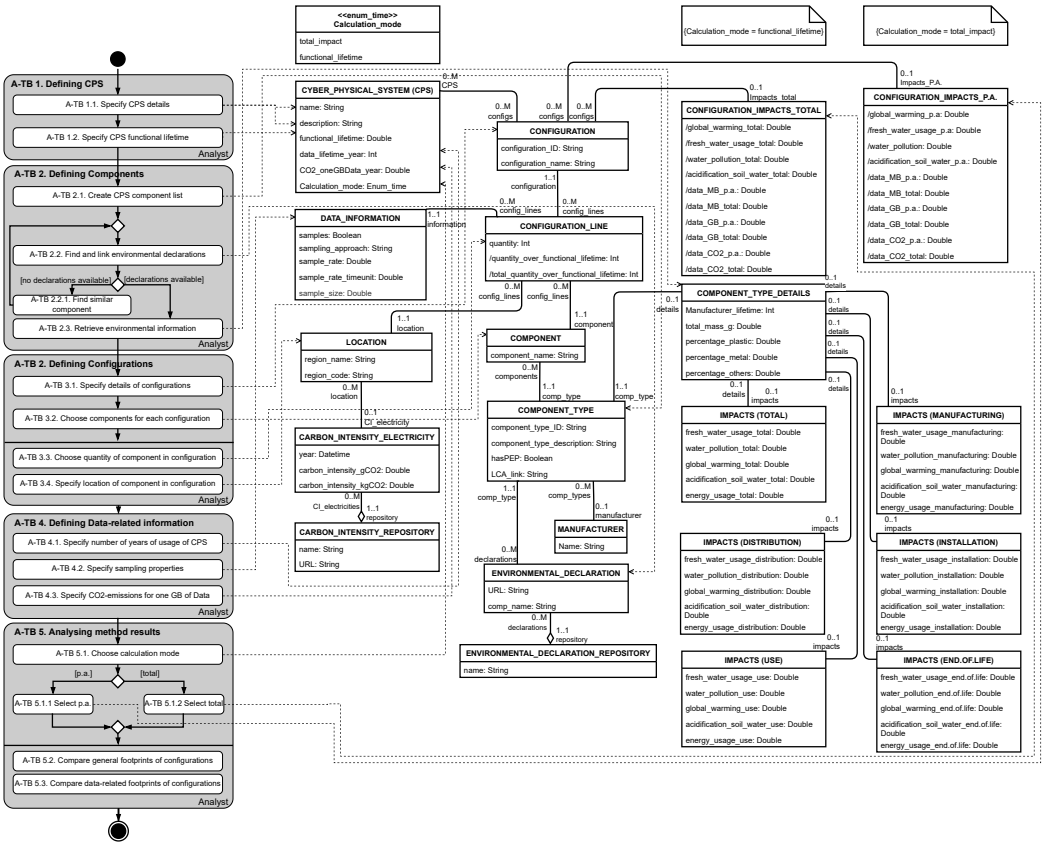


FIGURE 5.2: PDD of LCA for CPS to-be method

structure as given in environmental declarations. Lastly, we introduce `configuration_impacts_p.a.` to show the environmental impacts of configurations annually, while `configuration_impacts_total` presents the cumulated total of the environmental impacts.

5.2.2 To-be Process Deliverable Diagram

The proposed method comprises five major activities. The PDD is depicted in Figure 5.2. The following briefly explains each activity's important subactivities and most important deliverables. *Appendix C* shows the full concept and activity tables associated with the PDD.

The initial activity, "Defining CPS" (A-TB 1 in Figure 5.2), includes the essential steps to describe the analysed `cyber_physical_system (CPS)`. This phase entails outlining the specifics of the CPS and defining its functional lifetime, which is the intended duration for which the CPS is used. `Cyber_physical_systems (CPS)` is the resulting concept of this activity.

The second activity, "Defining Components" (A-TB 2), centres on components, which are devices in a CPS that are responsible for sensing, storing, and processing data. The main deliverable of this phase is the concept `component_type`, which represents a group of components of the same kind. This phase also involves the task of identifying environmental declarations for each `component_type`. When declarations are unavailable, a suitable alternative `component_type` with available declarations has to be used. Moreover, the environmental information associated with each `component_type` is retrieved and results in the concept `component_type_details`.

In the third activity, "Defining Configurations" (A-TB 3), configurations are characterised. They are recognised as a combination of components that collectively represent a CPS. A CPS can have multiple alternative configurations. Each configuration is detailed with a unique ID and name encapsulated in the configuration concept. Subsequently, components for each configuration are selected from the previously defined `component_types`. The quantity of components per configuration is determined, and lastly, the geographical location, denoted by country, of each component in every configuration is specified. The concept `configuration_line` consolidates this information with the location details captured in the linked location concept.

In the fourth activity, "Defining data-related information" (A-TB 4), the focus is on detailing the data-related aspects of all components. This involves determining the number of years over which the data-related footprint should be calculated and defining sampling properties for each component, including sampling approach and frequency. Lastly, the value for CO2 emissions for one gigabyte of data per year, used in calculating the data-related environmental footprint, is sourced from scientific research. This activity is related to the concepts `data_information` and `cyber_physical_system (CPS)`.

In the fifth activity, "Analysing method results" (A-TB 5), the emphasis lies on interpreting the method's outcomes. The initial step involves deciding on the calculation mode, whether results are presented annually or in total over the intended functional lifetime of the CPS. In the final steps, both the general and data-related footprints of different configurations are compared.

5.2.3 LCA for CPS Tool and its Features

Building on previous research findings, the tool named *LCA for CPS*[1] is developed on Google Sheets and integrates customised JavaScript functions to automate various tasks. Opting for Google Sheets offers a user-friendly interface familiar to many users, whilst the integrated JavaScript functions extend the capabilities beyond conventional spreadsheet functionalities. The tool is online accessible and can be easily duplicated and shared amongst multiple users. The tool's core task is the architectural configuration of CPS and the calculation and representation of its environmental footprints.

The tool has seven main features, which are also a central part of the interview and analysed in the section *Validation of the improved LCA Method*. The core features of the method are presented in Figure 5.3 in the form of a feature model. Feature modelling is a technique used to capture and manage the features of systems within a product line (Czarnecki, Helsen, and Eisenecker, 2004). We utilise the feature model to represent the tool's features and their inter-dependencies graphically. A solid dot connection indicates that a parent feature mandatory requires a child feature, while an unfilled dot connection denotes that the child feature is optional. An example of an optional feature is "Fetch PEP data automatically". Striped lines represent a cross-tree relationship, indicating a required relationship between features.

We assigned identifiers, which are also represented in 5.3 to each feature to quickly refer to them, as follows:

[1] Link to the tool

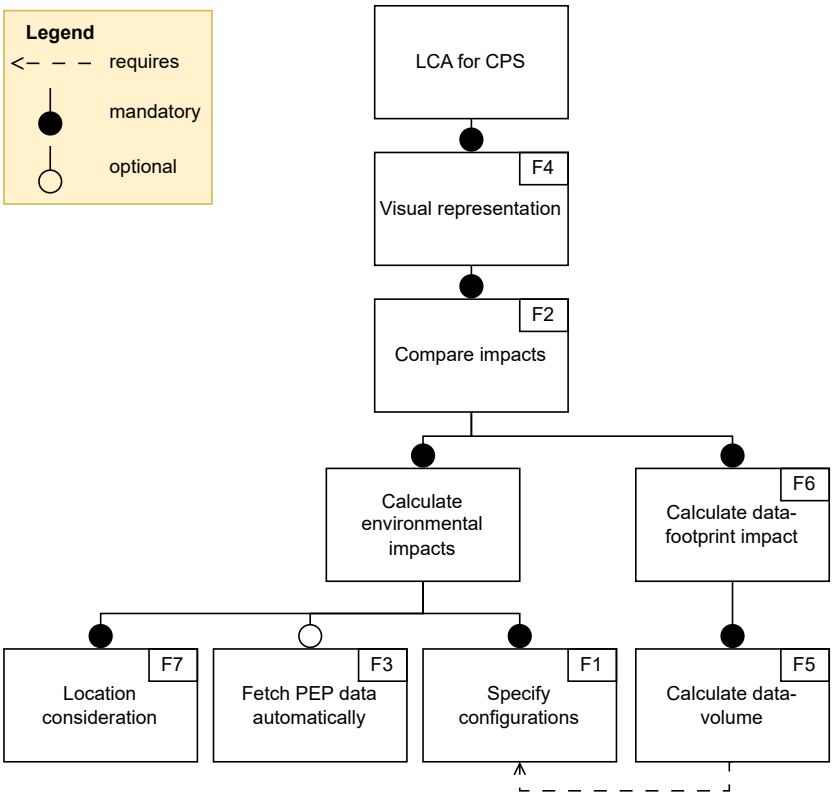


FIGURE 5.3: Feature model for LCA for CPS tool

F1: Specification of different configurations of a CPS
Users have the ability to create diverse configurations. In this context, a configuration refers to a combination of components that collectively build a CPS. An ID and corresponding name, such as "1" and "Smart Home Spain," uniquely identify each configuration. Furthermore, a configuration may have multiple component types, each with its respective quantity. The tool facilitates the creation of various configurations of the same CPS.

F2: Comparison of the environmental impacts of configurations
The tool has the capability to perform a comparative assessment of the environmental footprints of different configurations. The consolidates of environmental impacts for each component are aggregated on the configuration level. On an overview sheet, the user can compare the cumulated results of the different configurations, determining configurations with the most and least environmental impact. Such insights can help with the decision-making process.

F3: Automatically extraction from Environmental Declaration PEP
The tool has a function designed to extract data from online repositories containing Environmental Declarations automatically. For automatic extraction, the environmental declarations have to be in the form of a PEP. Users can refer to a specific PEP of a component by linking its URL, and the tool accesses the PEP repository and retrieves the relevant environmental information. The tool creates an extra sheet for every component type and stores the retrieved environmental information there. This feature enhances efficiency by significantly reducing time consumption. It also minimises potential false data entries compared to a manual

data entry.

F4: Visual representation of environmental impacts
This feature encompasses the visual representation of the calculated environmental impacts. All four impact indicators have separate charts plotting the different configurations' impacts. Such graphical representations help to discern the different configuration's impacts quickly.

F5: Calculation of data volume generated by the CPS
The tool offers the functionality to calculate the amount of data the examined CPS configuration generates. Users can enter data-related properties for every component type, which are subsequently employed in the computation to estimate the cumulative data volume of the configuration. This helps to understand the data footprint of the CPS.

F6: Calculation of the environmental impact of data
The feature uses the previously calculated data volume and combines it with estimates of CO2 emissions for data. Users can identify the emitted amount of CO2 for one gigabyte of data per year. They can retrieve this number from scientific research. In our example, we use 0.0379 kg of CO2 per gigabyte of data per year, derived from a paper by Charret et al. (2022). The feature helps users understand data's environmental impact and can help with decision-making.

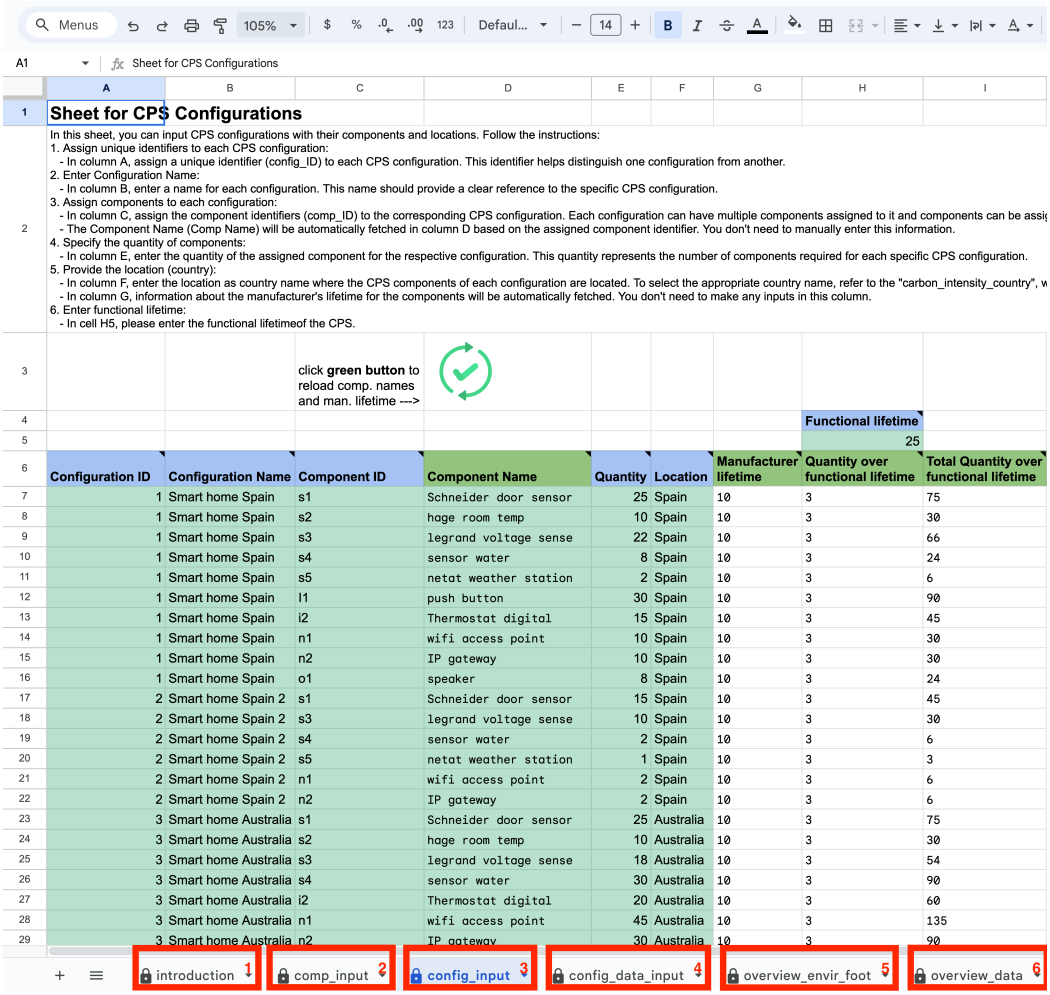
F7: Consideration of location-related carbon intensity of electricity
The tool incorporates the location of CPS components within the environmental impact computations. Recognising that disparate regions and nations have varying energy supplies, with varying carbon intensity of electricity generation, which also influence the environmental impact of energy-powered components. The user specifies for every component type its location as a country. This feature subsequently cross-references the country with a pre-existing database detailing the average carbon intensity of electricity for various countries. The tool computes the accurate carbon intensity for one kWh with the energy consumption of the component. This feature guarantees a more comprehensive and precise representation of predicted environmental impacts by considering location factors.

The structure and order of the tool align coherently with the processes delineated in the to-be PDD. The spreadsheet has ten sheets, from which the user operates on six actively. Figure 5.4 shows a screenshot of the *configuration input* sheet. The following section elaborates on the six sheets, which in Figure 5.4 are highlighted and numbered in red. The remaining four sheets are reserved for calculations or serve as data repositories and are not discussed in depth.

The six main operation sheets of the LCA for CPS tool are as follows:

1. **Introduction Sheet:** This introductory sheet provides an overview of the tool's purpose and functionality. It also contains essential contact details, links to relevant information, and a guide on using the tool. Additionally, it describes the colour scheme with its meaning.

2. **Components Input Sheet:** This sheet defines and lists individual components. Each component type is accompanied by a direct link to its corresponding PEP. Additionally, the tool automatically generates separate



Sheet for CPS Configurations

In this sheet, you can input CPS configurations with their components and locations. Follow the instructions:
1. Assign unique identifiers to each CPS configuration:
   - In column A, assign a unique identifier (config_ID) to each CPS configuration. This identifier helps distinguish one configuration from another.
2. Enter Configuration Name:
   - In column B, enter a name for each configuration. This name should provide a clear reference to the specific CPS configuration.
3. Assign components to each configuration:
   - In column C, assign the component identifiers (comp_ID) to the corresponding CPS configuration. Each configuration can have multiple components assigned to it and components can be assig
   - The Component Name (Comp Name) will be automatically fetched in column D based on the assigned component identifier. You don't need to manually enter this information.
4. Specify the quantity of components:
   - In column E, enter the quantity of the assigned component for the respective configuration. This quantity represents the number of components required for each specific CPS configuration.
5. Provide the location (country):
   - In column F, enter the location as country name where the CPS components of each configuration are located. To select the appropriate country name, refer to the "carbon_intensity_country", w
   - In column G, information about the manufacturer's lifetime for the components will be automatically fetched. You don't need to make any inputs in this column.
6. Enter functional lifetime:
   - In cell H5, please enter the functional lifetimeof the CPS.

click **green button** to reload comp. names and man. lifetime --->

Functional lifetime
25

Configuration ID	Configuration Name	Component ID	Component Name	Quantity	Location	Manufacturer lifetime	Quantity over functional lifetime	Total Quantity over functional lifetime
1	Smart home Spain	s1	Schneider door sensor	25	Spain	10	3	75
1	Smart home Spain	s2	hage room temp	10	Spain	10	3	30
1	Smart home Spain	s3	legrand voltage sense	22	Spain	10	3	66
1	Smart home Spain	s4	sensor water	8	Spain	10	3	24
1	Smart home Spain	s5	netat weather station	2	Spain	10	3	6
1	Smart home Spain	l1	push button	30	Spain	10	3	90
1	Smart home Spain	i2	Thermostat digital	15	Spain	10	3	45
1	Smart home Spain	n1	wifi access point	10	Spain	10	3	30
1	Smart home Spain	n2	IP gateway	10	Spain	10	3	30
1	Smart home Spain	o1	speaker	8	Spain	10	3	24
2	Smart home Spain 2	s1	Schneider door sensor	15	Spain	10	3	45
2	Smart home Spain 2	s3	legrand voltage sense	10	Spain	10	3	30
2	Smart home Spain 2	s4	sensor water	2	Spain	10	3	6
2	Smart home Spain 2	s5	netat weather station	1	Spain	10	3	3
2	Smart home Spain 2	n1	wifi access point	2	Spain	10	3	6
2	Smart home Spain 2	n2	IP gateway	2	Spain	10	3	6
3	Smart home Australia	s1	Schneider door sensor	25	Australia	10	3	75
3	Smart home Australia	s2	hage room temp	10	Australia	10	3	30
3	Smart home Australia	s3	legrand voltage sense	18	Australia	10	3	54
3	Smart home Australia	s4	sensor water	30	Australia	10	3	90
3	Smart home Australia	i2	Thermostat digital	20	Australia	10	3	60
3	Smart home Australia	n1	wifi access point	45	Australia	10	3	135
3	Smart home Australia	n2	IP gateway	30	Australia	10	3	90

introduction 1 | comp_input 2 | config_input 3 | config_data_input 4 | overview_envir_foot 5 | overview_data 6

FIGURE 5.4: Screenshot of LCA for CPS tool configuration input sheet

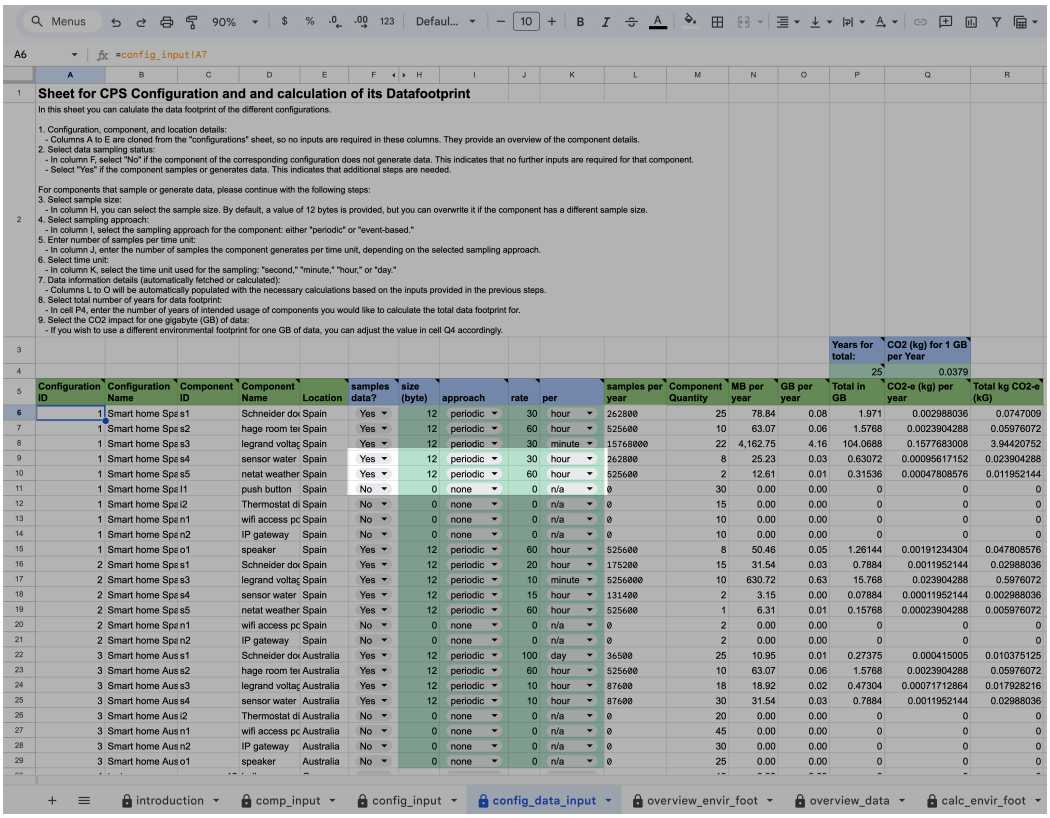


FIGURE 5.5: Screenshot of LCA for CPS tool configuration data input sheet

sheets that retrieve specific details from the PEP. The process described in the PDD activity "A-TB 2. Defining Components" occurs on that sheet.

3. **Configuration Input Sheet:** This sheet, depicted in Figure 5.4, defines configurations. The PDD activity "A-TB 2. Defining Configurations" relates to this sheet. This sheet records both the quantity and geographical location of components. Calculations for 'Quantity over functional lifetime' and 'Total quantity over functional lifetime' are executed within this sheet. These calculations consider the manufacturer's lifetime sourced from the PEP.

4. **Configuration Data Input Sheet:** This sheet, represented in Figure 5.5, is intended for inputting specific data-related attributes for each component within each configuration. The highlighted part in Figure 5.5 shows example inputs a user can make. The PDD activity "A-TB 4. Defining Data-related information" is executed on this sheet.

5. **Overview of Environmental Footprint:** This sheet provides a comprehensive view of the environmental footprint outcomes, showcased annually or as a cumulative total. Figure 5.6 showcases an example from the tool, in which charts visually represent the results. The PDD activity "A-TB 5. Analysing method results" is carried out on this sheet.

6. **Overview of Data Footprint:** Equivalent to the prior sheet but focusing on data-related footprints, this section displays the results and offers graphical visualisations through charts. Figure 5.7 shows that sheet. Users apply the PDD activity "A-TB 5. Analysing method results" on this sheet.

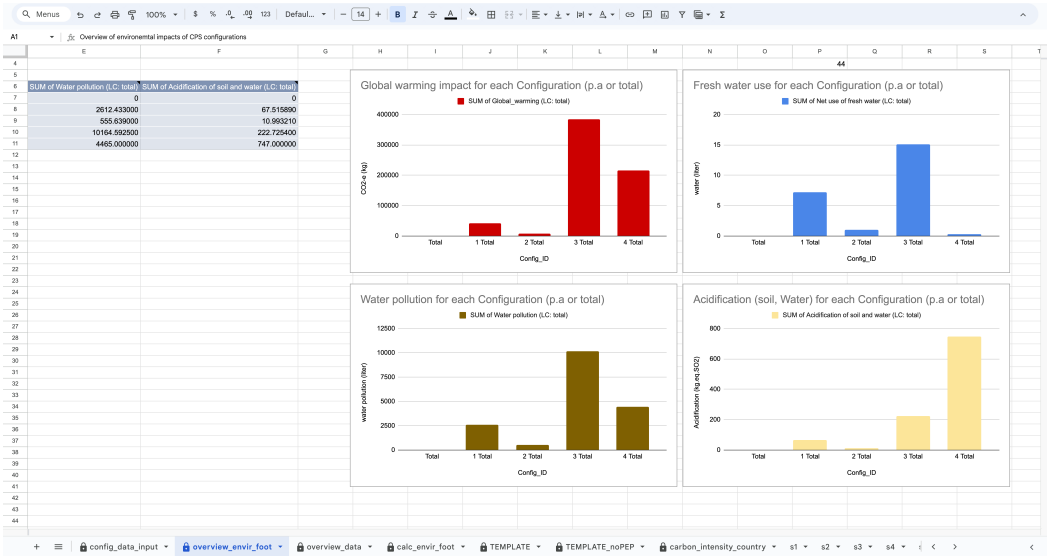


FIGURE 5.6: Screenshot of LCA for CPS tool overview environmental footprint

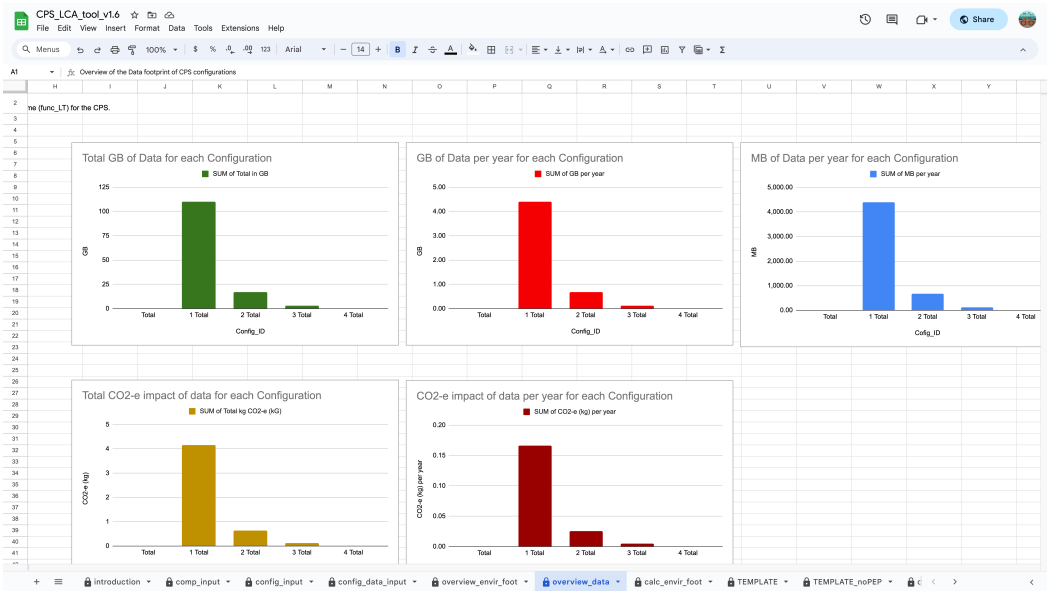


FIGURE 5.7: Screenshot of LCA for CPS tool overview data footprint

5.2.4 Calculation of Impact Indicator CO2/Global Warming

This section delves into the calculation of the Impact indicator for CO2/Global Warming to shed light on the underlying calculations within the tool. This specific indicator has been selected for detailed description due to its in the interviews analysed significance. There are three other indicators: Acidification of soil and water, water pollution, and freshwater usage. Their calculation aligns closely with the CO2/Global Warming indicator and are not elaborated upon further in this section.

$$\textbf{Global Warming (use)} = \frac{\textbf{energy\_consumption (use)} \times \textbf{carbon\_intensity}}{\textbf{manufacturer\_LT} \times \textbf{functional\_LT}} \times \textbf{quantity}$$

Global Warming (use) This represents the impact of global warming of a configuration component measured in CO2e due to energy consumption over the life cycle use phase.

energy_consumption (use) This variable denotes the energy consumption of a component type consumed during the life cycle use phase. It is measured in kWh.

carbon_intensity This represents the amount of CO2 emitted per kWh of energy produced of the configuration component's location. It is measured in kilograms of CO2e per kWh.

manufacturer_LT Stands for the manufacturer's lifetime and is the period of time given in years a component type can operate without failure, according to its manufacturer.

functional_LT The functional lifetime denotes the duration of time expressed in years the CPS is intended to operate and is specified by the user.

quantity This variable indicates the number of components (quantity) used simultaneously for a given configuration of a CPS.

This formula represents how environmental indicators are calculated within the tool.

5.3 Ensuring Traceability of Artefacts

Throughout the development of the research artefacts, we place significant emphasis on their traceability. This ensures a thorough understanding of the connections between requirements and the respective artefacts, such as the tool with its features, and the PDD with its concepts. By establishing these connections, we monitor the development progress throughout the project's duration and discern how each artefact interrelates. A visual representation of this traceability is shown in Figure 5.8. It elucidates a sample of requirements and its relationships between, to-be PDD concepts, and tool features.

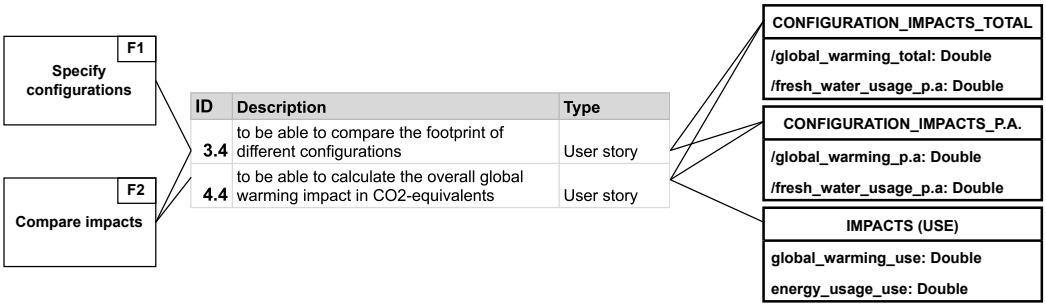


FIGURE 5.8: Visualisation of the traceability of artefacts

The figure delineates the connections between requirements, tool features, and PDD concepts. For instance, it illustrates that requirement ID 3.4 is realised in Feature 1, and is partly represented in the concept `configuration_impacts_total` within the to-be PDD. While the figure captures only a subset of the connections, many artefacts have multiple associations. A comprehensive list detailing the full traceability connections between artefacts is available in *Appendix E*, where we list the IDs of the requirements and their corresponding concept and tool feature IDs.

5.4 Validation of the improved LCA Method

This chapter addresses **RQ3**: 'What are the benefits and drawbacks of the proposed LCA method?' and presents the results of the conducted interviews. We interviewed experts in the field to validate our developed LCA for CPS tool and its functionalities and features. We conducted eight interviews. During one of these interviews, two interviewees participated, resulting in a total of nine participants (**N=9**). Table 5.3 displays the profiles of the nine respondents, each with an identifier and workplace. The workplace combination means that the participants work for both research institutions and private companies. Transcriptions of the interviews are available in *Appendix B*. Figure 5.9 displays the distribution of the interviewees' workplaces in a pie chart. The majority of the interviewees work for research institutions.

Participant ID	Workplace
P1	private company
P2	research institution
P3	combination
P4	research institution
P5	research institution
P6	research institution
P7	research institution
P8	combination
P9	combination

TABLE 5.3: Research Participant Table

To gain insights into the interviewees' depth of expertise and experience, we record the number of years they have been working in their field. Figure 5.10 visually shows this data. Most participants have been active in their field for more than ten years.

General consideration of environmental impacts

No interviewee measures or analyses the environmental footprint of CPS actively, and most respondents do not consider environmental impacts at all. However, respondents state that they indirectly consider environmental impacts. Third parties, like clients and partners, often indirectly influence the environmental considerations of system designers. Some companies have missions to reduce their environmental footprint, which indirectly influences some interviewees to align their designs with these environmentally conscious objectives. In general, some

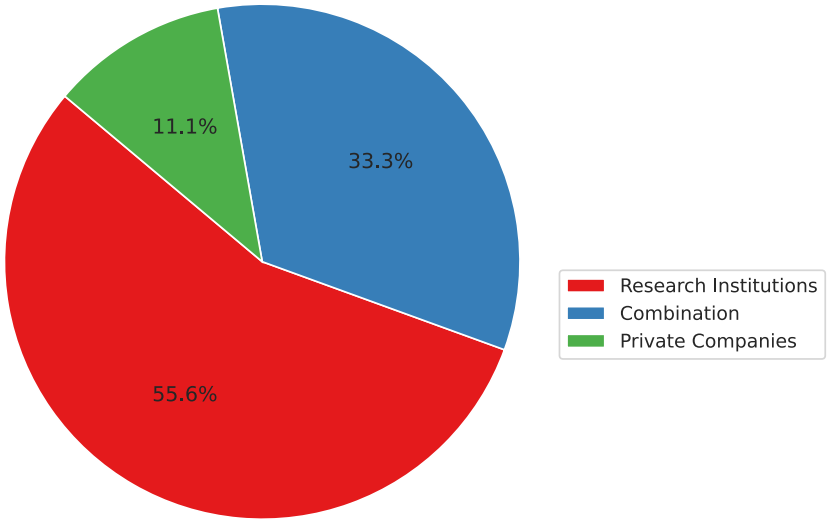


FIGURE 5.9: Main workplace of interviewees

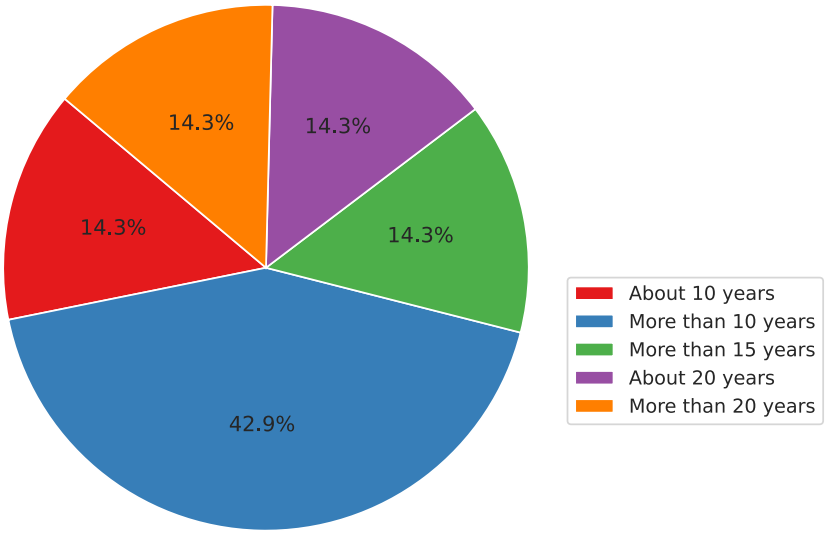


FIGURE 5.10: Years of experience of interviewees

respondents acknowledge efforts to reduce energy consumption and waste. However, it is worth noting that the motivation for energy reduction frequently aligns with system requirements rather than explicit environmental considerations.

General usefulness of the Tool

In assessing the tool's usefulness, a significant majority (8 out of 9) find the tool in general useful. One respondent expresses reservations, citing the perceived added extra effort and work when using the tool and does not feel the need to study the numbers that are calculated with the tool. But the positive impressions of the tool outweigh what is also represented in the numbers. Respondents emphasises the tool's importance by highlighting the importance of the topic and the usefulness of the tool. Respondent 9 states, "The tool is very effective and very useful and provides very good insights".

Usefulness of Features

Figure 5.11 presents a boxplot illustrating the quantitative analysis of the perceived usefulness of seven features. We asked respondents to rate the usefulness of each feature using a Likert scale ranging from 1 to 5, where one signifies 'not useful' and five denotes 'extremely useful'.

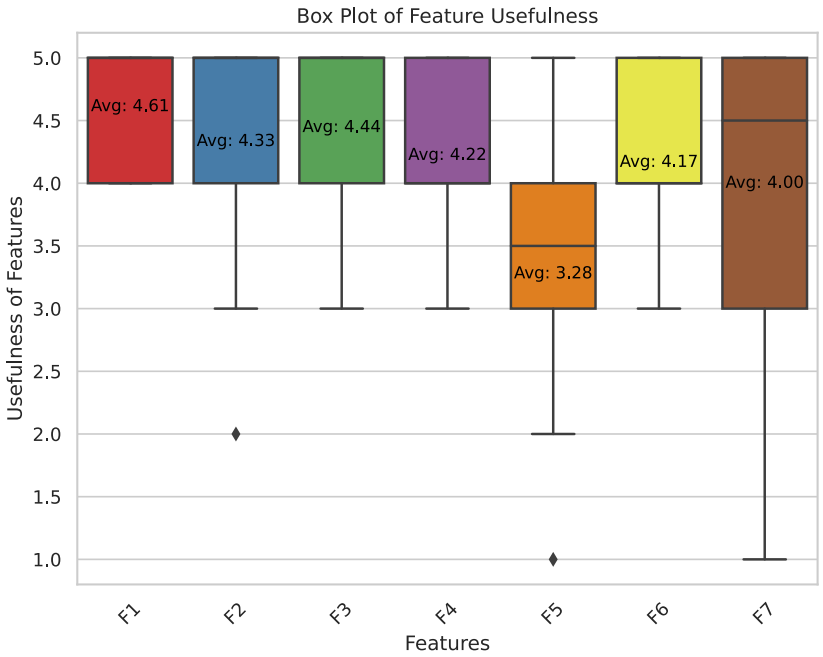


FIGURE 5.11: Usefulness of Features

Feature 1 and 2 In the evaluation, Feature 1 (F1) received an average rating of 4.61 (extremely useful), and Feature 2 (F2) garnered an average of 4.33 (very useful). Participants mention that configurations vary greatly, emphasising the importance of specifying different configurations (F1). Additionally, participants state that F2, which enables the comparison of environmental impacts of configurations, significantly helps in decision-making. Specifically, when alternative configurations are available, they can choose environmentally friendly options. Furthermore, the participants actively emphasise the growing importance of sustainability.

Feature 3, which allows for automatic extraction from PEP, received a high average rating of 4.44 (very useful). Participants find this feature very impressive and state it aids in the automation of LCA. Furthermore, participants state that F3 reduces user effort and enhances ease of use and time efficiency. Additionally, it minimises errors in data entries. However, it is noteworthy that the usefulness of this feature increases with the complexity of the CPS; it is more advantageous for larger CPSs than smaller ones. One participant finds the feature useful but did not deem it an essential function, suggesting that it serves as an added benefit rather than a critical feature (P1).

Feature 4, which visually represents environmental impacts, garnered an average rating of 4.22 (very useful). Interviewees noted that F4 facilitates the "end user to intuitively [...] see and understand the magnitude of the differences between

various configurations much more than a number may do."(P8). Participants valued it as the most important feature. Additionally, the feature enhances the ease of comparing configurations. The visualisations help understand numerical data, making the information more accessible. However, the usefulness of F4 is context-dependent, according to different use cases. One participant found F4 to be highly helpful but did not consider it to be essential for the tool (P1).

Feature 5 and 6
Feature F5, which calculates the data volume generated by CPS, received a rating of 3.28 (moderately useful). Conversely, F6, focused on calculating the environmental impact of data received a score of 4.17 (very useful). Interviewees considered both features as beneficial, highlighting that the environmental impact of data is an under-discussed yet critical issue. However, participants also mentioned that F5 and F6 are not as important as other features that focus more on the core impacts of CPSs. Sampling frequency is noted as a significant factor affecting data volume. Nonetheless, participants state that many unknown factors are needed to calculate the data volume, which decreases the overall usefulness of F5. One respondent pointed out that knowing the data volume could be counterproductive because many systems only have a very low data volume (P4). Furthermore, a minority of participants deemed the features less useful, citing a general lack of interest in data analysis and arguing that the cost of data is more meaningful than its environmental impact.

Feature 7, which accounts for considering location-related carbon intensity of electricity, received an average rating of 4 (very useful). Interviewees acknowledged the importance of this feature, emphasising that the location and its carbon intensity of energy production are critical factors for the environmental footprint. They further stated that the electricity mix is fundamental to assessing CPS's environmental impact. The electricity mix can drastically influence the environmental footprint of CPSs. However, some pointed out that the feature is mostly useful for comparison of configuration with different locations. Furthermore, participants acknowledged that energy costs also differ by location, adding another dimension to the feature's relevance.

Important impact indicator

A majority of interviewees, 7 out of 9, identified "CO2 footprint/global warming" as the most critical environmental indicator out of the four impact indicators used in the tool. Participants emphasise its widespread recognition both in the scientific community and industrial sector. Furthermore, the urgency of addressing global warming makes this indicator an essential metric to focus on. The impact indicator "acidification of soil and water" emerged as the second most important indicator.

Strength of the tool

Based on feedback from the interviews, the tool has several key strengths. First and foremost, the tool effectively raises awareness about the environmental implications of ICT. Participants also commended it offers a very structured approach

to accessing the environmental footprint of CPS. Furthermore, participants highlight that the tool is both important and necessary for enabling a clear understanding of the actual environmental impacts of CPS. Users praised its user-friendly design and great interface, enhancing its ease of use. The direct linkage to environmental declarations, which enables the incorporation of verified data and the automatic retrieval of the declarations, was particularly well-received. Interviewees noted that the tool provides valuable insights into sustainability, making it an excellent resource for planning new CPS projects. Overall, the tool emerges as a comprehensive solution for assessing, planning, and understanding the environmental impact of CPS.

Weaknesses of the tool

While the tool offers various strengths, interviewees also mention several weaknesses that merit attention. First, the tool demands the user to know a large amount of detailed information about the CPS. Additionally, the tool requires repetitive data entries, obliging users to input redundant information multiple times. Interviewees deem the usage of the tool as time-consuming. Scalability presents another weakness; the tool faces limitations due to its platform, Google Sheets, particularly concerning the performance when analysing very complex CPSs. Another issue is that calculating the data volume and its environmental impact is imprecise, affecting the results' validity. Additionally, the tool's use of Google products raises data privacy concerns, which may discourage companies with strict data privacy policies from adopting it. Participants of the interview stress that the impact of CPS, compared to the impact of companies' operations, is marginal. Furthermore, a few limitations were raised during the interviews. The method assumes that all CPS components have environmental declarations. Additionally, the tool cannot predict unforeseen impacts that occur during the runtime of the CPS. Finally, the tool focuses exclusively on direct environmental impacts, neglecting to consider indirect effects that might also be significant. These weaknesses point to areas for improvement in future versions of the tool.

Identified improvements for the tool

In addition to the identified weaknesses, interviewees offer a series of constructive suggestions for tool improvement. First, they advocate for including costs as an additional factor, particularly focusing on data storage costs, to provide a more holistic analysis that balances economic and environmental considerations. Furthermore, interviewees recommend including a metric for total electricity consumption. Additionally, transitioning from the current spreadsheet-based platform to a graphical user interface supported by a database would resolve scalability issues, making the tool more flexible and user-friendly. The user should be able to select the type of storage solution used for the CPS, such as on-premise or cloud storage, to enhance the accuracy of predictions related to data-related environmental impact. Interviewees also recommend including the option of benchmarks in the visualisations and offering more explanation alongside.

Environmental impact and its influence on decision-making

When we ask if a CPS's environmental impacts would affect their design decisions, 67% of interviewees (6 out of 9) indicate that these impacts would play

a role in their decision-making. Participants state that the tool enhances design decision-making, particularly given the rising significance of environmental considerations. They also mention that environmental impacts could influence their decisions, especially when alternative configuration options are available. On the other hand, interviewees mention that a cost-driven focus within companies might override the influence of environmental factors on design decisions.

Interviewees' intention to use the tool

A majority of interviewees, specifically 71% (7 out of 9), express an intention to use the tool. Some participants condition their intention to use the tool on some factors: they would use the tool when a relevant use-case arises, when the tool proves not to be time-consuming, and when the necessary information for the tool is easily accessible. However, some participants indicate that they see no need to use the tool at the present moment.

This marks the end of the *Results* chapter, where the core outcomes of our research have been presented. As we transition into the *Discussion* chapter, we will delve deeper, positioning these outcomes and interpreting them in the broader scientific context.

Chapter 6

Discussion

6.1 Summary of Results and Interpretations

In summarising the findings, we uncover insights into the role and potential of the proposed LCA for CPS tool within the CPS domain. We refer to the LCA for CPS tool as the "tool" for simplicity.

All interviewees at present do not actively measure the environmental footprint of CPS. This underscores the demand for a tool that can assess the environmental impacts of CPS. Almost all respondents recognise the tool's usability, highlighting its user-friendliness, structured design, and seamless integration of environmental declarations. These results support the tool's real-world application.

Regarding environmental indicators, "CO2 footprint/global warming" stands out as the most important parameter, which justifies its focused use in the tool.

In evaluating feature usefulness, all but one – F5 – consistently scored high, suggesting their continued relevance. F5, which deals with calculating the data volume, scored 3.28 as last. This feature might benefit from further optimisation or positioning in a less pivotal role.

Identified **weaknesses** include repetitious data entry demands, time intensity, restricted scalability due to the spreadsheet-based platform, and data privacy concerns stemming from dependence on Google services. A solution for these weaknesses is migrating from a spreadsheet format to a database-backed graphical user interface, improving user experience by avoiding redundant entries, saving time, and addressing scalability and privacy concerns. Moreover, criticisms revolve around calculating data volume and its environmental impact estimations. Improvements can be made by allowing users to specify different storage options, such as on-premise or cloud systems, increasing CO2 estimation precision.

Additional **improvements** include incorporating metrics like total electricity consumption of CPS configurations, improving visualisation with benchmarks, and providing additional explanations alongside the charts. These improvements can be included in future versions of the tool. However, including cost parameters might steer the tool from sustainability-centred toward an economic dimension. Further research needs to be done to include economic factors into the tool.

Certain weaknesses are inherent in the tool. One such constraint is CPS's perceived marginal environmental impact compared to production processes. Furthermore, the method does not account for unforeseen impacts, as these cannot be predicted. One assumption is that every CPS component comes with an accessible environmental declaration. Finally, the tool demands that users possess in-depth knowledge about the CPS. Another weakness is that it focuses exclusively on direct environmental impacts, overlooking potential indirect ones. We see these

inherent weaknesses as tool limitations. They are boundaries of the tool that tool improvements can hardly mitigate.

However, there are positive silver linings for the sustainable development of CPSs. Most interviewees admitted that environmental insights from such tools could sway their design decisions. A positive shift towards sustainability is a possibility. Almost all participants are inclined to use the tool; this indicates the tool's acceptance within the CPS community. In conclusion, while the tool bears both strengths and limitations, its potential value in promoting sustainable design choices in the CPS sector is recognisable.

6.2 Limitations and Threats to Validity

We have done our best to mitigate threats to the validity of this research, but we acknowledge that limitations and potential threats remain. The results and insights obtained in this study contribute to the fields of LCA and CPS; however, the limitations inherent to this research must be recognised.

An **internal validity** threat arises from a singular instance where an interview session included two participants simultaneously, presenting a risk of mutual influence and a potential compromise to the independence of their responses. Despite this, all other interviews were conducted individually, and utmost care was taken to maintain a consistent environment across all sessions.

External validity is also a concern, primarily due to the limited sample size of nine interviewees. This constraint implies that the acquired findings might only partially represent the broader CPS community. This constraint, categorised as population validity, refrains from making overarching assumptions about the proposed method's wider application.

Additionally, selection bias is another external validity threat. The participants who voluntarily opted to participate presumably have a pre-existing interest in the subject matter, which can influence their responses. This can affect the reliability of the research outcomes.

In conclusion, acknowledging these limitations sheds light on the research's contextual constraints without compromising its inherent value. The subsequent section, *Suggestions for Future Research*, explores and proposes potential ways to address and mitigate these identified limitations.

6.3 Suggestions for Future Research

Acknowledging the limitations and potential threats to the validity of this research is essential, and it opens several ways to improve in future work.

The risk of mutual influence of responses and their independence arising from simultaneously participating in interviews can be avoided in future research. It should strictly conduct individual interviews.

Concerns regarding external validity, primarily due to the restricted sample size and selection bias, call for a more diversified participant selection in subsequent studies. Enlarging the sample size and ensuring representation of the whole CPS community, for example, by including more experts working for private companies, will enrich the research's insights and enhance its generalisability.

Future studies also need to delve deeper into the practical application of the proposed method, extending the design cycle by Wieringa utilised in this research and applying the entire engineering cycle with its additional phases of Treatment

Implementation and Implementation Evaluation. This implies applying the proposed method in real-world contexts and initiating comprehensive user testing of the tool to assess its usability and effectiveness. Additionally, surveys for quantitative analysis to determine the necessity and the users' intentions to use the method can shed light on its significance and identify potential areas for improvement.

Chapter 7

Conclusion

In this research, we discussed the state of the art of LCA within the domain of ICT, with a focus on CPS. We have developed an as-is model of the LCA for CPS method and gathered requirements to develop the improved to-be method. By introducing a tool based on the to-be method, we found a way to assess the environmental impacts of CPS cost-effectively. The thorough validation of the proposed method and tool uncovered their benefits and drawbacks by interviewing CPS experts.

Reflecting upon our **research findings**, it becomes apparent that the proposed LCA method for CPS, complemented by its tool support, has significant potential to enrich the impact measuring methodology landscape in the ICT domain. The method and tool, in their entirety, have been discerned as overall useful, with most features receiving high ratings, thus underscoring their usefulness. Significantly, the research highlighted the pivotal role of CO2 footprint and global warming as primary impact indicators, indicating the urgency to address it predominantly. However, despite the benefits of the proposed method and tool, several drawbacks were identified. These included its time-consuming nature and the limitation to solely direct environmental impacts, overlooking CPS's indirect and often positive impacts.

Moreover, the method shows several limitations. One important one is only to incorporate components with environmental declarations. Our study identified viable ways of improvement, such as implementing a database-backed graphical user interface in future versions. On a brighter note, the proposed method and tool can inform and influence the design decisions of CPS experts regarding environmental impacts, thereby contributing to the overarching goal of sustainability within the realms of CPS and ICT.

The **limitations** of our research predominantly stem from a scarcity of data due to the lower participation in interviews, and they reveal areas for future exploration. Future research should address the outlined limitations and delve deeper into the practical application of the proposed method. Further empirical assessments involving user testing of the tool and quantitative surveys are essential to evaluate the tool's usability, effectiveness, and real-world adaption.

In **conclusion**, while this research has acknowledged limitations, it still paves the way for positive transformations within the CPS sector. The proposed method and its potential to influence design decisions indicate well for fostering more sustainable and responsible choices in CPS development, thus acting as a beacon leading towards a more sustainable future. This work lays the foundation for continued research in assessing CPS's environmental impacts, thereby contributing to the larger vision of sustainability within the ICT domain.

We have the opinion that every sector must commit to reducing emissions radically to save our planet. Similarly, individuals across the globe must adopt more sustainable lifestyles — consider adopting a plant-based diet, consuming fewer products, and limiting air travel. The time to act is now for the prosperity of our world and the well-being of our generations and the ones to come. Let us embrace this challenge and create a sustainable future for all.

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Appendix A

Interview Guide for Treatment Validation

Introduction to the interview

Thanks for your interest! As part of my master's graduation project titled: "A life-cycle assessment method to evaluate the environmental impacts of Cyber-physical Systems", I have engineered a method with **web-based tool support to assess the environmental impacts of Cyber-Physical Systems (CPSs)** throughout their life cycles. The aim is to **provide insights into the sustainability issues associated with CPSs**, to improve decision-making for system designers. My project is supervised and supported by a team of researchers from Utrecht University (Netherlands), University of Grenoble (France), Concordia University (Canada), and Universitat Politècnica de València (Spain). In this interview, I would like to ask you some general questions. Afterwards, I will present the tool to you in the form of a video demo and ask you questions about it. To use this in our research I would like to record our meeting to later anonymised transcribe it. Are you ok with me recording the Interview?

Background of participant

1. Are you mainly working for private companies or for research institutions/Universities or a combination?
2. What is your field of expertise? And what's your connection to Cyber-Physical Systems(CPS) / Internet of Things/ smart home/ LCA?
3. What type of involvement do you have in CPS projects?
   (a) Analysis and design of CPS
   (b) implementation and programming of CPS
   (c) evaluation and testing of CPS.
4. What is the typical size/complexity of CPS you're working with? (Measurements, number of components of CPS)
5. How long have you been active in the field?
6. Do you consider environmental impacts when working with CPS?
   If yes:
   (a) Which environmental impact factors do you take into account?
   (b) How do you analyse them?
7. In your experience or observations, is it common that components of CPS are reused if they are not needed anymore, or are they usually disposed of? Are components replaced or repaired?

Presentation tool (video)

Link to video: Link to Tool Presentation

Main Question/Topics

1. Do you have any general questions about the tool or how it works?
2. How would you describe your overall impression of the tool? What are its strengths and weaknesses?
3. Do you think the tool is useful? Now I will ask you some questions about the usefulness of some features of the tool. Please indicate on a Likert scale from 1 to 5 how useful you find them. (1 is not useful and 5 is extremely useful)
   (a) Not Useful
   (b) Slightly Useful
   (c) Moderately Useful
   (d) Very Useful
   (e) Extremely Useful
4. To what extent is it useful to specify different configurations of a CPS?
   (a) 1-5
   (b) why?
5. To what extent is it useful to compare the environmental impacts of different CPS configurations?
   (a) 1-5
   (b) why?
6. To what extent is it useful to automatically extract information from the Product Environmental Profile (PEP) documents?
   (a) 1-5
   (b) why?
7. To what extent is it useful to visualise environmental impact in charts?
   (a) 1-5
   (b) why?
8. To what extent is it useful to calculate the amount of data generated by the CPS?
   (a) 1-5
   (b) why?
9. To what extent is it useful to calculate the environmental impacts of generated data from a CPS?
   (a) 1-5
   (b) why?
10. To what extent is it useful to take the component's location-related carbon intensity for electricity consumption into account?
    (a) 1-5
    (b) why?
11. Would the environmental impacts of a CPS influence your design decisions? If so, how?

12. If you were using the tool which of the four impact indicators would you pay the most attention to, and influence your design decisions?
    (a) CO2 footprint / global warming
    (b) Fresh water usage
    (c) Water pollution
    (d) Acidification of water and soil
13. Would you use the tool to calculate the environmental footprints of CPS? If yes and no why?

Closing and Ending of the Interview

Would you like to receive the final paper on this project and get access to the tool when it's finished? Thank you for your help and time!

Appendix B

Transcripts of interviews

Transcript of Interview 1

June 30, 2023, 12:04PM

22m 22s

Schöllhammer, (Felix) started transcription

Interviewer: Felix Schöllhammer 0:04
Change spoken language. German.
OK.
Perfekt. Gut, dann sind wir jetzt soweit, wird aufgenommen, gut, also dann kommen wir zur ersten Frage, arbeitest du hauptsächlich für private Unternehmen oder Universitäten, Forschungseinrichtungen ohne eine Kombination aus dem Ganzen?

Respondent (1) 0:21
Mittlerweile private Unternehmen.

Interviewer: Felix Schöllhammer 0:37
Okay und zuvor?

Respondent (1) 0:43
Genau, also ich hab bis bis letztes Jahr habe ich promoviert in Kollaboration von [Technical University of City] und [CAR MANUFACTURER COMPANY], also eine Kombination von Industrie und Wissenschaft.

Interviewer: Felix Schöllhammer 0:48
Okay und was ist dein Fachgebiet und was die Verbindung zu Cyber Physical Systems, IOT, Smart Home?

Respondent (1) 1:02
Mein Fachgebiet ist Machine Learning und Computer, bitte.

Interviewer: Felix Schöllhammer 1:06
Mhm.

Respondent (1) 1:06

Bei [CAR MANUFACTURER COMPANY] gesagt, konkret um die Systeme, die dann im autonomen Fahren eingesetzt werden.

Interviewer: Felix Schöllhammer 1:11
Mhm.

Respondent (1) 1:12
Also sehr gute zu Cyber-physical systems passt. Mittlerweile bin ich das allgemeiner in generative AI tätig, was natürlich auch mit Internet of Things viele Verbindungen hat.

Interviewer: Felix Schöllhammer 1:24
Mhm.
Perfekt. Und.
In, in, in welcher Art warst oder bist du jetzt beteiligt? In CPS Projekten.
Also in welcher Phase?

Respondent (1) 1:39
Am vor allem die die Software Entwicklung.

Interviewer: Felix Schöllhammer 1:42
Mhm okay.

Respondent (1) 1:43
Und welche Algorithmen da dann miteinander laufen?

Interviewer: Felix Schöllhammer 1:46
Okay und zur nächsten Frage, was ist so die typische Größe oder Komplexität von diesen Systemen?

Respondent (1) 1:57
Kleinere also bei [CAR MANUFACTURER COMPANY] waren es natürlich dann Autos. Mittlerweile sind dann eher kleinere.

Interviewer: Felix Schöllhammer 2:01
Mhm.

Respondent (1) 2:03
Ich hab er.
Applikations zuhause also kleinere Laptop oder auch PC oder auch im Kontext von Healthcare haben wir auch Projekte. Also dann sag mal.

Interviewer: Felix Schöllhammer 2:08
Mhm.

Respondent (1) 2:17
Geräte an der Station bei Betten, also in der Größenordnung.

Interviewer: Felix Schöllhammer 2:21
Berücksichtigst du mit dem CPS verbundene Umweltauswirkungen bei Ihrer Arbeit mit CPS?

Respondent (1) 2:32
Nein, leider nicht.

Interviewer: Felix Schöllhammer 2:33
Okay so gute Antwort, ok.
Und.
Aus deiner Erfahrung werden bestimmte CPS Komponenten wiederverwendet. Wendet danach bestimmte Sensoren oder werden die entsorgt? Meistens.

Respondent (1) 2:51
Am die werden aufgrund der schnellen Entwicklung leider auch entsorgt, also insbesondere beim Autonomen Fahren werden einfach Prototypen so schnell weiterentwickelt, das dann ja Sensoren sind veraltet, Kameras insbesondere sind veraltet, Chips für Machine Learning Anwendungen sind veraltet und werden dann entsorgt.

Interviewer: Felix Schöllhammer3:12
Okay danke.
OK, dann würden wir jetzt schon zur ja Präsentation kommen. Dafür würde ich einmal gerne meinen Bildschirm mit dir teilen.

----- Video PRESENTATION – LCA for CPS tool -----

Interviewer: Felix Schöllhammer10:17
Ja, das war's von der Präsentation.
Hast du irgendwelche Fragen über die ja über das Tool, über die Methode, die beantwortet werden sollten.

Respondent (1) 10:39
Vielleicht eine Frage, wenn ich viele Systeme hat. Also gerade wenn ein neues System entwickelt, kann man die damit vergleichen, also vielleicht ist es 2 Systeme dann parallel würde man die die Visualisierungen quasi abspeichern oder zwei Excel Tabellen darstellen, also wird man am besten 2 vergleichen.

Interviewer: Felix Schöllhammer10:54
Also wenn wenn du 2 unterschiedliche CPS vergleichen würdest, also die die das ist, die die Idee der Konfiguration, dass du quasi sagst, wir haben ein CPS und du kannst einmal die Konfiguration 1 und 2 machen und ganz sagen die beiden miteinander vergleichen. Wenn es sich aber um komplett unterschiedliche CPS handelt.

Respondent (1) 10:58
Ja, genau.
Mhm.
Nee, also meint das gleiche System genauso, ja.

Interviewer: Felix Schöllhammer11:16
Okay ja genau das mit den Konfigurationen gemeint. Also im Endeffekt gehst du hin, machst die Konfiguration 1 und 2 ja mit unterschiedlichen Sensor anzahlen zum

Beispiel und gehst dann hin und sagst dann siehst ja die eine hat den Impact und die andere hat den Impact.

Respondent (1) 11:30
Okay und der Impact am Ende. Also ich hab das gesagt, hatte diese verschiedenen Kategorien mit Water, etc., wir es dann auch noch irgendwie auf eine Zahl zusammengeführt. Am Ende hab ich nicht gesehen oder bleibt es dann diese Kategorien?

Interviewer: Felix Schöllhammer11:36
Mhm.
Es ist mit einmal, also es wird pro Konfiguration auf eine Zahl zusammengeführt. Also man kann den totalen Impact pro Konfiguration sehen und das dann halt vergleichen. Genau und dann halt die pro Jahr oder die Totalen werte zusammenfassen.

Respondent (1) 11:54
Okay und dann lässt der Frage vielleicht, wenn man jetzt so zum Beispiel [CAR MANUFACTURER COMPANY] sagt, er hat wirklich richtig Komplexe systeme, viele Zulieferer, viele, also wirklich jede Menge zu liefern, wo man auch eventuell nicht alle Kontrolle drauf hat.
Wie ist das mit Nested Sachen, und viele Komponenten hat die von anderen Komponenten abhängen müsste man dann die sag mal als einfach als Black Box gehen und sagen man trägt die Zahlen einfach ein und oder könnte man da verschiedene Systeme abhängig voneinander einbauen.
Wenn zum Beispiel ein Sensor ein eigenes Cyber-physical System wäre?

Interviewer: Felix Schöllhammer12:41
Okay.
Ja gut, also wenn jetzt gerade ist, so dass das nur das Component eingetragen wird und jedes Component, wenn natürlich einzelne Component.

Respondent (1) 12:48
Wo ist

Interviewer: Felix Schöllhammer 12:53
Mehrere Abhängigkeiten haben.
Das ist bis jetzt nicht möglich, ne, aber man könnt könnte quasi, man könnte ja theoretisch das ganze Tool dann zweimal benutzen und sagen, ok wir gehen hin und greifen auf den Impact des anderen CPS zu.

Respondent (1) 12:59
ja was?
Ja nee, also da wär auf jeden Fall denk ich ne, also mir ist das jetzt im Kontext von [CAR MANUFACTURER COMPANY] eingefallen, weil das ist komplex halt immer so hoch, dass.
Das das dann ne schöne Erweiterung von dem Tool wäre wenn an aufeinander aufbauen könnte auf verschiedene Systeme.

Interviewer: Felix Schöllhammer 13:26
Ja.

Respondent (1) 13:26
Also wenn man dann mal überlegt wie man das bei einem Auto das ansonsten berechnen will. Das sind so viele Systeme, die auch wieder von anderen System abhängen sind. Aber das kann man dann ja wenn man von unten anfängt sich nach oben zusammenarbeitet.

Interviewer: Felix Schöllhammer 13:30
Ja.

Respondent (1) 13:35
Nochmal.

Interviewer: Felix Schöllhammer 13:35
Okay dann kommen wir zur ersten Frage. Vielleicht wird sich nochmal was wiederholen. Was ist dein Gesamteindruck von dem Tool, und was sind die Stärken und Schwächen dieses?

Respondent (1) 13:51
Also ich finds gut, ich fands sehr schön. Ich finde es wichtig, dass man auch dem Punkt ein eigenes Tool widmet, weil es ziemlich unabhängig ist, denke ich von anderen Kriterien wie zum Beispiel ob es funktioniert, wie teuer ist einfach eine komplett oktogonale quasi Komponente von Entwicklung.
Das Interface der Super aus Visualisierung fand ich schön. Wirkt jetzt intuitiv verwendbar und das alles super.
Genau.
Dann schwächen. Ich würde jetzt nicht sagen schwächen vielleicht höchstens.
Wenn die Komplexität steigt, muss man schauen, wie man das dann quasi verwaltet.
Also zum Beispiel, wenn man Abhängigkeiten hat von verschiedenen System.
Aber gut, dann hätte man im Wesentlichen mehr ebenen denke ich, also ich glaube, das sollte auch skalierbar sein, das Tool.
Insofern, ja, ich würde sagen, es ist eher eine Stärke das man es wahrscheinlich skalieren kann.
Wenn man halt halt quasi diese nested Excel Struktur verwendet.

Interviewer: Felix Schöllhammer14:45
Perfekt. Denkst du das Tool ist nützlich?

Respondent (1) 14:51
Ja, also auf jeden Fall. Ich hab jetzt bei mir in meiner Erfahrung gesehen das halt sowas teilweise einfach nicht wirklich gemacht wird, gut.
Liegt natürlich auch daranob es eine Sensibilisierung gibt es zu tun, aber auch wenn man es machen will ist aktuell denke ich schwer das zu tun, weil ja man muss es irgendwie angehen und ich nehme an, wenn das jetzt nicht immer das Beispiel von [CAR MANUFACTURER COMPANY] nehmen aber mit Autos in dem Kontext.
Wenn man das machen will, deutlich besser mit so einem Tool das zu tun, als wenn mir jede Abteilung in einem unternehmen das selber zusammen trägt. Also ich glaub das es wichtig ist es zu strukturieren und zuordnen und da so ein Tool sehr gut dafür.

Interviewer: Felix Schöllhammer15:25
Dankeschön. Und jetzt würde ich über ein paar Fragen gehen, da würde ich gerne deine deine Antwort von 1 bis 5, also einer Likert Scale hören von 1 ist nicht nützlich

und dann 5 ist äußerst nützlich.
Um die allgemeine Nützlichkeit dieses Tools zu evaluieren, die die erste Frage ist, inwieweit ist es nützlich, verschiedene Konfigurationen eines CPS zu spezifizieren?

Respondent (1) 15:45
sehr nützlich also 5.

Interviewer: Felix Schöllhammer15:54
5.

Interviewer: Felix Schöllhammer15:56
Ok und warum?

Respondent (1) 16:01
Ja, weil ich glaube, wichtig ist das jetzt das flexibles, weil einfach das Feld so weit ist. Und wenn es ein Tool soll es wirklich bei sagen mit verschiedensten Anwendungsbereichen verwendet werden soll, dann muss man auch verschiedene Konfigurationen spezifizieren können und vergleichen können und es sind nicht nur zur Analyse von einem einer Konfiguration, sondern eben auch zum Vergleich oder zum dokumentations Archivierung. Also Flexibilität ist ja glaub ich super wichtig und denke, dass die Konfiguration da helfen.

Interviewer: Felix Schöllhammer16:32
Dankeschön. Inwiefern ist es nützlich, die Umwelt Auswirkungen verschiedener CPS Konfigurationen zu vergleichen?

Respondent (1) 16:40
Ja, auch auch 5.

Interviewer: Felix Schöllhammer16:44
Mhm.

Respondent (1) 16:45
Weil, na gut, das ist das Ganze, die ganze Idee vom Tool ist, diesen einen Wert zu

bestimmen und wenn wir irgendwie zur Entscheidungsfindung beitragen sollen, muss man n bisschen welche Optionen die Firma, die eine wissenschaftliche Forschung hat.
Welche Optionen hat quasi welchen Einfluß? Also das ist glaube ich sehr wichtig.

Interviewer: Felix Schöllhammer 17:03
OK.
Inwiefern ist es nützlich, automatisch Informationen aus dem Produkt im war mental Profile zu extrahieren?

Respondent (1) 17:14
4.
Äh, das ist nützlich. Es ist nicht so essentiell, man kann es natürlich theoretisch auch manuell machen, aber das macht wenig weniger spaß als automatisch, also nützlich, aber nicht ganz so kritisch, würde ich sagen.

Interviewer: Felix Schöllhammer 17:22
OK
Inwiefern ist es sinnvoll, Indikatoren für Umweltauswirkungen in Diagrammen zu visualisieren?

Respondent (1) 17:35
Auch 4.
Auch wir super angenehmen, super hilfreich, aber auch da. Theoretisch würde man wahrscheinlich auch ohne Visualisierung zurecht kommen. Also ich sage nicht kritisch für die einzelnen Einsätze, aber einfach besser.

Interviewer: Felix Schöllhammer 17:47
OK! Inwiefern ist es sinnvoll, das Volumen der durch das CPS erzeugten Daten zu berechnen?

Respondent (1) 17:57
4
Ja, will ich sagen, je nach Anwendung. Also ich würd sagen durchschnittlich 4 , ich würd sagen je nach Feld ist es ist auch eine 5, also gerade wenn man in Richtung AI

geht wenn die Daten einfach einen sehr Signifikaten Einfluss auf die Umwelt haben, ist es eher hoch. Aber in Hardware nahmen Systemen eher ne 3 und daher würde ich sagen eine 4.

Interviewer: Felix Schöllhammer18:16
Danke.
In wie weit ist es sinnvoll, den Co 2 Fußabdruck, der von den CPS generierten Datenvolumen zu berechnen?

Respondent (1) 18:29
Dann Punkt 5 würd ich sagen. Also wenn man Daten hat und ich meine auch wenn es wenige sind, Daten können immer eskalieren kommt drauf an wie viele man verwendet, insbesondere jetzt wo sich so ziemlich alle Disziplinen immer stärker Richtung AI oder zumindest Datadriven ausrichten. Sehr wichtig zu berechnen, auch wenn bei kleinen Projekten der Impact sehr kleines ist ja trotzdem gutes Zeichen. Also ja sollte man auf jeden Fall berechnen.

Interviewer: Felix Schöllhammer18:52
Okay danke. Inwieweit ist es sinnvoll, die Standortbezogenen Kohlenstoffintensität des Stromverbrauches der Komponenten zu berichtigen berücksichtigen?

Respondent (1) 19:04
Auch würde ich sagen 5. Das ist nicht ganz meine Expertise, aber zumindest dann von dem, wie ich es auch Einsätze wie internationale Zulieferer zusammenarbeiten, muss man natürlich die Gegebenheiten des Ursprungslandes berücksichtigen. Und ja, das kann bei großen Firmen halt schnell mal wirklich dutzende Länder sein, also glaube ich richtig, dass man das berücksichtigt.

Interviewer: Felix Schöllhammer19:24
Okay vielen Dank so, das waren erstmal die Fragen über die Nützlichkeit. Nächste Frage würde dann sein, würdest du Umweltauswirkungen eines CPS in die Designentscheidung, als würde das deine den seinen Entscheidungen beeinflussen.

Respondent (1) 19:39
Auch wieder von 1 bis 5 oder auf eine Frage.

Interviewer: Felix Schöllhammer 19:41
Ne, einfach ne offene Frage jetzt.

Respondent (1) 19:44
Ja, würde es. Ich glaub insbesondere wenn man äqualente alternative Optionen hat, also man verschiedene Richtungen hat wie man gehen kann und.
Ja, würd ich sagen, ist einfach ein weiterer Faktor, den man berücksichtigen kann und gerade auch mit der aktuellen Entwicklung, zumindest in Europa das auch stärker das Ganze auf auf gesetzlicher Ebene unterstützt wird oder vorgeschrieben wird glaub ich jetzt auch immer wichtiger Unternehmen das frühzeitig berücksichtigen und frühzeitig auch ja Systeme entwickeln das erstens bekannt ist, wie der Einfluss ist und zweitens auch natürlich irgendwelchen Richtlinien die da sind oder noch kommen werden entsprechen. Also ich glaub das ist sehr sehr wichtig.

Interviewer: Felix Schöllhammer 20:25
Wenn du das Tool verwenden würdest, welche der 4 Impact Indicators würdest du am meisten aus Aufmerksamkeit schenken und auch dann in Designentscheidungen am meisten beeinflussen? Die 4 Impact Faktoren sind CO 2 footprint/ global Warming, Fresh water usage, Water pollution and Acidification of soil and water.

Respondent (1) 20:55
Ich würde sagen CO2
Aber das liegt auch daran, dass das das Wort ist was am häufigsten verwendet wird. Also ich glaub aus Sicht von so, Wissenschaft ist auch Industrie, damit erzeugt man im Zweifelsfall am meisten positives Feedback aktuell, das kann sich ja auch ändern, aber weil der gegebenen soziopolitischen Situation ist CO2 glaub ich am wichtigsten.

Interviewer: Felix Schöllhammer 21:16
Vielen Dank.
Und dann zu der letzten Frage hier würdest du das Tool verwenden um den Umwelt Fußabdruck von CPS zu berechnen?

Respondent (1) 21:29
Ja, also ich kenn mich nicht im Kontext was Alternativen sind aber.

Basieren auf meinem Stand der Dinge, was jetzt effektiv nur dein Tool ist, würde ich das auf jeden Fall anwenden und es sah auch sehr benutzerfreundlich aus. Also wäre ich glaube ich, absolut dafür, dass auch bei [CAR MANUFACTURER COMPANY] oder jetzt auch in meinem Feld es zu verwenden, wenn es denn von der Firma entschieden wird.

Interviewer: Felix Schöllhammer 21:51
Dankeschön okay ja, das war es schon so weit mit den Fragen. Die letzte Frage wäre dann, ob du interessierst bist Updates über das Projekt zu erhalten und auch Zugang zu dem Tool und der Abschlussarbeit, wenn das Ganze fertig ist.

Respondent (1) 22:05
Ja klar, auf jeden Fall ich bin gespannt.

Interviewer: Felix Schöllhammer 22:07
Cool, ja cool, das freut mich, das ging schneller als erwartet, sehr gut.
Okay dann werd ich jetzt mal hier die.
Recording stoppen oder willst du noch irgendwas anderes sagen?

Respondent (1) 22:19
Ne Pass gut. Gute Arbeit!

Schöllhammer, (Felix) stopped transcription

Transcript of Interview 2

3 July 2023, 06:02pm

Interviewer: Felix Schöllhammer started transcription

Respondent (2) 0:06
OK, no problem.

Interviewer: Felix Schöllhammer 0:08
OK. Then let me just see if it works.

Respondent (2) 0:15
That looks like it's recording on my side.

Interviewer: Felix Schöllhammer 0:15
Yeah, it's working perfect. Yeah. OK. Thanks a lot. OK, then we start with the first question. Are you mainly working for private companies or research into institutions, universities, or a combination of both? (Quest I: 1)

Respondent (2) 0:30
I work in the university and I do have consultations with the some companies.

Interviewer: Felix Schöllhammer 0:35
But you're mainly working with the university.

Respondent (2) 0:39
Yes, my main job is actually in research. In the university.

Interviewer: Felix Schöllhammer 0:46
OK. Thank you for that. What is your field of expertise and what is your connection to cyber physical systems, Internet of Things and smart home? (Quest I: 2)

Respondent (2) 0:57
So my field in general is, IoT. My job is the [country] research chair of IoT.
And my work is in research of IoT systems from the application layer to the physical layer. Some cyber physical system deployments such as sensors and a system that can collect and gather data. And some of them are in harsh weather conditions. Deploying sensors in the extreme cold or in the forest? So this is this is my exposure to the CPS systems.

Interviewer: Felix Schöllhammer 1:37
OK. Thank you for that. And then might be a little of an overlap, but what type of involvement do you have in CPS projects? (Quest I: 3)

Respondent (2) 1:46
So mostly the sensing components in this sensing components, we deploy these sensors in the wild. Uh. In the streets, like traffic lights or in the forest? Or collecting data from water streams? Uh, and all of those has some environmental.
Condition that we have to consider in our design for the systems.

Interviewer: Felix Schöllhammer 2:10
And in what steps are you involved: design/ implementation/ evaluation deployment testing?

Respondent (2) 2:22
Yes. So in it's mainly implementations and deployment, testing is done in the lab settings. And sometimes if we have a problem that we have to send somebody in the field to check which part of the assessment in general for,
or you can call it maintenance afterwards.

Interviewer: Felix Schöllhammer 2:41
OK.

Respondent (2) 2:42
But we do follow the best practises in our design. So, for example if we deploy something in the extreme heat or in the extreme cold, we have to isolate the

conditions. The components from these environmental conditions and make sure that there is no extreme heat that would expose to the components. So that would affect our cost failure to the system.

Interviewer: Felix Schöllhammer 3:06
OK.
Thank you. And what is the typical size complexity of a CPS that you are working with? (Quest I: 4)

Respondent (2) 3:15
Typically very small sizes. We don't have a large-scale system. In most cases we do have about 10 to 15 sensors in our systems and those are in controlled environment that we can always resort to do some kind of maintenance.
Uh, we haven't put anything in the wild yet of large scale systems, but you can say, ranging from small to medium size.

Interviewer: Felix Schöllhammer 3:41
Thank you. And then how long have you been active in the field? (Quest I: 5)

Respondent (2) 3:47
I've been in the field since, uh 2013, so you can say about 10 years.

Interviewer: Felix Schöllhammer 3:52
OK. And next question is do you consider environmental impacts when working with CPS? (Quest I: 6)

Respondent (2) 4:01
Of course. So the two major thing that we consider in our design or working with the CPS in general is exposure to extreme heat or extreme cold and humidity and moisture. So extreme heat and extreme cold is basically the two condition that can affect the system performance and reliability, specifically for the components of the CPS systems like hot temperature can lead to overheating or accelerate the component degradations or increased failure rates.
And as well as extreme low temperatures such as snowing or freezing can reduce

efficiency and cause the material to degrade or impair the functionality of the CPS in general.

Interviewer: Felix Schöllhammer 4:51
I'm OK. Thank you for that. In this question we focus on the environmental impacts of the CPS. We consider environmental impact as, for example, the environmental impacts that the sensor, the production, the usage and it's whole lifecycle has on the environment. For example, if you produce a certain sensor, you have a CO2 impact of let's say, 5 kilogrammes. So, it's more about the actual environmental impact of a certain CPS component on the environment, and not the impact of the environment on the sensor. What you say you also consider this somehow? (Quest I: 6)

Respondent (2) 5:29
Yes. So, we don't manufacture sensors, or something related to CPS manufacturing, but when we choose our components for the design, we choose the sensors that are reliable for the condition. So, for example, if we're doing something with a high vibration, we choose the sensor that has some kind of vibration resistance or can sustain high vibrations in the system. Those sensors that we use for temperature were in the high temperature or severe call. We choose those sensors to have an extended range of Temperature up and down so we can ensure that the system can cannot fail in in the middle of the task.

Interviewer: Felix Schöllhammer 6:18
OK. Thank you. And then the last question here is in your experience or observation, is it common that components of the CPS are reused if they're not needed anymore or are they usually disposed? (Quest I: 7)

Respondent (2) 6:34
So in our case we mainly reuse the components for some other systems. So, for example, if we're using camera in a in a certain application and we're done with this application, we reuse the camera for a different purpose.
But if we're deploying a sensor in the water stream and we're done with this task and then it's no longer needed, the only thing that we can do is we can e-waste the sensor. So, in most of the cases, we reuse the sensors or the CPS components into

different things unless the component was designed specifically for an application, that no longer exist, so we have to dispose it.

Interviewer: Felix Schöllhammer 7:15
OK, perfect. Thank you for that.
And now I would like to just send you here a link. You can find it in the in the chat.
It's the YouTube video that presents the tool we developed together.
Just watch it and let me know when you're done with it. It's six minutes long and afterwards I will ask you some questions.

Respondent (2) 7:36
OK, good. So it says video unavailable.

Interviewer: Felix Schöllhammer 7:42
OK, I'm sorry for this. Let me see.

Respondent (2) 8:31
I believe you can go to the settings and make it, publicly available for me.

Interviewer: Felix Schöllhammer 8:57
True.

Interviewer: Felix Schöllhammer 9:00
Here I can. Public. OK.
Let's see if it works now.
It should be the same line. I'm sorry for the inconvenience.

Tool Presentation

Interviewer: Felix Schöllhammer 15:31
Thank you.
OK, first question is, do you have any general questions about the tool or how it works? (Quest M: 1)

Respondent (2) 15:39

No, I just have a general comment. I was under the impression that you guys are looking for the environmental impact on the CPS system, but it looks like you're looking for the environmental impact of the CPS. So, looking into the footprint of the CPS systems, not how environmental conditions can negatively affect the CPS systems. Is that correct?

Interviewer: Felix Schöllhammer 15:53
Yes.
Yeah, exactly.

Respondent (2) 16:04
Okay. So, you're looking for emission CO2 footprint, water consumption, e-waste stuff, stuff like this.

Interviewer: Felix Schöllhammer 16:08
Yeah.
Exactly in that direction. I'm sorry if that didn't come through before.

Respondent (2) 16:15
No, it's OK. I so the keyword here is on and of. So, when you say on CPS system, it looks like you're looking into how environmental conditions can negatively impact the design of CPS systems like exposure to extreme heat, extreme cold and vibrations and stuff like this versus the environmental impact of the CPS system, which is basically how much impact CPS system would have in the environmental such as. CO2, green gas, stuff like this. So, this was the difference that I think should be clarified.

Interviewer: Felix Schöllhammer 16:50
OK. Thank you for your insight.

Respondent (2) 17:05
Yeah. So, from that perspective, I think you need to focus more on energy consumption. So, for example, when you generate data or when you use CPS, there is a back end, always, which is the back end support system.
In which there is server room there is energy consumption. There is cooling systems.

So, this is all required for CPS systems. They would generate consumer power, which may contribute to green gas emission and greenhouse stuff like this, as well as the electronic waste.
So, when a sensor is out of life or something like this, what you do, so you just e-waste so you increase the e-waste in the system which is also having a negative impact on the environment in general.
So and resources. For example, if you e-waste a sensor, you need to reproduce different sensors. So, which is most of these sensors used in their manufacturing cycle? They use minerals and raw material extraction process itself would impact the habitat or affected the biodiversity of the system.
So those raw material cause imbalance in the environmental systems in general.

Interviewer: Felix Schöllhammer 18:34
Yeah. Thank you for that.

Respondent (2) 18:35
Doesn't make sense.

Interviewer: Felix Schöllhammer 18:36
Yeah, that makes sense.
And that's also the idea of the tool that you basically go and have different configurations of one CPS and then you say, OK, once we have 10 sensors of this type and then maybe in the second configuration, we have a different type of sensor. And then in the end you would compare the environmental impacts of your configurations and then you can make the decision what you would actually implement on what, what makes the most sense.

Respondent (2) 19:09
Right. But do you guys make recommendations on, for example, a sensor does not need to frequently send the data, so it can only send that the data when there's a change. So, in the system design itself, this can reduce a lot of the traffic or the data or the use of communications and or the energy used for this stuff. So, this optimised operations can reduce very much the impact on the environment.

Interviewer: Felix Schöllhammer 19:23

Yeah.
Yeah, definitely.

Respondent (2) 19:34
And in this case, if you suggest some reconfigurations. So, if you if you look into a system and say we're sending the temperature every one second.
And in in these small period of time, temperature that does not change it too much. So, there is no need to actually send it the temperature that frequent in the system design. You can only sense when there is a difference plus or minus one and then you can send the data when there is a change. Otherwise, you assume it was the same like the previous value for example.

Interviewer: Felix Schöllhammer 20:06
Yeah.
That's very good input. That's also what we thought about.
And you can also say we have an event-based approach, so only if a change occurs or something then the data is being sent in this. In this example in the tool presentation, we only used the periodic sample approach.

Respondent (2) 20:36
Event based for example sends only when an event happens like if there is an overheat caused by something. So, you'd send this information if doesn't overheat.

Interviewer: Felix Schöllhammer 20:39
Exactly, yeah. It is. Yeah.
OK, let's come to the second question. That would be how would you describe your overall impression of the tool and what would you say is it strength and weaknesses? (Quest M: 2)

Respondent (2) 21:03
I very much like the tool I think you're providing good data for the user.

But it looks like you're focusing more on CO2 and emission. You're not focusing too much on power consumption, for example.
I didn't see power consumption like graphs in the tool, but I think adding power

consumption would be very important to cause a power consumption is very much connected with too many things like cooling and heating and CO2 gas emission.
On this stuff as well as the power itself. So, the power, the power generators that the amount of consumption you have. So, from generation to disposal is very important to have this life cycle.
And most of the CPS impact in general does not come from the small sensor that which is in the front end. It comes from the back-end support system, like in the infrastructure. So those if you have a way to quantify those energy consumption in the back-end support system, I think that will be very much valuable to the users as estimating the footprint of the environmental impact on CPS.

Interviewer: Felix Schöllhammer 22:02
Very good. Thank you so much for that. Just to once clarify, we do consider actually also the energy consumption of the CPS components and that's why you specify also the country, because every country has a different carbon intensity for producing electricity and so that we do in take into account.
But a whole data centre if it's not seen as a part of the CPS like as a component like a computer or the server or PC and then we don't directly take this into account. Only in the data footprint. Thank a lot that is a very good input from your side.

Respondent (2) 23:00
Yeah, I think you can. What you can do is you can calculate how much computing units required for the CPS system and based on this computing units, there is an estimation on how much energy is required. So, it doesn't have to be connected to the entire data centre, but you can calculate for example the amount of CPU cycles required for this data. And if you have then estimation then you can very much estimate the power consumption for the CPU cycles. Including the heating, generation and processing in all these, these things would be calculated.

Interviewer: Felix Schöllhammer 23:40
Thank you.
OK. Then the third question.
Do you think the tool is useful? (Quest M: 3)

Respondent (2) 23:48

I think it's very useful and overtime when you add more insights from the feedback from the interviewers as well as your own experience into the system itself. You would end up having a very nice tool for people to use.

Interviewer: Felix Schöllhammer 24:04
Thank you.
And now I will go over some questions and I will ask you to write from 1:00 till 5 how useful you find them and certain features. One is not useful at all. And then five would be extremely useful.
The first question is to what extent is it useful to specify different configurations of the CPS? (Quest M: 3.1)

Respondent (2) 24:29
I think this is very useful, so I would rate that as five.

Interviewer: Felix Schöllhammer 24:32
And why would you write it at 5 past five?

Respondent (2) 24:35
Because the configuration can very much affect the footprint. So certain configuration can have an optimized operation. An operation can have a list optimised or inefficient Pipeline in the process so that will affect the footprint.

Interviewer: Felix Schöllhammer 24:52
Very good.
To what extent is it useful to compare the environmental impacts of different CPS configurations? (Quest M: 3.2)

Respondent (2) 25:01
Again, this is tied to the first question. So, once you have a configuration you need to quantify and estimate the footprint and based on the footprint you can trade-off between your efficiency or system requirement and the environment impact. So, if you care more about environmental impact, you can accept a lower efficiency if you care too much about efficiency, maybe you can reduce your considerations to the

environment depending on the system design and requirement.
Five, this is very important.

Interviewer: Felix Schöllhammer 25:37
Thank you. And to what extent is it useful to automatically extract information for the from the product environmental profile (PEP) documents? (Quest M: 3.3)

Respondent (2) 25:49
Yeah, I think this is important. So, I would rate it as three. In most cases there, are some standards that most of the people who care about the environment follow. So, it might not differ too much from a country to a country except for pricing. But the footprint would not very much be different. So, if I have a system in Spain, it will be the same system in Canada. The only thing that would differ is the price. But the footprint would be the same.

Interviewer: Felix Schöllhammer 26:16
OK.
To what extent is it useful to visualise environmental impact indicators in charts? (Quest M: 3.4)

Respondent (2) 26:27
I think it's important. I would rate it as four. People would visually see the environmental impact and would very much appreciate the result.

Interviewer: Felix Schöllhammer 26:37
Thank you. To what extent is it useful to calculate the amount of data generated by the CPS? (Quest M: 3.5)

Respondent (2) 26:47
I think this is important, I would rate it three. But again, depending on my understanding, I might not be correct.
The amount of data you generate, you need to be tied to the communications, for example, or a storage system. So, if it's related to the storage or communications it really has an impact on the environment because you're consuming much energy,

you're using more communications. So, If I would assume that. I would rate 4 because it causes some kind of footprint.

Interviewer: Felix Schöllhammer 27:19
Thank you.
To what extent is it useful to calculate the environmental impacts of generated data for CPS? (Quest M: 3.6)

Respondent (2) 27:31
Same thing, like the previous ones we generated. Data is basically amount of data you generate out of the CPS which requires storage. Required communications, require analysis and insight. So, all of this require some computing cycles and storage, so it would generate some footprint as well. So, I would I put it as four.

Interviewer: Felix Schöllhammer 27:52
Okay, thank you. And last question here, to what extent is it useful to take the components location related carbon intensity for electricity consumption into account? (Quest M: 3.7)

Respondent (2) 28:05
I don't think this is very important. I would read it as one. As I mentioned in my previous example, the footprint would not change, but the price would matter from a place to place. So, a component would generate the same footprint in different locations, but the price of using the energy is what would be different. So, I don't think this is very important in the system design.

Interviewer: Felix Schöllhammer 28:26
OK, thank you. Would you the environmental impacts of a CPS influence your design decisions? (Quest M: 4)

Respondent (2) 28:35
Of course. But I would trade off with the system requirements, so I would look into the system requirement first and I would favour the system requirement over environmental impact unless environmental impact affect is actually severe. Then I

would rethink of my design strategy to mitigate those impact or reduce the impact on the environment.

Interviewer: Felix Schöllhammer 29:04
Thank you.
If you were using the tool, which of the four impact indicators would you pay the most attention to and influence your design decisions and the first one is CO2 footprint, global warming and the 2nd is freshwater usage. The third is water pollution and the 4th is acidification of soil and water. (Quest M: 5)

Respondent (2) 29:30
I would choose in order.
three, four and one. Two is gonna be the last one.
[water pollution]

Interviewer: Felix Schöllhammer 29:38
OK. Okay, thank you so much.
Would you use the tool to calculate environmental footprints of the CPS? (Quest M: 6)

Respondent (2) 29:53
If I would have tested it and I have confidence in it, I definitely would.

Interviewer: Felix Schöllhammer 29:59
OK. Thank you so much. And then the last question, would you like to receive when we're done with the project, the final paper and also get access to the tool? (Quest C: 1)

Respondent (2) 30:08
Of course, if you if there's a chance, I would very much appreciate having the access to have a look and see what will be the result.

Interviewer: Felix Schöllhammer 30:18

Perfect. Thank you so much. So, thanks a lot for your answers and your time, I would stop the recording now.

Interviewer: Felix Schöllhammer stopped transcription

Transcript of Interview 3

4 July 2023, 09:03am

Interviewer: Felix Schöllhammer started transcription

Interviewer: Felix Schöllhammer 0:05
Ok I have started the recording.
OK, so I will start with the first question. If you are ready for that and don't have any other questions, OK.

Respondent (3) 0:15
OK.
I have no idea what the questions will be.

Interviewer: Felix Schöllhammer 0:21
You don’t have to be prepared for it. It's all really just your opinions about our research and how you think about it? And also, you might have to repeat what you just said. But the first question would be: Are you mainly working for private companies or research institutions/ universities or a combination of it?

Respondent (3) 0:45
Ohh I'm working mainly.
Well, it's a combination of it. I mean I work in a Research Institute, an education institute, but I collaborate significantly with the private companies.

Interviewer: Felix Schöllhammer 1:03
Hmm. What kind of private companies would that be?

Respondent (3) 1:08
Many chemical industries and within that chemical industry, food industry.

Interviewer: Felix Schöllhammer 1:14
OK. Thank you.
And then:

What is your field of expertise and how would that be connected to cyber physical systems, Internet of Things, smart home or maybe also life cycle assessment?

Respondent (3) 1:30

My expertise is a mathematical modelling of chemical systems or processes systems and within that we do also.
I do a lot of research on model-based control which could be consider as intelligent decision making in a way.
So we developed algorithms, we developed technology, software technology that will drive these systems that we are interested in. This could be a smart home or a chemical plant or uh, electrolyser too, you know, drive these systems in the way that we want them to operate. So there is always a direct an natural connection between software and physical system.
Um, and within that sensors uh for us for control engineer sensors place they play an important role because these are there to sense these tools, devices that we get information data.
And then use this data for our own purpose.
Yeah. So that's a nice thing and gives me a nice setting for in my research that gives me the opportunity to collaborate with different aspects of cyber physical systems.

Interviewer: Felix Schöllhammer 3:01

Very good. Thank you for that. What type of involvement do you have in CPS projects? So, in what kind of phase?
Where are you involved? So, would it be, for example, the analysis and design of CPS implementation, programming, evaluation and where would you see yourself? Or maybe it's also a combination of it.

Respondent (3) 3:26

Yeah. I will say in the beginning there developing the technology and most of the times when we collaborate with the company, we show them the proof of principle and we don't get involved in the implementation because we don't have access to the physical area or their infrastructure.
They don't let us now. We are a little bit, restricted in that and of course that,
I'm not happy about it. I would like to be closer to the implementation because once

we develop our Technology and show the proof of principle. We don't know what happens with our technology within the company. We don't hear anymore.

Interviewer: Felix Schöllhammer 4:17
Yeah.

Respondent (3) 4:19
And that's the downside of it.

Interviewer: Felix Schöllhammer 4:19
OK, I see I can understand that. Yeah.
And what is it? Typical size or complexity of the CPS you working with?

Respondent (3) 4:36
Can you be a more elaborate? What do you mean by size?

Interviewer: Felix Schöllhammer 4:47
Yeah, maybe the quantity of the components of it or.
And yeah, just to kind of see, yeah how big it is and how big these projects are?

Respondent (3) 5:06
So yeah, it ranges. It could be a small reactor 1, some sometimes just a simple reactor.
A Physical System which you can have only two or three handles to play with. It could also be a network of systems together like exchanges or.
Couple of many, many units altogether, so the IT it can go from one small thing to big, large scale.
System because our methods or technologies generic and we can adjust. Yeah, different levels of complexity.

Interviewer: Felix Schöllhammer 5:55
OK.
Thank you.
And how long have you been working in the field?

Respondent (3) 6:04
Ohh, quite some time. I've been in the university since 2009.
And yeah, my PhD was also in the model-based control. Uh. So more thank 23 years.

Interviewer: Felix Schöllhammer 6:20
Very nice.
OK, then we come to the next question. Do you consider environmental impacts when working with CPS and we talking about the environment impact we mean the environmental impacts of the CPS on the environment?

Respondent (3) 6:38
So if OK, I assume when you say cyber physical you hin mind the combination of the physical system and software part.

Interviewer: Felix Schöllhammer 6:54
Hmm.

Respondent (3) 6:54
Yeah. And environmental impact could have different aspects.
In chemical industry, yeah.
Environmental impact is quite important, we are. Technology always tries implicitly, let's say implicit the tries to minimise this impact the physical system is doing to the environment when it comes to software part. Of course, some of these algorithms can require a lot of energy or computation load and we also strive to reduce this computation load. So in in some in different ways.
We consider environmental impact, but it's not very explicitly defined, in our technology, to be honest.

Interviewer: Felix Schöllhammer 7:52
OK, very good. And then could you then maybe specify in what kind impacts or what factors you take into account so energy consumption then?

Respondent (3) 8:03
Main energy consumption most of our projects are based on energy consumption,

but also waste reduction.
But as I said, they are not explicitly mentioned or considered in a mathematical formula in our technology. We assume that if we drive the system to a certain operating point or operate the chemical plant in a certain way, we will achieve these goals. But there are implicitly defined.

Interviewer: Felix Schöllhammer 8:15
OK!
And next question would be how do you analyse them?

Respondent (3) 8:49
We don't analyse them. We don’t do life cycle assessment analysis now.

Interviewer: Felix Schöllhammer 8:58
Thank you for that. And then here the last question in this field would be: In your experience/observation is it common that components of a CPS are reused if they are not needed anymore? Or are they usually disposed?

Respondent (3) 9:18
I think they are not reused, no?
They're not, reused. I have to say. I mean I am in a group where
we have collaborated with different type of industry.
There's the high-tech industry.
Which is quite advanced I think when it comes to this kind of technology, or at least open to innovation.
There this question could get a different answer.
In my case I deal with an industry that is very conservative and in when it comes to cyber physical systems.
Our software taking advantage of available software or new technology.
It's very conservative and primitive and infrastructure goes back to 1960s an 1970s and you cannot do much.
And especially in the food industry, most of the systems controlled or managed by Manal operator.
So a reuse of technology or recycling or some cyber physical system components. I don't think this exist.

Interviewer: Felix Schöllhammer 10:52
Thank you for that.
So now I'm gonna send you a link to a YouTube video that we created.
It's a presentation of the tool we developed and it's 6 minutes long and afterwards I will ask you some questions about what you think of that tool?

Respondent (3) 11:10
OK Good!
Yep.
Okay.
OK I have a problem. I'm blocked.

Interviewer: Felix Schöllhammer 11:30
It doesn't work?

Respondent (3) 11:31
No, it doesn't work for me.
Let me try again.
Now it works!

Interviewer: Felix Schöllhammer 11:44
Now it works okay perfect!

Respondent (3) 11:45
Yeah.
OK.

Interviewer: Felix Schöllhammer 18:13
Do you have some general questions about the tool or how it works before?

Respondent (3) 18:17
Is the tool is the developed for Excel users.

Interviewer: Felix Schöllhammer 18:21

It's and it's on Google Sheets, so it's online and like excel.

Respondent (3) 18:33
It looks like excel to me.

Interviewer: Felix Schöllhammer 18:34
It's basically excellent. It's basically excellent.

Respondent (3) 18:37
OK.

Interviewer: Felix Schöllhammer 18:41
You can easily define some custom functions and also access online databases, for example. And you can write custom functions with JavaScript, so that's a little bit of a difference. But in in general it's like excel, but online accessible.

Respondent (3) 18:53
How safe it is to work in Google Sheets?
I think what if you want to sell this tool to a company or something. Yeah. They the first thing they will ask is, you know how safe it is.
Privacy data issues. Uh, I think that's quite important for them because they're very sensitive about these things.

Interviewer: Felix Schöllhammer 19:21
That is definitely very important. That's a good point. And a very good insight. I mean companies need to take this into account. We used Google Sheets in this research because we wanted to develop something that is easier and free to access for everyone and open.

Respondent (3) 19:53
Ah yes open and free!

Interviewer: Felix Schöllhammer 19:56
So for us it was that was why we made that decision. But I guess if we look at a step

further into the future and see how people see this tool and maybe even using it, then of course these issues need to also be taken into account and maybe an alternative platform can be used.

Respondent (3) 20:14
Yeah. Another thing is that I need LCA background.
Life cycle assessment background. I know what it in general what it means.
But I don't know the technology behind it. Maybe for as a researcher, I would be interested in that, but what's going on here? But maybe for a user who doesn't want to know, then it's OK you don't see anything, but could be nice for that type of user.
[More information about LCA]

Interviewer: Felix Schöllhammer 20:45
Yeah, I see.

Respondent (3) 20:50
But you. Yeah. So that that's why I question the tool a little bit. What's going on?
Yeah, but that is a personal thing, I think. Yeah.

Interviewer: Felix Schöllhammer 21:02
Yeah. Yeah, just a general short Summary. What the tool does you basically can give different configurations of one CPS and then you Access an online available LCA repository with environmental declarations about the components. And then you can in the end see OK compare the different configurations and then maybe a influence your decision.

Respondent (3) 21:33
OK

Interviewer: Felix Schöllhammer 21:36
How would you describe your overall impression of the tool? What is its strength or weaknesses?

Respondent (3) 21:46
So 6 minutes is not very long. It's a short period to get an impression, but I think

Yeah, let me think.
You don't have to do much yourself. I mean everything. Is there arranged for the user. But you have to know that you have to go from one shot to another.
And I am not sure whether it is explained in the introduction part because it was very small, and I didn't have time to read it.
The charts are nice.
Ok you have many, many options does the tool make the decision for the user or says OK still the use his or her inside to decide which configuration?

Interviewer: Felix Schöllhammer 22:53
So the idea is just to provide the user with information.
To say OK. You can compare yourself.
You can also see what's most important for you, and now you have this information, and you'll see what you do with that, yeah.

Respondent (3) 23:11
Yeah, um, how about the the criteria I couldn't get it. I mean in the in the tool.
All these configurations are compared with respect to one performance criteria.
Just environmental impact and what is that impact? What are the components of that impact I mean?
So that was not clear to me. Where do users define what his or her own criteria is?

Interviewer: Felix Schöllhammer 23:40
Thank you. So, what we are comparing is the four impact for impact categories: CO2 and footprint, fresh water usage, water pollution and acidification of water and soil.
So it's all environmental impacts and then the user has to define the number of components they have in their CPS.

Respondent (3) 23:55
OK.
Yeah, I see, in the in the video I didn't get that. That's why I said you have to have a LCA background. That that is not provided I think or provide or provided and I didn't have time to read.

Interviewer: Felix Schöllhammer 24:28

OK. Thank you.
Do you think that you that the tool is useful?

Respondent (3) 24:43
I think it could help people to make decisions.
But not for researchers, I would say.
Uh, but for people in the company. They have to design new things. They have to change the way they build new plants, new chemical plants for example.
They have to meet new guidelines.
Guideline or you know some tool that could, helped them to compare different options?
Maybe that some of the options they haven't considered. Yeah.
In that sense, I think it will be useful for them.

Interviewer: Felix Schöllhammer 25:34
OK, thank you. And now I will ask you some questions and I would like you to indicate from a Likert scale from 1:00 to 5:00, how useful you find the features and what one is not useful at all. And then five would be extremely useful.

Respondent (3) 25:34
Yeah.

Interviewer: Felix Schöllhammer 25:54
The first question is to what extent is it useful to specify different configurations of a CPS? (3.1)

Respondent (3) 26:02
I think quite useful.
5

Interviewer: Felix Schöllhammer 26:05
Five, OK. And and why is that the five?

Respondent (3) 26:05
Yeah, yeah.

I yeah, if we have options. Uh, we need to see all the options and I feel in the industry that I collaborate. I feel like it's always copy from previous years when they will open a new system. It's like copying from 30 years ago but they have designed, and they don't consider alternatives. So it makes sense.
It should be.
Should I mean that if the tool has that feature, it's good?

Interviewer: Felix Schöllhammer 26:43
Thank you.
And to what extent is it useful to compare the environmental impacts of different CPS configurations? (3.2)

Respondent (3) 26:56
It is useful, of course, but in decision making, especially for the industry that I have in mind, let's say profit is in very important.
You don't consider them, so it's always a balance, environmental impact, and the profit.

Respondent (3) 27:17
And I.
This is the tool at the moment only focus on the environmental impact.
So if in addition to that, if you also include how much it will cost. Measures in your tool that will be much better.
Maybe, maybe I grade of three, I will say, yeah.

Interviewer: Felix Schöllhammer 27:46
OK. Thank you.

Respondent (3) 27:49
But just keep in mind, and I'm answering these questions based on the industry that I'm collaborating my experience. Uh, with that industry.
Yeah. For different industry, it could be a different answer.

Interviewer: Felix Schöllhammer 28:03
Thank you.

And to what extent is it useful to automatically extract information from the product, environmental profile and pet documents?

Respondent (3) 28:22
So you want you did this analysis and you want of course it. If you just press a button and you get a report that would be great. I think for people, yeah.
Five, it's important.

Interviewer: Felix Schöllhammer 28:35
OK.
Thank you.
And to what extent is it useful to visualise environmental impact indicators in charts? But yeah. (3.4)

Respondent (3) 28:48
Yeah, it is it.
I think in addition to the charts, you have to give some explanation.
What does this chart mean?
It's not just creating chart, it's easy to create.
But what it means for the user?
And that is always difficult. Do you speak English? Does the chart speak English to the user.
Yeah. So that's also important. I think it is. Then I think in just charts is not enough.

Respondent (3) 29:31
So I will give it a three again.

Interviewer: Felix Schöllhammer 29:34
OK. Thank you.
And then to what extent is it useful to calculate the amount of data generated by the CPS? (3.5)

Respondent (3) 29:53
What does that mean? I mean, what do you mean by this question?

Interviewer: Felix Schöllhammer 29:56
So in the in the second part we calculate how much data is produced by the sensors, for example.

Respondent (3) 30:04
Yeah.
I don't think people are interested in that. If you are a researcher and if you're deal with the data, maybe.
Then it is important for you the quality of the data, amount of data.
Other discrepancies, but if you are just a user and you want to compare different combinations, you're not interested in the data no.
It's one for me.

Interviewer: Felix Schöllhammer 30:36
OKOK.
That's OK.
And then to what extent is it useful to calculate the environmental impacts of the generated data from it from a CPS? (3.6)

Respondent (3) 30:49
I think it is important, but no one thinks about it.
This data is being used somehow in the competition and this computers run and servers and they use a lot of energy, but the users, they don't care.
It's not their priority.
But it is important.
Do you need to sample every minute, every second?
Have but if your call is life cycle assessment of a system. The generated data is not relevant. I think.
But it is related. Yeah, it is an interesting question. It's difficult to answer I think.
I would say 4.

Interviewer: Felix Schöllhammer 31:54
OK. Thank you.

Respondent (3) 31:55
OK.

Interviewer: Felix Schöllhammer 31:58
And to what extent is it useful to take the components location related carbon intensity for electricity consumption into account? (3.7)

Respondent (3) 32:11
That's a very good question because electricity prices are different, differs from country to country.
It's cheaper in France, and it's much more expensive in the Netherlands.
I think it's important five.

Interviewer: Felix Schöllhammer 32:25
OK. Thank you.
OK, now we come back to more open questions.
Would to environmental impacts of a CPS influence your decision making? (4)

Respondent (3) 32:40
Naaaaah, yes it would!

Interviewer: Felix Schöllhammer 32:43
How would it influence you?

Respondent (3) 32:46
I will look for the better solution, if I'm not happy with the result, I will think of an alternative.
But that is my personal view. Not everybody's cares about environment.

Interviewer: Felix Schöllhammer 32:53
Thank.

And then if you were using the tool, which of the four impact indicators would you pay the most attention to and maybe influence your decision making?
And one is CO2 footprint, slash global warming to is freshwater usage?
At 3:00 is water pollution and four is acidification of water and soil.
(5)

Respondent (3) 33:28
I think they are all important.
CO2 is dominating, but water is also important freshwater.
One and two, I will give more preference.
Can I answer in that way?

Interviewer: Felix Schöllhammer 33:45
Yeah, but could you make an order? Maybe what would be then the first or is that add a general both the same bottle usage and CO2 footprint?

Respondent (3) 33:55
Yeah, it's it's all equally important.

Interviewer: Felix Schöllhammer 33:58
OK.

Interviewer: Felix Schöllhammer 34:00
Thank you.
Okay the last question here is would you use the tool to calculate the environment footprints of CPS? (6)

Respondent (3) 34:17
I would!
However, I need more inform I need to study it a little bit. I'm not someone that will take a tool and accepts it as it is, you know I would like to understand it.
May on a benchmark problem I will use it and then compare it with the result of this benchmark problem. I would like to see whether the outcome of this tool, does it make sense?

Interviewer: Felix Schöllhammer 34:52
Thank you OK. And then we come to the closing question already. Would you like to receive the final paper and access to the final method as soon as we have done with the project? Yeah, yeah, you'd like to. OK. (C1)

Respondent (3) 35:02
Yes.
Yes, I will.

Interviewer: Felix Schöllhammer 35:07
And then I will stop the recording. If you don't want to say anything more.

Respondent (3) 35:13
Yeah, yeah. I want to say I don't have no additional remark. Maybe I want to make some remark. I want you to keep in mind that I answered the questions with my background and with my experience for a different person with different.
Experience in a different industry, the answers could be different.
Yeah, I always when I answered your questions, I had the mind, the chemical industry and the people working for the chemical industry.

Interviewer: Felix Schöllhammer 35:45
Yeah, that's very good. Thank you for that.

Interviewer: Felix Schöllhammer stopped transcription

Transcript of Interview 4

6 July 2023, 14:35pm

Interviewer: Felix Schöllhammer started transcription

Interviewer: Felix Schöllhammer 0:22
Any questions beforehand. Or can we just start right away?

Respondent (4) 0:24
No. It's all good.

Interviewer: Felix Schöllhammer 0:28
OK. Are you mainly working for the for private companies or research institutions, universities or a combination? (Quest I: 1)

Respondent (4) 0:38
Research Research Institute.
I just worked once for a private company and in this subject I just worked once for a private company.

Interviewer: Felix Schöllhammer 0:47
And at the moment you're working for a university.

Respondent (4) 0:50
Yeah.

Interviewer: Felix Schöllhammer 0:51
OK.
And then what is your field of expertise and what is the connection to cyber physical systems, Internet of Things, smart home? (Quest I: 2)

Respondent (4) 1:02
My field of expertise in more on ambient intelligence.
And the main domain, the main application that it's wide ambient intelligence is

quite wide, but my main application domain since the last 13 years is a smart energy and smart home.

Interviewer: Felix Schöllhammer 1:20
What type of involvement do you have in the project? So in what phase are you involved in in these projects? (Quest I: 3)

Respondent (4) 1:32
It's mainly research project. We're just trying to solve some research problem, some research question. So we are not developing a product, we are not developing something that will go to market quite soon. Hopefully we would like to to go to market at one time, but it's not the main point.
So, so basically what I'm doing is trying to find a way for people to better understand how the energy is used in their houses.
I moved from energy manager, which are quite autonomous and try to do intelligent things without the help of the user. And now I'm more some cooperative works between user and energy management systems.
I don't want to have an autonomous energy management system which drives the House alone. I want to user to be involved and it's a cooperation between the user and the system to reduce energy consumption.

Interviewer: Felix Schöllhammer 2:37
Very interesting. Nice. Thank you. And where are you involved in CPS projects? Do you design/Analyse/implement?

Respondent (4) 2:49
It depends on what you mean by cyber physical systems. If it's the IoT stuff, I'm not designing them, I'm just using them. I took it of the shelf and then we are designing the programme using it and cooperating with the users.

Interviewer: Felix Schöllhammer 3:09
OK, so in the end you are using IoT and you're also implementing it.

Respondent (4) 3:17

We just programme stuff above the IoT we are using IoT to get information and we are just programming stuff using this information.

Interviewer: Felix Schöllhammer 3:21
OK. Thank you.
And what is the typical size of? Yeah, these IoT systems. (Quest I: 4)

Respondent (4) 3:35
Well, it's something which is moving also.
We were considering at the time to have IoT devices in every houses, I mean, so of course you cannot put a lot because it's quite expensive and it's not that easy to deploy.
Now we are considering more having a kind of kit; We are having a set of devices that we can give to someone for a certain time to two, three months just a time for him to understand what's happening in his house and then we take it away and put it away and put it in another house.
The number of measure points, because some times one device can measure several ….. Sorry my English is not very good. Can measure this several physical quantities we are considering between 200 and 300 measure points in the house.

Interviewer: Felix Schöllhammer 4:31
OK. Thank you. How long have you been active in the field? (Quest I: 5)

Respondent (4) 4:49
Well, for the smart home, it's 13 years now.

Interviewer: Felix Schöllhammer 4:52
Do you take environmental impacts into account when working with CPS or smart home? (Quest I: 6)

Respondent (4) 5:09
So, yes and no. I would say no for the devices because as I told you we have a lot of devices and we are not considering the impact of those devices.
But now we are considering not having devices in every house, but moving from house to house to reduce the total number of devices.

And it's yes, because, uh, what? I'm really taking care of doing algorithms and systems that doesn't consume that much energy.
Because, you know, trying to reduce energy with doing deep learning and very consuming learning algorithms, it's pointless.
If you consume more energy in running the system that we can save, it doesn't mean anything. So, I'm we are trying to do things you know that should work on Raspberry Pi and with so very low algorithms.
We're going have algorithms, the lower process, the more, less complex, or at least not too complex.

Interviewer: Felix Schöllhammer 6:14
OK, interesting. And is there somehow a way how you analyse that or measure that or is this an overall approach we try to use less? (Quest I: 6)

Respondent (4) 6:26
No, it's an overall approach. We just try to do implicity by design in a way.
And I'm not measuring the consumption of every algorithm we are doing. I'm not doing it. But you know, I'm really considering that at the end it should work on a Raspberry Pi. So, I restrained myself from doing very complex things.

Interviewer: Felix Schöllhammer 6:48
OK. Thank you.
And then the next question, in your experience or observation and is it common that components of a CPS are reused when they're not needed anymore or are they usually disposed? (Quest I: 7)

Respondent (4) 7:04
Those are reused, they reused. How we worked the last years is that we first equipped our own apartments. The researchers of the project. And you know, when we stopped in our apartments, we just take the components and put it in the apartments of another colleague which wants to participate or join the team. So, we are all the time reusing.
You're using when we finish with it, we put it in the in, in the desk. It's here and when we need it, we take it from here. We don't buy a new one.

Interviewer: Felix Schöllhammer 7:45
Thank you. Now I would like to show you the tool presentation video. It's 6 minutes long and then afterwards I will ask you some questions about it.

Tool Presentation Video

Interviewer: Felix Schöllhammer 8:21
Yeah, there is sound.

Respondent (4) 8:23
I don't hear it.

Respondent (4) 8:27
Wait, this is a problem with once again. It works now!

Interviewer: Felix Schöllhammer 8:37
OK.

Interviewer: Felix Schöllhammer 15:08
Yeah.
OK, I think that was a probably a lot of information. So, if you if you have any questions about the tool or how it works, you can just ask me. (Quest M: 1)

Respondent (4) 15:21
I was just wondering this PEP sheets information. Is it available for every kind of sensors?

Interviewer: Felix Schöllhammer 15:34
So the pep, the product environmental profile, it's.

Interviewer: Felix Schöllhammer 15:39

It's not available for every single sensor out there, but a lot of companies in the field they put up their information publicly. So, it's not for everything available, but for a lot of sensors.

Respondent (4) 15:54
And where are you extracting the information from. Because it looks like you're extracting the information directly from the website. So, it’s normalised as the presentation is more or less normalised for this.

Interviewer: Felix Schöllhammer 16:04
Yeah, exactly.
So but also some components of a CPS if they don't have the pep declarations, then you must find another life cycle assessment another source of environmental declarations and put them in manually yourself. But if there is a pep available then it's automatically extracted.

Respondent (4) 16:40
Okay and you're using the mix energy mix from to compute the CO2. I'm not sure what you're doing exactly with the data produced.

Interviewer: Felix Schöllhammer 16:54
Yeah. So, the data part is what we do is we calculate or we predict how much data will be produced by the by the configuration. And so, we go and say, OK, if this sensor will shoot data every second or every 10 seconds, this is still amount of data it will produce per year.

Respondent (4) 17:15
Yeah, but environmental impact depends on what is this data remains local or go to cloud or.

Interviewer: Felix Schöllhammer 17:24
Yeah. So that's an assumption we make. We found some data about how much environmental CO2 footprint, 1 GB of data has in average and then we just multiply this with that amount. But of course Every data can be stored differently, so of course

it can have a different environmental footprint. For that the user can if they want also to adjust and say actually our data footprint for one GB is less or more.

Respondent (4) 18:00
Oh ok nice!

Interviewer: Felix Schöllhammer 18:01
But so this part basically puts emphasis on the topic that data also can have or has an environmental footprint.

Respondent (4) 18:09
Ohhh.
No, I was talking to you about that because in our case, it's not for environmental reason it’s for a privacy reason. We are trying always to develop something that doesn't go to the cloud, all the data remain in the house. People are owning their data, and they don't leave the house. But it was more for privacy purposes than for environmental purposes. But the data are not navigating and not going to a cloud which consume energy for etcetera.

Interviewer: Felix Schöllhammer 18:18
OK.

Respondent (4) 18:42
OK. Well, that's interesting. What you do.

Interviewer: Felix Schöllhammer 18:46
Thank you.

Respondent (4) 18:47
But you know, it is really important because you know, as I told you in doing things, especially for the energy and we're trying to do something which reduce the environmental impact in the home and we are producing environmental impact and we are always making that assumption that we are not producing that much environmental impact. But we don't measure it. So, it's interesting to have a way to, to know exactly what's our impact.

Interviewer: Felix Schöllhammer 18:47
Yeah, it's very interesting and I guess. Ohh. So, in general in the smart home to see what the benefit is actually and how much are we getting and but yeah, I guess we are here in the right topic and maybe it's a good input, OK. How would you describe your overall impression of the tool and would you already know what is strength and weaknesses of the tool are? (Quest M: 2)

Respondent (4) 19:16
As I told you, my overall impression is that it's very useful to know this information. If I had to use this tool my problem would be that it will be maybe too complex to enter the information as I told you, maybe sometimes you have 200 sensors and I just cannot imagine. OK, they're not all 200 different sensors. OK, but it's we are quite a lot of different sensors and it's. I don't know if I will be able to enter in each kind of sensors and using the PEP information and all this stuff.
But it's a lazy argument, you know. It's because it takes time to do it. That's OK. But it's very interesting to have this information definitely. This is very interesting.

Interviewer: Felix Schöllhammer 20:24
OK. So, do you think the tool is useful? (Quest M: 3)

Respondent (4) 20:29
Ohh yes, sure sure. As I told you, we have the same problem for environmental impact on our algorithms, for instance.
Without tools to measure we are doing, we are, we are pushing our students to do it. I'm not doing it myself, but I'm pushing my students to do it to measure the consumption of the algorithms, using tools to do that. But without this information you just have very vague ideas, and you don't know exactly if what you're doing is good or not good.
And this exactly the same thing for the smart home. As I told you, we are trying to do things better, but maybe we are doing things worse because we have no idea of the environmental impact of what we are using to do it.
And we tried to measure the benefits, but we don't measure at all the what you are doing in fact. So, this is very, very interesting, very important.

Interviewer: Felix Schöllhammer 21:27
Thank you.
So now I will go over some features of the tool and then you can say on a Likert scale from 1 to 5 where one is not useful and five is extremely useful. How you would rate the different features.
And so the first one is: To what extent is it useful to specify different configurations of the CPS? (Quest M: 3.1)

Respondent (4) 22:00
I'm I'm not sure I understand the different configurations in fact.

Interviewer: Felix Schöllhammer 22:06
The idea is that if you have one CPS, you can go and have the same CPS with different component. So, in one configuration you can say I have ten types of this 10 times of that sensor. In another configuration you could say OK we can also try to only use five. Configurations are alternatives of an CPS.
So, it's basically the alternatives of one CPS.

Respondent (4) 22:51
You know, for instance, we I'm using a device which can measure the CO2, the COV and maybe temperature also on the same device. And sometimes I use it only as a detector. Is it what you mean by configurations?

Interviewer: Felix Schöllhammer 23:00
So that device would be one component. And a configuration has multiple components.

Respondent (4) 23:26
OK, see that because you know I have devices which I use partly I don't use all the everything in the device. This is not what you're considering here.
Okay so it's important to know how many devices and how many. If it's a configuration, the number of devices you have in the house, it's important for us for

sure, because it can vary a lot. It can vary a lot houses from houses. It can be completely different.

Interviewer: Felix Schöllhammer 23:44
Ok. How would you rate it? To what extent is this useful to specify different configurations of the CPS?
From 1:00 to 5:00. (Quest M: 3.1)

Respondent (4) 24:02
Five

Interviewer: Felix Schöllhammer 24:04
Five, OK.

Respondent (4) 24:04
Yeah, it can be very different from one house to another one.

Interviewer: Felix Schöllhammer 24:11
OK. And then the next question, to what extent is it useful to compare the environmental impacts of different CPS configurations? (Quest M: 3.2)

Respondent (4) 24:23
As it seems to me, it's the goal of the approach to have the impact. It's very important to compare the impact. It looks like it's important.
The way we are working in my case in a way I'm not considering the environmental impact and the configuration I will consider will be just only driven by the results I want to have. So, if I need more sensors in the in a particular room.
To have finer result, to have better results in this room, I will put more sensors.
But in fact you know. I'm not sure we're talking about the same thing, but you will tell me. But you know, in the in the project, in the research project. I'm engaged now.
We have been asking by the [institute] , there is the [country] agency which finances the research project. One of the things they asked us to do at the end is to try to reduce the number of sensors we're using. And to see if we are having very bad results, how the results will degrade considering that will reduce the number of

sensors.

So we try to reduce the environmental impact, so if we can measure this, reduce overall environmental impact with respect to the the scientific results, it can be interesting also.
If removing 10 sensor doesn't change the scientific results, it's good to remove them. If remove it 10 sensors just totally reduce the environmental impact and justice reduce slightly the scientific results. Then it's good to do it also.
That's why it can be interesting to have this value to so let's say 3 or 4.

Interviewer: Felix Schöllhammer 26:28
OK, thank you. But that's exactly what we are thinking about. So that was like exactly what you were expressing. That's what we're looking at. OK. And then to what extent is it useful to automatically extract information from the product environmental profile PEP documents? (Quest M: 3.3)

Respondent (4) 26:48
Oh 5 without hesitation.
Yes, you just don't want to do that by hand.
You know these tools. If it's easy to use, then people will use it. If they have a lot of work to do before starting using it, then you have to be very motivated in a way. So, if you can extract information automatically, just do it.

Interviewer: Felix Schöllhammer 27:12
OK. And to what extent is it useful to visualise environmental impacts in charts? Quest M: 3.4)

Respondent (4) 27:20
From my point of view it's five. Also, it's I liked having visual representation of information. It's talks to me a lot, much more than just numbers.

Interviewer: Felix Schöllhammer 27:32
To what extent is it useful to calculate the amount of data generated by the CPS? (Quest M: 3.5)

Respondent (4) 27:42
That's a good question.
I think, you know, it's interesting to realise how many data it represents, but it's a.
You speak French or a little bit or not.

Interviewer: Felix Schöllhammer 28:06
A petit peu.

Respondent (4) 28:10
Good you said it.
It in French, we say. à double trenchant.
It means it can be good in one way, but bad in the other way.
When you talk to people in a smart house and you just ask them, do you have any ideas how many data are produced? They have really no idea, really. No idea. But sometimes when you just do the calculation, you realise that it's not as much as maybe you expected.
And then you think that, OK, it's not that big problem finally. Especially it depends on the frequency of course. I my case where we are taking information Two times an hour or one times an hour. So, it's we're not producing that much data and you can have the inverse in fact saying, OK, this is not a problem finally the data.
Let's go where we can produce more.
But it's interesting to have an idea. It's interesting to have an idea. I will say three. OK, let's say three.

Interviewer: Felix Schöllhammer 29:17
OK. Thank you.

Respondent (4) 29:18
And in my case, I'm not going to the cloud. I'm not concerned of having data remaining for the next 10 hours on the cloud somewhere with consuming electricity because I remain locally.
It's on my Raspberry Pi and ok it’s not consuming electricity. I can switch it off and it's not consuming electricity.
So I'm not very concerned about this subject.

Interviewer: Felix Schöllhammer 29:48
The next question is.
To what extent is it useful to calculate the environmental impacts of the generated data from a CPS? (Quest M: 3.6)

Respondent (4) 30:12
For me, calculating the amount of data is only useful for calculating the environmental impact. It's useful in my case to know which size of SD card I will put in my Raspberry. OK but it's a very practical concern. But in in your subject, I think it's interesting to have the data to know the impact, but other way it's not a problem. So five.

Interviewer: Felix Schöllhammer 30:47
OK. And then the next question: to what extent is it useful to take the components location related carbon intensity for electricity consumption into account? (Quest M: 3.7)

Respondent (4) 30:58
It's fundamental. Also, it's totally fundamentally if you're near a coal plant. Sure, if your electricity is produced by coal It's not the same thing as not. It's very important. It's very important to know and to know the energy mix which is used in your place. You are using your system.
It's five. You have to know that it changes a lot of everything.

Interviewer: Felix Schöllhammer 31:21
Thank you for that. And the next question is then again, a bit more open.
Would the environmental impacts of the CPS influence your decision, your design decisions? (Quest M: 4)

Respondent (4) 31:28
No. I was not really concerned by this aspect, not deeply concerned. I mean we tried to reduce the number and to reuse the sensors, but we're not selecting the sensors

based on their environmental impact. In fact, I didn't. I didn't know this pep you talked about. So, I had no idea how many impact it has in terms of construction, in terms of all those things. I know it's not good, but I'm not able to compare two different sensors and the selection I will make between two different sensors.
Is very practical it for the precision of the data.
It's for the consumption electricity consumption of the sensor, so I would not have to change the batteries every two months because you know if you have 200 sensors in the house, it's a problem. If you have to change the batteries all the time. But this is the reason but not the environmental impacts, except the event for the batteries it's not environmental impact, it's practical impact not going to change the batteries all the time.
So I must recognise that no, I'm not taking into account environmental impact when selecting sensors.

Interviewer: Felix Schöllhammer 32:47
And if you wouldn't know, the environmental impacts, would that it is.
Influence your decision. (Quest M: 4)

Respondent (4) 32:56
Yes, if I can have something equivalent. For you know, it's two different parts in this question. That's for the research part. And then the industrial industrialization part, I mean for the research part, my concern is based on the having some systems that will work to prove that we can do something. What we're expecting to do and we can solve the scientific problem with. Try to solve.
So my decision for the sensor will be really the sensor that can produce the exact information I'm I need, whatever its environmental cost.
But of course, if it works now, I will ask the question that can we do the same thing with a less environmental impact.
And as I told you before, if I take this sensor will I have more or less the same result? At the end we cannot degrade too much my result.
And but at the beginning I would just take the sensors that I need to show that my problem I can solve my problem. Because my research problem is not finding the good sense and research problem is after the sensor.

Interviewer: Felix Schöllhammer 33:59

And the next question, I also send it in the chat is if you were using the tool, which of the four impact indicators would you pay the most attention to and maybe influence your decision?
And would it be CO2 footprint, global warming, fresh water usage, water pollution or asset acidification of water and soil? (Quest M: 5)

Respondent (4) 34:33
It will be the first one.
[CO2 footprint/ global warming]

Interviewer: Felix Schöllhammer 34:35
OK.
And the next question is.
Would you use the tool to calculate the environmental footprints of the CPS? (Quest M: 6)

Respondent (4) 34:50
That's what I told you before. If it's easy to enter all the information we have, yes.
It depends the number, the time. If I take the classical house I'm working on with my 200 sensors. If it takes me a lot of time to enter and find the information, then I'm not sure I will use it for the research part. I mean for the research part. If we go to a product then I think it's important to have this information. But for the research part it's not priority right now.
If it's easy to have the information, yes, it would be interesting to have this information. If it's easy to enter this into the data.

Interviewer: Felix Schöllhammer 35:26
OK, I see. Thank you. And then the last one would be, would you like to receive the final paper and also get access to the method when we're done with our project? (Quest C: 1)

Respondent (4) 35:36
No sure, sure.

Interviewer: Felix Schöllhammer 35:37

OK. Thank you so much. I will stop the recording now if you don't have anything to add.

Respondent (4) 35:43
Ohh, it's okay, it's perfect.

Interviewer: Felix Schöllhammer 35:45
Thank you

Interviewer: Felix Schöllhammer stopped transcription

Transcript of Interview 5

6 July 2023, 04:00pm

Schöllhammer, N.F. (Felix) started transcription

Interviewer: Felix Schöllhammer 0:06
Okay. Yeah, we are recording. Do you have any general questions before we start or should we just go into straight into the?

Respondent (5) 0:15
Yeah, we can go straight to the.

Interviewer: Felix Schöllhammer 0:17
OK, very nice. OK, then I ask you some questions about you. First, are you mainly working for a private for private companies or research institutions, universities or combination of that? (Quest I: 1)

Respondent (5) 0:17
The University. Only university.

Interviewer: Felix Schöllhammer 0:36
OK. And then what is your field of expertise and how is it related to Internet of Things, cyber, physical systems? (Quest I: 2)

Respondent (5) 0:48
OK so. I can share with you, my background. I'm my PhD is on the wireless communications.
OK. And then this year I get slowly into sensors and IoT because we need to install or sensors to collecting the data in the wireless manner, OK. So that's how I gain to the IoT and then because of that, then slowly move into smart grid, travel green, you know, energy management because the IoT can helps us to collect a lot of data where we can look at the data optimised to help people, to save energy.
And then this how I move into this this area and for cyber physical system.
So this is how we look at it as well. We look at it from the security perspective.

And then we also look at applying the blockchain for such system.
And something that I agree for your interview is that because recently we are working on something to look at the application approach in the circular economy. We're looking into different steps of this circular economy and how I find your interview, maybe it's quite interesting and that's how I agree.

Interviewer: Felix Schöllhammer 2:08
OK. Thank you. And in what phase are you involved in cyber physical projects? So, is it analysis and design implementation or evaluation? Do you know where you are involved in the project? (Quest I: 3)

Respondent (5) 2:40
I would say it is both from design to analysis to evaluation. We are involved in all.

Interviewer: Felix Schöllhammer 2:48
OK, perfect. And then what is the typical size of a cyber physical system or IoT you are working with? (Quest I: 4)

Respondent (5) 2:58
Hmm. OK. It varies. OK. So, for example, if you talk about smart grid? We are doing it for simulation.
Okay so for solution the size can be large, no can be more than 100 knots of network.
OK, we do deploy real wireless sensors as well, but 400 knots, we deployed such network before in real world. But of course, in some cases it could be just prototype.

Interviewer: Felix Schöllhammer 3:31
OK. Thank you. And how long how many years have you been active in the field? (Quest I: 5)

Respondent (5) 3:36
You know more than 10 years.

Interviewer: Felix Schöllhammer 3:43
OK. Yeah. Thank you.
And then the next question.
Do you consider environmental impacts when working with cyber physical systems? (Quest I: 6)

Respondent (5) 3:58
OK. So, for example our sensors, a lot of them are solar powered.
Because the environment does not allow us to have the power supply. So, we do make use of renewable energy. And if you talk about the sustainability in terms of do we recycle the materials, unfortunately there is not.
OK, whenever we can, we can recycle, we are trying we try to. But however, a lot of times the environment is because they are out in an outdoor environment, the sensors can be in quite a bit shape after we are taking back to deployment, so it takes a lot of effort if we going to change it out and for recycle.
You know, it makes our life much easier if we just create a new one.
So there are a lot of so-called the electronic-waste, which I feel quite bad, but unfortunately that is the case.

Interviewer: Felix Schöllhammer 5:08
OK. And do you somehow measure it or analyse the amount for example or?
Do you just try to reduce it? (Quest I: 6)

Respondent (5) 5:20
It is hard to reduce. I mean I we didn't try to measure. All of them, after we take it, we can’t recycle unfortunately.

Interviewer: Felix Schöllhammer 5:35
OK.
And then the next question is also related to that one. And in your experience or the observation, is it common that components of a CPS are reused the if they're not needed anymore?
Or are they often disposed? (Quest I: 7)

Respondent (5) 5:54
OK, so I know sure about your context about the CPS. OK. So, for example, the one example I give you a sensors model, smaller box of sensors.
But I not sure if you are talking about a bigger system. My power grid etc. They can be a different story. So, sorry, you cover your question one more time.

Interviewer: Felix Schöllhammer 6:17
Are certain components of the CPS be reused usually, or if they are disposed?

Respondent (5) 6:30
OK, so will I say whenever we can reuse, we are trying to, but the challenge we face is that if we reuse it takes us a lot of effort.
But we need to clean that out. We need to check whether are they still in the good or the good shape. So it's easier for us to just use a new one.

Interviewer: Felix Schöllhammer 6:50
OK. Thank you. So now I will send you a link to a YouTube video and this is the presentation of our tool. And then afterwards I will ask you some questions about it.

Tool Presentation

Interviewer: Felix Schöllhammer 13:48
OK. Thank you for watching it. Do you have some general questions about the tool or how it works? (Quest M: 1)

Respondent (5) 13:57
Yeah, I understand it.

Interviewer: Felix Schöllhammer 14:02
OK. Do you have a question about it or should I start with some questions?
(Quest M: 1)

Respondent (5) 14:08
Yeah, you can continue with question.

Interviewer: Felix Schöllhammer 14:10
OK. How would you describe your overall impression of the tool? (Quest M: 2)

Respondent (5) 14:19
It's quite tedious to feeling. I want to feel it for all my projects will be extra work.

Interviewer: Felix Schöllhammer 14:30
And sorry, could you repeat that?

Respondent (5) 14:32
I mean to our will be quite a number of extra work and effort for me to feel the form.

Interviewer: Felix Schöllhammer 14:39
Okay. And do you see some strengths and weaknesses of the tool? (Quest M: 2)

Respondent (5) 14:47
Okay so.
I still cannot feel the need to study those numbers because.
We think those are some estimates. And even understand that what can I do? You know, I mean, I understand that that your mission or your video this the first step you know. But the problem is understand that may not help me much.
You know where I am coming from?

Interviewer: Felix Schöllhammer 15:23
Okay.
And do you think the tool is useful? (Quest M: 3)

Respondent (5) 15:32
So far, no.
From what I see now, no

Interviewer: Felix Schöllhammer 15:37
OK. Now I will go over some questions and you can answer from 1 till 5. How useful

you find a certain features. One is not useful and five is extremely useful.

Interviewer: Felix Schöllhammer 15:55
To what extent is it useful to specify different configurations of a CPS? (Quest M: 3.1)

Respondent (5) 16:15
Different configuration in what sense?

Interviewer: Felix Schöllhammer 16:18
Different configurations are ways you can design a CPS so one can configuration can have different components and then you can for example one configuration that can be that you design your CPS with 10 sensors, but then a second configuration can be that you design it with 22 sensors so that you can specify different alternatives of one CPS.

Respondent (5) 16:43
No, that would be useful: 4

Interviewer: Felix Schöllhammer 16:47
Four, OK. And to what extent is it useful to compare the environmental impacts of different CPS configurations? (Quest M: 3.2)

Respondent (5) 16:59
OK, so you study the so-called environmental impact of this CPS, but you don't study the indirect impact of this the CPS. So, for example I put in a sensors to measure the indoor temperature by installing that that may help me save energy and by saving that energy the impact can be much larger than this sensor alone.

[indirect impact of this the CPS]

The environmental impact of these sensors may not mean much, you know, I mean, because it may bring up a greater indirect impact. So, mentioning that could be more meaningful than measuring the sensors itself, you know where I'm coming from.

Interviewer: Felix Schöllhammer 17:48
Yeah, I know exactly what you mean. It's a. It's a trade off in the end.

Respondent (5) 17:48
Yes. So, measuring the environmental impact of this sensor alone.
Is minimum.

Interviewer: Felix Schöllhammer 18:01
OK, so why would you rate it from 1:00 till 5?

Respondent (5) 18:07
The one is minimum, and fife is a lot. I would say 2.

Interviewer: Felix Schöllhammer 18:10
OK. Thank you.

Interviewer: Felix Schöllhammer 18:13
And the next question to what extent is it useful to automatically extract information from the product environmental profile (PEP) documents? (Quest M: 3.3)

Respondent (5) 18:27
Okay so.
I will say that may be useful if someone is doing it in a larger scale.
OK so for example they have a new building they will need to install this then maybe it makes sense for them to study it. Or maybe someone coming out with a new product going to compare their new products with the existing one then they believe useful for this for them.
For me I would say three. I mean I find it's quite impressive that you can do that.
But how to use it? I I'm not sure. For my case.

Interviewer: Felix Schöllhammer 19:08
Thank you. To what extent is it useful to visualise environmental impacts in charts? (Quest M: 3.4)

Respondent (5) 19:19
Visualisation always helps.
But it's just a suggestion. I will think that you should set a benchmark.
Something people know that they can compare with. Just by looking at the numbers, I know yes, one year etc., but without a benchmarking I have no idea what it is.

Interviewer: Felix Schöllhammer 19:43
OK. And where would you rate it from 1 to 5?

Respondent (5) 19:47
Four.

Interviewer: Felix Schöllhammer 19:48
Next question, to what extent is it useful to calculate the amount of data generated by a CPS? (Quest M: 3.5)

Respondent (5) 20:00
OK, this one. I have seriously concerned because my background in communications so it's hard for you to estimate the amount of the of data because depending on the sampling rate you know different applications can vary.
We are sampling from 5 minutes one readings to some high sampling rates. So it can vary significantly.
But it went to transmit. The data can be some form of compression some kind of edge processing at the edge. So, I know that you provide some estimation but to me this is not so meaningful because my background in communications.

Interviewer: Felix Schöllhammer 20:26
OK, so where would you rate it write it?

Respondent (5) 20:44
I will say two.

Interviewer: Felix Schöllhammer 20:48
OK. And to what extent is it useful to calculate the environmental impacts of the

generated data from a CPS. (Quest M: 3.6)

Interviewer: Felix Schöllhammer 21:09
So this question now is about the environmental impact that are associated to the amount of data that's generated by the CPS.

Respondent (5) 21:09
Ahh, it's a different question.
OK, I mean it's meaningful, but provided you can estimate the data correctly.
Hmm. So, if you can submit data correctly I would say 4. It's important.

Interviewer: Felix Schöllhammer 21:36
Okay. To what extent is it useful to take the components location related carbon intensity for electricity consumption into account? (Quest M: 3.7)

Respondent (5) 21:50
Yes, they should take to account. Five.

Interviewer: Felix Schöllhammer 21:56
Very good. And now we come back to more open question. Would the environmental impacts of a CPS influence your design decisions? (Quest M: 4)

Respondent (5) 22:10
OK, I shared with you previously. The indirect impact or the benefit this piece can bring is more significant. So, if it can bring me a lot more benefit, I wouldn't care about this one.

Interviewer: Felix Schöllhammer 22:28
Would you say at the moment, it would not influence your decisions?

Respondent (5) 22:37
Yes, because. Most people the focus is on what kind of benefit this CPS can bring and usually it should.
I think it should outweigh significantly the impact of this CPS.

Interviewer: Felix Schöllhammer 22:58
OK. And then at the next question is if you were to use the tool, which of the four impact indicators would you pay the most attention to an influence, your design decisions? And one is CO2 footprint / global warming. Two is freshwater usage, three is water pollution and forest acidification of water and soil.
What would be your main focus one? (Quest M: 5)

Respondent (5) 23:24
So see one. [CO2/global warming]

Interviewer: Felix Schöllhammer 23:31
Would you use the tool to calculate the environment footprints of the CPS. (Quest M: 6)

Respondent (5) 23:40
No, in this moment.

Interviewer: Felix Schöllhammer 23:44
And why wouldn't you use it?

Respondent (5) 23:48
I don't need to know the numbers now.

Interviewer: Felix Schöllhammer 23:51
OK, that where the questions for now the last one would you like to receive the final report when we're done and also get access to the method? (Quest C: 1)

Respondent (5) 24:01
Yes, I would love. I would love to. When you have done all your survey, your paper's publication. Please share with me. I would love to take a look.

Interviewer: Felix Schöllhammer 24:10
Thank you so much OK would stop the recording now.

Schöllhammer, N.F. (Felix) stopped transcription

Transcript of Interview 6

July 12, 2023, 1:06PM

Interviewer: Felix Schöllhammer started transcription

Interviewer: Felix Schöllhammer 0:09
Change spoken language to German.
Gut, dann würden wir auch schon loslegen. Die erste Frage ist, arbeiten sie hauptsächlich für private Unternehmen oder Universitäten, Forschungsinstitute oder eine Kombination aus dem.

Respondent (6) 0:41
Universität.

Interviewer: Felix Schöllhammer 0:43
Ok.
Und was ist ihr Fachgebiet und welche Verbindung haben Sie zu Cyber-physical Systems, Internet of Things, Smart Home?

Respondent (6) 0:54
Ja, also ich hier an der [Name of University] Professur für Software-Engineering in Cyber-Physical Systems inne. Wir haben verschiedenste Projekte, wo wir uns hauptsächlich mit Software Engineering Themen wie Softwarequalität, Softwarearchitektur, Softwarevariabilität im Kontext von Cyber-Physical systems beschäftigen, auch mit verschiedenen Industriepartnern und internationalen anderen akademischen Partner.

Interviewer: Felix Schöllhammer 1:25
Okay sehr gut und welche Art von Beteiligung haben Sie in diesen Projekten, also in welcher Phase von den CPS-Projekten?

Respondent (6) 1:37
Das ist unterschiedlich. Meistens während geht es um deren Entwicklung, aber es geht auch um die um die Wartung, also Änderungen, die Halt durch die Wartung

entstehen und deren Auswirkungen auf die Software zum Beispiel zu untersuchen oder auch die Weiterentwicklung, also eigentlich über den gesamten Lebenszyklus hinweg, aber immer mit einem starken Fokus eben auf die Software, vor allem die Automations-Software in solchen Systemen und Steuerung, Produktion und Steuerungssoftware.

Interviewer: Felix Schöllhammer 2:05
Vielen Dank. Und was ist eine typische Größe oder Komplexität von den CPS-Projekt? Wenn Sie das sagen könnten?

Respondent (6) 2:18
Anhand was misst messen wir denn Komplexität oder Größeres?

Interviewer: Felix Schöllhammer 2:24
Zum Beispiel die Anzahl an Komponenten.

Respondent (6) 2:30
Das ist schwierig zu sagen, also Anzahl an Komponenten. Ich meine zum Beispiel den Steuerungssoftware, wenn wir reden wir von Funktionsbausteinen in einem Funktionsbaustein können potenziell viele Lines of Code stecken und die größeren Systeme, mit denen wir uns beschäftigen, gehen schon in die Millionen Funktionsbausteine. Nicht jedes System, mit dem wir uns beschäftigen, ist so groß, wir haben auch kleinere Systeme, an denen wir arbeiten dürfen, die sich mit ein paar 1000 solchen Baustellen begnügen sag ich mal.

Interviewer: Felix Schöllhammer 3:01
Okay, aber dann sehe ich schon eher, dass es hier um größere Projekte handelt. Also Und wie lange sind sie in dem Bereich tätig?

Respondent (6) 3:13
Korrekt. Also in konkret dem Bereich Software Engineering für cyber-physical systems seit in etwa 2006. Allerdings im Hinblick auf Steuerungssoftware das ist erst so ungefähr seit 2019 vorher war es eher die die Automations- und Optimierungssoftware seine verschiedene unterschiedliche Ebene in der

Automatisierungspyramide darstellt, also quasi wie nah man an der Maschine dran ist.

Interviewer: Felix Schöllhammer 3:39
Ok, vielen Dank
Berücksichtigen Sie mit dem CPS verbundene Umweltauswirkungen bei ihrer Arbeit.

Respondent (6) 3:52
Wir persönlich nicht, unsere Partner sehr wohl, weil es ein sehr wichtiger Aspekt ist für die Industriepartner, um am Markt erfolgreich sein zu können. Dementsprechend berücksichtigen die das. Und das hat natürlich Auswirkungen darauf, wie die Software entwickelt wird und diese Auswirkungen wiederum sehen wir, aber wir, wir forschen nicht zu diesem Thema.

Interviewer: Felix Schöllhammer 4:14
OK, aber wird es dann in irgendeiner Form analysiert oder wird es irgendwie gemessen?

Respondent (6) 4:22
Bei mir nicht nein, also im Institut oder in bei uns in der Forschung nicht, aber ich weiß, dass die Industriepartner das natürlich machen.

Interviewer: Felix Schöllhammer 4:31
Ok, vielen Dank und in Ihrer Erfahrung und Beobachtung ist es üblich, dass CPS-Komponenten wiederverwendet werden oder werden sie oft entsorgt?

Respondent (6) 4:44
Also was Software angeht, wird eigentlich sehr viel wiederverwendet. Die Frage ist mit welchem Ansatz, also die Industrie setzt da sehr stark auf clone and own, Wiederverwendung bestehender Programmbestandteile, und passt halt das bei jeder neuen Instanz für jeden neuen Kunden so lange an bis halb die Anforderungen des neuen Kunden erfüllt sind. Dadurch wird Wiederverwendung heißt ich kopiere es mir und dann ändere ich, die Wiederverwendung ist in 1 zu 1 Wiederverwendung ohne Anpassung das das muss das Ziel sein aber da sprechen wir dann von Standardisierung, die abhängig ist vom System, wie hoch der Standardisierungsgrad

sein kann. Aber es ist immer eines der großen Ziele der Industrie den Wiederverwendungsgrad zu maximieren.

Interviewer: Felix Schöllhammer 5:30
Und wie ist das dann bei physischen Geräten, wissen sie da, ob es da Wiederverwendung gibt?

Respondent (6) 5:39
Naja, die Anlagen, mit denen wir üblicherweise zu tun haben, haben eine sehr lange Lebensdauer wir sprechen dann zwischen 30 und 50 Jahren, das Ding existiert, und wenn das dann mal so lang überlebt hat in dieser Phase, wo es so lange lebt, wird oft modernisiert, bis es halt irgendwann nicht mehr, geht und dann ist es irgendwann so weit, dass man das quasi physisch abmessen muss, einfach dann seine Lebensdauer überschritten hat und dann kann man doch natürlich nur die Komponenten wieder verwenden zum Beispiel den Stahl oder die Bestandteile.

Interviewer: Felix Schöllhammer 6:11
Ok.
Vielen Dank. Dann würde ich Ihnen jetzt gerade hier einmal den Link zu dem Video schicken, das dauert 6 Minuten ungefähr und danach würde ich ihnen ein paar Fragen darüber stellen.

Respondent (6) 6:24
Ich versuch Grad den Chat zu öffnen jetzt.

Interviewer: Felix Schöllhammer 6:26
Ja. Ton geht auch?

Respondent (6) 6:43
Ja. Ok Passt.

Interviewer: Felix Schöllhammer 12:54
Vielen Dank, Ich denke, das war jetzt bestimmt einige Informationen. Die erste Frage wäre dann, ob Sie allgemeine Fragen zum Tool oder der Funktionsweise haben.

Respondent (6) 13:08
Ja, man eindeutig ein spreadsheet, also das basiert halt auf vielen Formeln, die davor definiert sind und templates Informationen wird teilweise extrahiert aus dieser PEP Datenbank nehme ich an.

Interviewer: Felix Schöllhammer 13:12
Ja genau.

Respondent (6) 13:25
Was mir nicht ganz klar ist, wo die Default Werte natürlich herkommen. Das werden wahrscheinlich aus irgendwelchen gibt es wahrscheinlich Forschungsergebnisse, die sagen das ist ungefähr so, kam aber natürlich als User nicht nachvollziehen ob das 0,0378 was warum auch immer das zu.

Interviewer: Felix Schöllhammer 13:33
Auch.
Ja, ja, also genau die Default werte kommen aus ja aus anderen Papers aus Forschung, die können aber immer angepasst werden in dem Tool also das heißt, dass der User, wenn er weiß ok ja ich habe andere Werte und bin dessen bewusst, dass es anders ist, dann kann man diese auch ja verändern, genau.

Respondent (6) 14:01
Ich habe ja die Angst ist, dass diese Werte keiner weiß, ne, also dass jeder mit dem Default werten arbeitet und keiner weiß genau, was der Wert ist deswegen.

Interviewer: Felix Schöllhammer 14:05
Ja, genau deswegen. Deswegen braucht man dann wieder auf die Verwerter. Aber es ist natürlich dann die Frage, wie akkurat ist dann im Endeffekt ist genau.

Respondent (6) 14:18
Genau.
Ist wahrscheinlich auch nicht das Ziel, dass da, dass man das dann auf die auf die Ziffer genau akkurat nimmt, sondern nur um eher unterscheiden zu können. Wenn ich 2 oder 3 Konfigurationen zum Beispiel vergleiche, welche hat weniger Footprint,

ne, ob das dreimal so wenig oder zweimal so wenig ist, dann eigentlich wurscht, Hauptsache es halt mal weniger.

Interviewer: Felix Schöllhammer 14:32
Genau. Also das ist das ist, das ist das Ganze. Also man geht hin und vergleicht unterschiedlichen Konfigurationen und sieht wie sieht das Ganze aus und bei dem Daten teil kann man sehen ok wieviel Daten generiere ich mit meinem System und ja das Ganze hat auch einen Footprint und ja vielleicht kann ich da ein bisschen was verändern, wenn ich sage ich sample anstatt jede Sekunde nur alle Minute oder so. Um Aufmerksamkeit auf das Thema aufzubringen. Genau.

Respondent (6) 15:09
Na, ich habe alles verstanden.

Interviewer: Felix Schöllhammer 15:11
Okay sehr gut, dann würde ich zur ersten Frage ich hier kommen, was ist ihr Gesamteindruck von dem Tool und wie würden Sie es beschreiben und stärken und Schwächen zum Beispiel.

Respondent (6) 15:20
Ja, ich fang lieber mit den Schwächen an und kommen dann zu den Stärken. Ich denke, dass der Fakt, dass es in Tabellenbasiert ist, es ist eine Stärke und eine Schwäche, erlaubt natürlich jedem das relativ schnell zu nutzen, hat aber auch den Nachteil, dass man sehr repetitiv sehr viele Informationen in diese Tabelle eingeben muss und Fähigkeiten von graphischen Benutzerschnittstellen oder auch vor allem Web basierten grafischen Benutzerschnittstelle Halt nicht genutzt werden, wie man leichter und schneller diese Informationen zur Verfügung stellen könnte, spricht man könnte meiner Meinung nach, dass das Interface quasi ja dann noch ein Interface drüber stoppeln. Ich glaub das ist vor allem dann eine Schwäche, wenn man mit Leuten zu tun hat, die wenig Zeit haben, das heißt, du brauchst mit so einem Tool länger Daten einzugeben und reinzupflegen als mit einem mit einem vielleicht besser Designtem Tool. Was die Stärke angeht, der Vorteil ist jeder kann halt wirklich mit dem Ding arbeiten, weil ich glaub selbst meine Eltern können mit Excel Tabellen umgehen also das ist jetzt wirklich nicht schwierig.
Eine kleine Schwäche ist vielleicht zu erkennen, wo kann ich was editieren. Das wird

zwar farblich markiert, wenn man was eingegeben hat, aber ich kenne die User die User klicken überall hin, das ist dann wahrscheinlich gesperrt wo man nicht editieren soll, wenn nicht müsste man das auf jeden Fall machen, weil sonst wird das das kaputt gemacht, das ist garantiert so und das ist natürlich ein Problem das Skalierbarkeit gegeben weil wenn ich sehr viele Komponenten habe wird das irgendwann tabellarisch nicht mehr handhabbar und vor allem auch dann die verschiedenen Reiter unten.
Das wird nicht funktionieren das da dann Millionen Reiter sind ne blöd gesagt, das geht nicht. Da braucht man dann eine Datenbank und der grafische Benutzerschnittstelle um darüber, ist einfach so.

Interviewer: Felix Schöllhammer 17:08
Okay, vielen Dank. Die nächste Frage wäre, glauben Sie, das Tool ist nützlich?

Respondent (6) 17:18
Je nachdem, was das Ziel ist. Wenn das Ziel ist, awareness zu schaffen, ja, dann ist es nützlich. Wenn das Ziel ist, exakte Kalkulationen zu machen und die halt auch so nachzuweisen, dass das dann quasi rechtlichen Bestand oder irgendwie, dass man damit Geld machen kann, würde ich sagen, Nein, weil es dazu zu ungenau sein wird, … gefühlt.

Interviewer: Felix Schöllhammer 17:39
Okay.
Vielen Dank jetzt bei den nächsten Fragen würde ich über ein paar Features von dem Tool gehen und werde Sie fragen auf einer Skala von 1 bis 5 einzuschätzen, wie nützlich Sie diese Features finden, wo 1 dann nicht nützlich ist und 5 äußerst nützlich. Die erste Frage wäre, inwiefern ist es nützlich verschiedene Konfigurationen eines CPS zu spezifizieren?

Respondent (6) 18:07
4.

Interviewer: Felix Schöllhammer 18:09
Und warum ist eine 4?

Respondent (6) 18:12
Weil es schwierig ist, solche Konfigurationen nur zu spezifizieren, indem man sie listet. Ich glaub, da braucht man einen Konfigurator.

Interviewer: Felix Schöllhammer 18:22
Okay.
Inwiefern ist es nützlich, die Umweltauswirkungen verschiedener CPS-Konfigurationen zu vergleichen?

Respondent (6) 18:32
5.

Interviewer: Felix Schöllhammer 18:34
Danke und hier auch warum?

Respondent (6) 18:34
Ja, auf jeden Fall nützlich, das zu analysieren, vor allem, wenn man es macht, bevor man es baut oder ausliefert, ne.

Interviewer: Felix Schöllhammer 18:44
Vielen Dank. Inwiefern ist es nützlich, automatisch Informationen aus dem Product Environmental Profile (PEP) zu extrahieren?

Respondent (6) 18:55
Das ist schwer einschätzen, weil ich nicht weiß, wie nützlich das PEP ist, ohne dass ich die Daten extrahiere, wenn ich die dort sehr schnell aufbereitet finde, versteh ich nicht, warum ich sie ins Spreadsheet exportieren muss, wenn sie dort schwer zu finden sind und man das aus 3 verschiedenen Stellen irgendwie sich zusammensuchen muss und das Tool bereit das schön auf dann 5.

Interviewer: Felix Schöllhammer 19:17
Okay vielen Dank. Inwiefern ist es sinnvoll, Umweltauswirkungen in Diagrammen zu visualisieren?

Respondent (6) 19:27
Ich weiß nicht, wie ich es sonst visualisieren sollte also 5.

Interviewer: Felix Schöllhammer 19:30
Okay.
Inwiefern ist es sinnvoll, das Volumen der durch das CPS generierten Daten zu berechnen?

Respondent (6) 19:39
Ja da würde ich eher in Richtung 3 gehen oder 2, weil da zu viele Unbekannte sind, wie die Daten transportiert werden und was das für einen Environmental Cost das wirklich hat.
Mehr Daten bedeutet zwangsläufig mehr Environmental Footprint, aber wieviel mehr und ob das wirklich relevant ist, im Gigabyte Bereich überhaupt denken und nicht im Hexabyte Bereich, weiß ich nicht.

Interviewer: Felix Schöllhammer 20:07
Okay. Die nächste Frage baut darauf auf, Inwieweit ist es sinnvoll, den CO2-Fußabdruck, der von den CPS generierten Datenvolumen zu berechnen?

Respondent (6) 20:18
Selbe Antwort effektiv. Also ich glaub nicht ganz an diese Berechnung, weil mir ist halt auch die Forschung nicht bekannt, deswegen kann ich das schwer einschätzen. Es ist wahrscheinlich bei beiden Fragen eine 3 weiß in der Mitte liegt am besten als andere, weil ich nicht einschätzen kann.

Interviewer: Felix Schöllhammer 20:24
Ok, vielen Dank. Und inwiefern ist es sinnvoll, die Standortbezogenen Kohlenstoffintensität des Stromverbrauchs, der Komponenten zu berücksichtigen?

Respondent (6) 20:44
Da würde ich ganz bewusst auch eher 3 sagen, weil zum Beispiel Standort kann eine Auswirkung haben, also.
Aber zum dieser bisschen Augenwischerei, weil es ist ein Stromnetz in zum Beispiel in

ganz Europa, und ob ich in Spanien oder in Frankreich bin, macht effektiv keinen Unterschied, auch wenn man glaubt, die einen haben so viele Atomkraftwerke und der anderen haben so viele andere Kraftwerk, glaube ich, dass es innerhalb eines Netzes an einem Kontinent kaum Unterschiede gibt, aber wahrscheinlich schon zwischen Australien und Spanien oder so, also da würde ich dann wieder sagen 5, also so hängt davon ab, ich glaub Land ist dann nicht die die richtige Granularität. Ich glaube, es ist ein Stromnetz. Stromnetz sollte man unterscheiden also Hauptstromnetz, ne.

Interviewer: Felix Schöllhammer 21:28
Ok, vielen Dank. Jetzt kommen wir wieder zu eher offenen Fragen. Also sie müssen nicht mehr an der Scala antworten. Würden die Umweltauswirkungen eines CPS ihre Designentscheidungen beeinflussen.

Respondent (6) 21:36
Mhm.
Ja, glaube ich schon, dass das Auswirkungen hat, wenn ich weiß, dass etwas, was ich designe, schlecht ist für die Umwelt, dann würde ich eher vermeiden, ne.

Interviewer: Felix Schöllhammer 21:51
Ok, vielen Dank.
Und wenn Sie das Tool verwenden würden, welcher der 4 Impact Indicators würde sie am meisten Aufmerksamkeit schenken? Ich schick es auch in den Chat. 1 ist CO2 Footprint / global Warming, 2 ist fresh water useage, 3 ist Walter Pollution und 4 ist Acidification of Soil in Water.

Respondent (6) 22:05
Ich werde auf jeden Fall mal sagen CO2 footprint/ Global Warming, weil einfach am dringendsten ist und Wasser kann man wieder verwenden. Verunreinigtes Wasser kann man reinigen und auch Acids kann man wieder rausbringen aus soil and water also aber bei CO2 Footprint ist der Harm dann das ist halt schwieriger das wieder weg zu machen.

Interviewer: Felix Schöllhammer 22:40
Ok, vielen Dank dafür.

Okay und würden Sie das Tool verwenden, um Umwelt Fußabdruck von CPS zu berechnen?

Respondent (6) 22:50
Wenn ich die Informationen habe, die ich da eingeben muss, dann schauen ja. Üblicherweise habe ich diese Informationen nicht, weil das ja die Industrie Partner oder Kunden haben und nicht wir die Forschung zu dem Thema betreiben. Also ich persönlich. Nein, aber.

Interviewer: Felix Schöllhammer 23:06
Okay und dann kommen wir zur Abschlussfrage würden sie gerne ja, die Abschlussarbeit zu dem Projekt und auch dann Zugang zu dem Tool haben, sobald das Ganze fertig ist.

Respondent (6) 23:17
Ich sag mal ich, ich würde es auf jeden Fall gerne wissen, wo ist das Tool gibt und den Kontakt haben, weil man kann, nie wissen was sich ergibt. Ne also in Forschungsprojekten, wenn das Thema Green und das Thema Energy und Pollution er sich aufkommt und dann die Frage kommt na was könnte man denn da machen, dann hätte ich halt einen Anknüpfungspunkt also sehr gerne auf jeden Fall die Arbeit ob ich das Tool gleich brauchen werde das stell ich mal eher in Frage, aber ist gut den Kontakt zu haben.

Interviewer: Felix Schöllhammer 23:46
Ja, mach ich gerne. Vielen vielen Dank okay dann würde ich die das Recording einmal stoppen.

Interviewer: Felix Schöllhammer stopped transcription

Transcript of Interview 7

July 14, 2023, 9:02AM

Interviewer: Felix Schöllhammer started transcription

Interviewer: Felix Schöllhammer 0:14
Wir können es gerne in Deutsch machen.

Respondent (7) 0:17
Okay.

Interviewer: Felix Schöllhammer 0:18
Und das Gute ist, dass dieses Tool jetzt auch schon automatisch mit transkribieren kann. Ich musste nur gerade einmal die Sprache auf Deutsch wechseln.
Ja, ich geh dann nachher hin und kodiere und übersetze es auf Englisch.

Respondent (7) 0:37
Ja, ja.
Okay passt.

Interviewer: Felix Schöllhammer 0:46
Gut also erste Frage ist, arbeitest du hauptsächlich für private Unternehmen oder Universitäten, Forschungseinrichtungen oder eine Kombination aus dem Ganzen?

Respondent (7) 0:55
Universitäten also zweites.

Interviewer: Felix Schöllhammer 0:58
Universitäten.

Respondent (7) 0:59
Ja, genau.

Interviewer: Felix Schöllhammer 0:59
Okay und was ist dein Fachgebiet und wie ist die Verbindung zu Cyber Physical Systems, Internet of Things, Smart Home?

Respondent (7) 1:08
Mein Fachgebiet ist Software Engineering und der Anwendungsfall sind IOT und Cyber-physical Systems.

Interviewer: Felix Schöllhammer 1:16
Okay.

Respondent (7) 1:17
Ja.

Interviewer: Felix Schöllhammer 1:18
Und welche Art von Beteiligungen hast du in Cyber Fitti, Cyber Physical Systems Projekten? In welcher Phase bist du involviert?

Respondent (7) 1:28
Ich würde sagen, in hauptsächlich Design und Implementierung. Aber halt aus Forschungsperspektive, also Forschungsprototypen keine fertigen Produkte.

Interviewer: Felix Schöllhammer 1:39
Okay.
Ok.

Respondent (7) 1:44
Ist. Ich sehe also die CPS nicht im Unternehmen im Einsatz. Falls dir das weiterhilft.

Interviewer: Felix Schöllhammer 1:52
Mhm, geht mehr um die Konzeptualisierung des Ganzen?

Respondent (7) 1:56
Genau um prototypischen Implementierung, aber Proof of concept bis dahin

meistens und ein konkretes Produkt im Einsatz sehe ich nicht, welche ich selbst entwickelt haben. Natürlich hab ich auch Produkte im smart home schon genutzt, aber in der Entwicklung und Implementierung geht es bis zum Prototypen.
Genau.

Interviewer: Felix Schöllhammer 2:17
OK, dann die nächste Frage wie was wäre so ne typische Größe Komplexität von so einem CPS?

Respondent (7) 2:26
Ja.
Was hast du denn als als als orientierungs Maßgabe?

Interviewer: Felix Schöllhammer 2:33
Zum Beispiel wie viele Komponenten CPS haben würde.

Respondent (7) 2:47
Okay also das ist natürlich alles eine Definitionsfrage von CPS, aber sagen wir jetzt mal da ist jetzt ne Maschine Produkt, in der smarte Produktionsmaschine ist eine Komponente für dich oder eine Komponente, die aus vielen vielen anderen Komponenten besteht.

Interviewer: Felix Schöllhammer 2:54
Mhm.
Ja, das besteht aus vielen anderen Komponenten. Komponenten werden für mich zum Beispiel ein Sensor oder eine Einheit.

Respondent (7) 3:05
Okay.
Okay na dann würde ich ja schon sagen. Also wenn jetzt von Sensoren sprichst, würde ich schon sagen im Bereich 100 bis 1000, oder 100 bis 500 ungefähr.

Interviewer: Felix Schöllhammer 3:07
Okay.

Dankeschön.
Ok, wie lange bist du in dem Bereich tätig?

Respondent (7) 3:25
Also wenn du jetzt Forschung und so weiter mit mit Einbeziehst dann mal gut 10 Jahre.

Interviewer: Felix Schöllhammer 3:33
Okay.
Und Berücksichtigung Sie mit dem CPS verbunde Umweltauswirkungen bei der Arbeit.

Respondent (7) 3:42
Aktuell nicht! Nein.

Interviewer: Felix Schöllhammer 3:44
Okay.
Und nach deiner Erfahrung oder Beobachtung weißt du, ob bestimmte Komponenten vom CPS wiederverwendet werden, wenn oder ob die dann ja entsorgt werden. Normalerweise.

Respondent (7) 4:00
Ja, es ist schwer zu beantworten. Das war auch eine oder Frage. Natürlich ist wieder Verwendung schon aufgetreten, ja. Aber natürlich nicht zu einem großen Teil. Aktuell ist ich denk da ist immer noch.
Hauptsächlich die Entsorgung.
Falls dir das so weiterhilft als Antwort. Also zu einem kleinen Teil Wiederverwendung, aber hauptsächlich nicht.

Interviewer: Felix Schöllhammer 4:23
Okay ja, vielen Dank dafür.
Okay dann würde ich dir schon mal den Link jetzt schicken. Wo habe ich denn hier? Genau das ist n hier im Chat. Es ist ein 6-minütiges Video, sag mir einfach, wenn du es geschaut hast und dann machen wir weiter.

Respondent (7) 4:46
Mhm.

Interviewer: Felix Schöllhammer 4:48
Danke.

Respondent (7) 4:48
Okay ich hoffe, das funktioniert, gleichzeitig Video angucken und ich dir zuhören? Würde das Gehen?

Interviewer: Felix Schöllhammer 4:55
Ich werde nichts mehr sagen dann.

Respondent (7) 4:58
Okay.
Ich schau mal ok.
Funktioniert.
Ok, ich habe es mir angeschaut.

Interviewer: Felix Schöllhammer 11:22
Okay sehr gut. OK, dann erstmal hast du allgemeine Fragen zur Funktionsweise, oder?

Respondent (7) 11:31
So viele, so viele. Ne, ich glaube das kann man nicht in dem… Vielleicht allgemein dieses PEP sagt mir jetzt noch nichts, das ist etwas Offizielles was es irgendwo gibt und wo halt die Manufacturers auch angehalten sind die Daten bereitzustellen, wenn ich das so sehen.

Interviewer: Felix Schöllhammer 11:40
Ganz genau also das ist ein Repository online Zugreifbar, wo quasi LCAs durchgeführt worden sind für bestimmte Produkte also nicht alle die daran teilnehmen, aber eine ganz große Zahl und dann kann man bestimmte Impacts einsehen von den Produkten.

Respondent (7) 11:55
Und das ist natürlich auch deine Annahme, dass da die Produktdaten hinterlegt sind. Für deine Berechnung, richtig, ja genau.

Interviewer: Felix Schöllhammer 12:13
Genau. Also man kann angeben, ob es ein PEP gibt und das kann, automatisiert ja gefetched werden. Aber es gibt, wenn es für das Produkt kein PEP gibt, aber eine andere Source für in dem environmentalen Impact zum Beispiel kann das auch verwendet werden, aber dann muss natürlich das Ganze dann händisch gemacht werden, ja.

Respondent (7) 12:17
Okay okay verstehe Mhm.

Interviewer: Felix Schöllhammer 12:37
Genau. Okay ich denke, alle anderen Fragen können wir dann vielleicht klären, wenn du Fragen stellst.

Interviewer: Felix Schöllhammer 12:43
Ja ok, gerne da.

Respondent (7) 12:44
Okay.

Interviewer: Felix Schöllhammer 12:45
Perfekt. Ok, dann ja, wie würdest du den Gesamteindruck des Tools beschreiben?

Respondent (7) 12:52
Gibt es Kategorien oder gibt es?

Interviewer: Felix Schöllhammer 12:55
Nein, aber den Gesamteindruck. Du kannst gerne stärken und Schwächen nehmen, die du schon siehst.

Respondent (7) 13:02

Okay also auf jeden Fall sehr interessant, also definitiv gebraucht, auf jeden Fall sehr nützlich.

Ich denke auch, dass also als Informatiker bin ich jetzt hin und hergerissen. Das ist nur ein Excel Sheet ist oder irgendwelche irgendwie Sheets sind, weil das für mich ein bissel, ohne dich jetzt irgendwie zu finden, billig aussieht, aber ich sehe aber auch auf der anderen Seite den Nutzen für einen normalen End User, also für einen sagen wir mal Semi-Experten, der hat mit Excel Sheet umgehen kann und dort eintragen kann sich durchaus auch als Benefit, das jetzt nicht auf ein spezielle Tool, spezielles Interface und sowas gehen muss also das sehe ich jetzt beides als Stärke und als Schwäche. Potenziell ist für mich auch.

Die Frage, vielleicht auch eine Schwäche. Was muss der Endnutzer am Ende hier alles wissen und können?

Das ist ein bisschen schwierig einzuschätzen, wenn ich jetzt davon ausgehe, dass das PEP alles hat, dann ist es vielleicht nicht so einfach, da muss ich einfach das lable lesen vom Sensor und das Eingeben und dann holt das es.

Aber zum Beispiel in Richtung Data Storage sehe ich auf jeden Fall Bedarf, dass da jemand Ahnung hat, wie die Daten Kollektion funktioniert und auch der mehr einschätzen kann und muss. Also, dass ich auf jeden Fall den Benefit für einen Experten für den technologischen Experten, der das einrichtet, nicht unbedingt für den User. Ich weiß jetzt nicht, was eure Zielgruppe genau ist.

Vor allem hinsichtlich der Daten hat hab ich hab ich, also Datensammlung ist auf jeden Fall interessant, aber da sehe ich halt eine Menge Konfigurationsparameter die vielleicht noch fehlen, Storage Costs, wo speichere ich Daten, wo liegen die werden die Lokal gespeichert oder werden die in einer Cloud gespeichert und so weiter wie kommen die Kosten rein, das ist für mich relativ schwach. Das würde ich eher noch als Schwäche sehen das nicht ganz so transparent ist, wie ihr das dann am Ende berechnet.

Und was mir noch aufgefallen ist, für das Smart Home Exempel ist es natürlich schön, da hat man relativ guten Überblick über die Sensoren, die man so hat, wenn man so ein Setup möchte. Ist jetzt ein typisches CPS, gehe ich mit, aber halt auch andere typische CPS und halt eher ja ist eine Definition Sache, aber so eine Smart Factory oder ein Auto mit vielen Sensoren sehe ich jetzt schwierig darin abzubilden. Und da weiß ich auch nicht, ob das jetzt auch so ein Use Case für euch, wer wo man das halt

berechnen kann. Nur so eine Maschine, die ja gleich mal 500 Sensoren mitbringen oder 1000 sind die extrem viele Messungen machen sehe ich sehr darin abzubilden. Ehrlich gesagt, das sehe ich auch eher als Schwäche für smart Home gehe ich mit, das ist sehr interessant ja sehr nützlich für den End User an der Stelle um den Impact zu sehen wenn ich mir jetzt denke jemand der vielleicht mal draufsetzen will einrichten wird da auch einen Überblick hat. Aber so für jemanden, der eine Smart Factory betreibt oder erhaltenen den Tesla baut mit ganz vielen Sensoren sehe ich das als ehrlich gesagt nicht sehr nützlich an, weil ich nicht weiß, wie ich mit diesem, weil ich einfach nicht sehe, dass das irgendwie die Sensorik gut abbilden kann und handeln kann. Das ist so meine ersten 5 Minuten so als allgemeinen Eindruck.

Interviewer: Felix Schöllhammer 16:03
Perfekt. Vielen Dank dafür.

Respondent (7) 16:06
Okay.

Interviewer: Felix Schöllhammer 16:11
Die dritte Frage. Glaubst du, dass das Tool nützlich ist?

Respondent (7) 16:12
Das kommt ganz drauf an. Also ich denke das kommt einfach auf die Zielgruppe und auf den Nutzer an, die dann am Ende das Nutzen und wie gesagt im Smart Home sehe ich das als sehr nützlich für jemand der ein Smart Home einrichten will zum Beispiel der ein bisschen technischer Expertise hat. Für andere Domänen, wo halt die Sensorik des CPS sehr komplex werden, sehe ich das als potenziell. Muss man nochmal drüber nachdenken, ob das jetzt ist oder nicht. Also wie gesagt, das ist halt einfach so ne Sache, ich weiß.
Ist kenne Professoren die reden sehr, sehr motiviert über ein CPS wenn sie einfach nur über den Bremssystem von einem Auto reden, hast du ein APS, also mehrere Sensoren und dann hast du quasi so ein Regelungssystem. Das ist für die schon CPS. Da hast du vielleicht 5-6 Sensoren drin, Bögen die man abbilden kann in dem tool wahrscheinlich. Aber ich kenne auch andere Leute, die Reden von Flugzeugturbinen, die mit Sensorik ausgestattet sind, die Halt unmengen von mehr Daten produzieren

pro Sekunde an der Stelle sich euer Tool jetzt nicht sinnvoll, also das ist immer Use-Case bezogen würde ich sagen.

Interviewer: Felix Schöllhammer 17:18
Ok, vielen Dank.

Interviewer: Felix Schöllhammer 17:21
Bei den nächsten Fragen würde ich dich bitten, von einer Skala von 1 bis 5 die Nützlichkeit der bestimmten Features auszudrücken. Und 1 Ist nicht nützlich und 5 ist äußerst nützlich. Die erste Frage wäre, inwiefern ist es nützlich verschiedene Konfigurationen eines CPS zu spezifizieren?

Respondent (7) 17:30
Mhm.
Ja gut.
Mhm.
Ja, lass mich kurz überlegen.
Das würde ich sagen, ist einer.
Am Anfang würde zuerst also im ersten Sheet legst du erstmal die, Sensorik an die du zur Verfügung hast generell und hol dir die Daten zu den Sensoren und im zweiten Schritt das wäre dann die Konfiguration machst du dann die konkrete Konfigurationen für ein konkretes Anwendungsbeispiel. Darum geht es genau.

Interviewer: Felix Schöllhammer 18:00
Genau und dich und eine Konfiguration, also ein CPS kann mehrere Konfigurationen haben. Das sind quasi die Alternativen wie ich das ganze CPS gestalten kann.

Respondent (7) 18:19
Ok.

Interviewer: Felix Schöllhammer 18:20
An und dann nachher quasi hinzugehen und zu sagen, ok, wie ist der. Ja, ja, genau.

Respondent (7) 18:21

Ich kann es vergleichen, zum Beispiel genau richtig. Also mit dem mit dem Ziel des zu vergleichen, die den Environmental Impact, würde ich sagen, ist das eine.
Ja, schon mindestens. Also ich würde sagen 4.
Wo ich dann genau mit der Einschränkung, dass vielleicht ich an einigen Stellen kann ich die Möglichkeit haben, wir Konfiguration, also für bestimmte, für bestimmte Szenarien hab ich vielleicht gar keine Möglichkeit mehrere Konfiguration anzulegen und kein Bedarf, aber jetzt im Smart Home um zu vergleichen von verschiedene Konfigurationen.
Das würd ich sagen 4.

Interviewer: Felix Schöllhammer 18:56
Danke.
Und inwiefern baut auch wieder drauf auf. Inwiefern ist nützlich, die Umweltauswirkungen verschiedener CPS Konfiguration zu vergleichen?

Respondent (7) 19:02
Mhm.
Also 5 würde ich dann an der Stelle sagen, weil war ja sustainability ist ja sehr wichtig heutzutage. Genau.

Interviewer: Felix Schöllhammer 19:15
Okay.
Inwiefern ist es nützlich, automatisch Informationen aus dem Produkt Environmental Profile (PEP) zu extrahieren?

Respondent (7) 19:23
Mhm.
Und da auch mit auch 5.

Interviewer: Felix Schöllhammer 19:29
Und warum?

Respondent (7) 19:30
Weil das halt den Aufwand deutlich reduziert für den Endnutzer und so die Daten händisch einzutragen oder irgendwo zu übertragen mit Fehlern und aus

irgendwelche Handbücher nachzuschauen, wo dann vielleicht irgendwie Fehler drin sind oder auch Manuals nachzuschauen, wenn das automatisierte in einem Repository vor allem standardisiert ist, wo du halt weißt ok da sind Standard Attribute drin, die du nutzen kannst die da eigentlich immer mitgeliefert werden müssen, dann ist es super nützlich, dann ist das ne 5. Dieses Repository alles nutzt und das ist ja für dich auch als Designer dieser Anwendung des Tools wichtig, dass du weißt es gibt standardisierte Attribute die immer drin stehen müssen und die kommen auch mit, wenn du dich darauf verlassen kannst ist das auch völlig nützlich.

Interviewer: Felix Schöllhammer 20:11
Dankeschön. Inwiefern ist es sinnvoll, die Umweltauswirkungen in Diagrammen zu visualisieren?

Respondent (7) 20:22
Da würde ich sagen eine 4. Es kommt natürlich drauf an, für wen diese Auswertung dann halt passieren soll. Wenn ich das als Nutzer natürlich mehr anschauen möchte und einschätzen möchte, wenn ich zum Projekt aufsetzen oder managen möchte. Dann ist das würde ich sagen, es ist sogar eine 5. Wenn ich jetzt aber zum Beispiel das automatisierte natürlich weiter verarbeiten möchte durch einen Computer oder durch weitere Tools, dann würde ich sagen, es ist jetzt nicht so nützlich, es kommt immer wieder ganz drauf an, wem diese Informationen dann zur Verfügung stehen sollen. Deswegen würde ich sagen vier.

Interviewer: Felix Schöllhammer 20:54
Danke. Danke.
Inwiefern ist es Nützlich das Volumen der durch das CPS geredeten Daten zu berechnen.

Respondent (7) 21:06
Ja, auch wieder Anwendungsfall abhängig.
Ich denke, da würde ich sagen.
Auch nur 4. Heutzutage, es kommt wieder auf die Menge der Daten natürlich an und Kosten für die Datenspeicherung ist natürlich auch irgendwie proportional zur Datenmenge, die produziert wird. Und da kann es dann schon relevant werden, bei wirklich größeren Datenmengen.

Wieviel es kostet, am Ende des zu speichern also wieder Anwendungsfälle abhängig für kleines CPS Konfiguration im Smart-Home, kann es interessant für den Nutzer sein. Allerdings ist sind, da die Storagekosten wahrscheinlich sehr gering im Vergleich zu anderen Anwendungsfällen wieder so eine Flugzeugturbine oder ein Auto wo halt die Datenmengen um Größenordnung größer sind, wo halt aber auf der Storage wichtig ist, zum Beispiel für die Nachvollziehbarkeit, für die Reliability, also für irgendwelche. Es gibt irgendwo Policies, zum Beispiel das irgendwie bestimmte Flugzeugdaten, zum Beispiel 10 Jahre gespeichert werden müssen und wenn dann so viele Daten anfallen, dann sind die Kosten natürlich super relevant an der Stelle also würd ich sagen auch wieder ne 4 kommt wieder auf den Anwendungsfall an.

Interviewer: Felix Schöllhammer 22:20
Okay.
In wieviel ist das nützlich? Den CO2-Fußabdruck, der von den CPS generierten Datenvolumen zu berechnen?

Respondent (7) 22:29
Oh.
Oh Gott.

Respondent (7) 22:31
Also ist bezogen auf die Daten jetzt ja.

Interviewer: Felix Schöllhammer 22:33
Ja

Respondent (7) 22:34
Mhm, ok.
Ja, dann würd ich sagen.
Vielleicht an der Stelle vielleicht einen 3. Ich denke die Kosten sind schon relevanter an der Stelle.
Heutzutage wird ja viel mit CO2 Fußabdruck gemacht, aber so wie ich finde, die Nützlichkeit dieser Aussage für den Endnutzer wenig bedeutsam. Was jetzt den CO2 Abdruck von Daten ist, da finde ich die Kosten schon besser zu interpretieren.
Daher würde ich sagen eine 3 an der Stelle.

Interviewer: Felix Schöllhammer 23:07
Danke. Inwiefern ist es nützlich, die Standortbezogenen Kohlenstoffintensität des Stromverbrauchs der Komponenten zu berücksichtigen?

Respondent (7) 23:16
Oh Gott.
Okay lass mich kurz überlegen.

Respondent (7) 23:27
Ja, da muss ich zugeben, da kenn ich mich nicht zu sehr aus, was jetzt zu regionalen Einfluss und dann am Ende wirklich, ob das wirklich einen großen Unterschied macht an verschiedenen Stellen. Daher würde ich auch sagen ja ne 3, weil mir jetzt die ich kann schwer einschätzen inwiefern das wirklich ein Impact hat, ob das jetzt ich sehe auf jeden Fall, dass es regionale Unterschiede gibt, je nachdem wie die.
Energie, Produktion ist und so weiter, in welchen Regionen und welche Energie Produktion stark ist und wie das dann linkt zu den einzelnen Daten und Komponenten. Aber für mich ist das da bin ich zu wenig Experte, um das einzuschätzen, ob das wirklich nützlich ist. Deswegen sage ich mal ne 3.

Interviewer: Felix Schöllhammer 24:06
Okay okay jetzt kommen wir wieder zu den offenen Fragen ohne Skala. Würden die Umweltauswirkungen eines CPS ihre / deine Entscheidung, die seinen Entscheidungen beeinflussen.

Respondent (7) 24:11
Ich denke schon, mittlerweile schon. Weil das ja sehr wichtig ist und wenn ich tatsächlich durch die Vergleiche und Konfigurationsprofile sehen kann, wie sich der entsprechende Impact verändert, würde ich dann natürlich auch entsprechend die Komponenten anpassen und dann vielleicht tatsächlich auch mal einen Sensor weniger nehmen oder nen bisschen besseren Sensor mit bessere Bilanz unserer letzten Endes zum einen natürlich Einfluss auf den Kosten zu sehen, aber auch im CO-2 Impact. Also heutzutage würde ich sagen ja.
Da bin ich auch Umweltbewusst genug, da würd ich sage okay, das hat auf jeden Fall

Einfluss auf meine Entscheidungen.

Interviewer: Felix Schöllhammer 24:57
Dankeschön. Die nächste Frage ist.
Wenn du das Tool nutzen würdest, welcher der 4 Impact Indicators würdest du am meisten Aufmerksamkeit schenken? 1. Ist CO2-footprint /Global warming okay du siehst im Chat.

Respondent (7) 25:14
Ja, ok.
Vermutlich würde das Wichtigste für mich sein, weil es am drastischsten klingt die 4 natürlich die Acidification of soil and water, weil das wahrscheinlich den stärksten Impact hat. Und dann nach. Also wenn du jetzt ein Ranking haben willst, würde ich sagen 4 zuerst. Das zweite wäre vermutlich Water pollution, danach der CO-Footprint Insgesamt und dann freshwater usage.

Interviewer: Felix Schöllhammer 26:03
Perfekt. Das geht. Danke schön und würdest du das tun verwenden, um den Fußabdruck von CPS zu berechnen?

Respondent (7) 26:14
Unter den Rahmenbedingungen, dass ich alle Daten habe und im übersichtlichen sheet, hab und so weiter dann ja unbedingt. Um einen Eindruck davon zu bekommen, also ob ich das jetzt also einfach mal einzuschätzen, denn das sind jetzt neue Informationen, die auch nicht so kenne, und das Tool kenne ich jetzt auch nicht so. Und hab noch keine ähnlichen Einsatz gesehen, der so berechnet. Deswegen wäre es auf jeden Fall interessant das zu sehen, was so der der Impact davon ist von den Sensoren die ich so nutze und von den Setups nicht so bauen.

Interviewer: Felix Schöllhammer 26:46
Mhm, vielen Dank okay dann kommen wir zur Abschluss frage, ob du gerne die Abschlussarbeit, wenn das fertig ist und auf Zugang zu dem Tool haben wolleb würdest.

Respondent (7) 26:54
Ja, sehr gern ja.

Interviewer: Felix Schöllhammer 26:55
Ja perfekt, vielen Dank okay dann war es auch schon, ich bedanke mich das waren tolle Insights von dir. Und ich stoppe jetzt die Aufnahme!

Interviewer: Felix Schöllhammer left the meeting

Interviewer: Felix Schöllhammer stopped transcription

Transcript of Interview 8 & 9

August 29, 2023, 2:06PM

Interviewer: Felix Schöllhammer started transcription

Interviewer: Felix Schöllhammer 0:05
Ohh, OK OK. It workes very nice.

Respondent (8) 0:09
Yeah.

Interviewer: Felix Schöllhammer 0:09
And OK, so the first question would be.
And are you mainly working for private companies or research institutions, or a combination of both?

Respondent (8) 0:23
I would say a combination of both. I mean that we work both in project and in both for private companies. We are a Research Institute but, we work with companies with two mechanisms. One is private consultancy or and one is a big [European + name] project.

Interviewer: Felix Schöllhammer 0:56
OK. Thank you. And what is your field of expertise and what is the connection to cyber physical systems, Internet of Things, life cycle assessment?

Respondent (8) 1:09
Okay, he says. Big question. Uh, I I've. I would probably take a few minutes.

Interviewer: Felix Schöllhammer 1:11
Yeah.

Respondent (8) 1:14
Yeah, we are working on last cycle assessment since, uh, 20 years I would say and I'm part of a of an institute that is an institute for Advanced Manufacturing that needs

skill of this is that was machine at the beginning so being specialised in LCA and working on machines. We worked on production systems.
Our experience in life cycle assessment was different along the year. I mean that at the beginning last assessment was just applied like a single assessment of things. I would say you implementing the technology, you compare products and you want to see what happen, what is the different the gap in then we moving more and more. On eco design assessment, which means you elaborate scenarios, you elaborate strategies in order to improve environmental impact.
And it done another application in order to provide an environmental view on simulation I would say or also for design and we work at that as an example. Also, on the system for shoes an example, and in order to provide an overview on what is the environmental impact of a single shootings like that.
And then in the last part we are trying to develop our own tools and particularly in in the iron sector.
And also, we work on standardisation, in particular on circular economy standardisation, but also it in environmental management system. So, we work both in ISO Technical Committee 207 and 323. What are these two technical Committee that works on environmental management and circular economy?

Interviewer: Felix Schöllhammer 3:49
OK. Thank you so much.
And do you also work with cyber physical system?

Respondent (8) 3:59
Yeah, we work on that as well on the production system.
Uh, we presented the work in particular in a conference in order to examine in deep the parading of cyber physical system applied to a company and we examined the framework in which life cycle assessment could be applied and in order to to provide the continuous homogeneous flow of data that can be elaborated at a higher level. Since bottom line, this approach in the reality in our, in our experience was applied not in the cyber physical system perspective, the pure cyber physical system perspective, but more in terms of simulation, real time simulation of production system and in particular we apply this concept in two cases to relevant cases one, in reality it is a little bit more but, OK. One is in the iron sector for specific facility in [country name], what big?

A big producer and another one is within a European project that is called (...), and this project in particular develop a tool that is a integrated within a platform and is able to have different interaction with other tools. As an example, is possible to link this tool with a simulation tool with the CAP tool and can provide very different things. As an example, you can also provide a sort of incremental environmental information in terms.
That can be used for digital product passport, and we apply this kind of we are developing these two in particular (Respondent 9) is developing and in with the three companies and one is in the food sector it's another one is in the wood sector and in another one another one is in the furniture sector. These are the three companies that are implemented in in the project.

Interviewer: Felix Schöllhammer 6:43
Very interesting. Nice.
So just said to see my or our perspective, we go and see what the direct environmental impacts of cyber physical systems are. So that's kind of like our perspective. And the next question would be then.
Do you consider environmental impacts when working with a cyber physical systems?

Respondent (8) 7:18
But for sure we work in the perspective of implementing environmental impact in current in the current simulation tools for industry. So, it's our commitment. So it's the perspective is quite different from the companies we work with. I mean that sometimes can be difficult for them to implement this kind of cyber physical system or this kind of perspective I would say for different reason. One reason is that you need a proper perspective, environmental perspective and not all the companies deeply understand the potential for introducing environmental impact in in real time management of their plants and the question is quite different. In two cases.
If the market. The CPS perspective is very useful because it's able to provide the information for single batches of products and this kind of perspective is not possible to be reached by common life cycle assessment tool that are quite static are based on yearly view, things like that and the other perspectives is instead is related to the policy perspective. I mean if he there is some governments or some big sector that is implementing a green transition path, I would say by having sectoral limits, things like that. In terms of, I would say CO2 emission, things like that. Every time that there

is a policy perspective you know that there is an a big initiative that calls the science based targets and except it this kind of perspective.
Try to depict the sort of mitigation path OK and in order to do this kind of mitigation path, it's quite important to have a very precise tracking or what are your actual emission or your actual environmental impact along the year to every single month. In particular more the time of implementation of some innovation is reduced more you're able to see. What is the effect within your path?

Interviewer: Felix Schöllhammer 10:12
OK. Thank you.
And in your experience or observation, is this common that components of a cyber physical systems are reduced if they're not needed anymore or are they usually disposed off afterwards?

Respondent (8) 10:31
It really depends. It's you know that the driver are so many that it is quite difficult just to. Limited the perspective to just to cyber physical system what is more important is in the way the cyber physical system is used. I would say if the cyber physical system is integrated within. To improve at benefit in it it's able to, uh, globally, reduce the environmental impact of a company. Let's make an example. If you have a cyber physical system that's able to identify and not spot in real time.
of change over some energy mix or things like that.
Um can enable a transition of the company in order to select specific supply chain configuration, things like that and the globally apart from the cyber physical system, the environmental impact or the whole company of the whole factory is is improved and apart from the energy use that what are the just the environmental aspect of the single or the single company?
So it's the perspective is quite different. You mean I understand that as an example more you require digitalization, more you require sensitization. Obviously, you have a lot of environmental impact related to the fact that you have more electronics, things like that and more energy consumption. But if you consider the CPS in the environment of perspective in order to improve efficiency of the whole system, maybe the whole effect is positive.

Interviewer: Felix Schöllhammer 12:28

Hmm.
Thank you for that.
And now I would send you a link to YouTube. It's a presentation of the tool, it's like 6 minutes long.

Interviewer: Felix Schöllhammer 12:49
Um, yeah. I sent you a link.

Respondent (8) 12:53
You are right.

Interviewer: Felix Schöllhammer 12:55
Yeah.
And then just let me know when you've watched the video.

Respondent (8) 13:00
Okay.
Ohh interesting.
Can I start and or you want to share the screen and and we see all together?

Interviewer: Felix Schöllhammer 13:11
No, you can just watch.

Respondent (8) 13:13
OK.
Okay. We can start independently, [Respondent 9]. OK.
See you in six minute.

Respondent (8) 13:21
Very interesting compliments, Felix.
(Respondent 9), have you seen it? OK, compliments. Compliments really.

Interviewer: Felix Schöllhammer 19:45
Thank you.

Respondent (9) 19:47

Yes.
Just finished.
Really, it seems like a very well done work.

Respondent (8) 19:56
Very well done. It's a massive work for what we understood. It's basically is a bottom up tool, very useful that provide an insight of the potential impact of CPS. It's very interesting. What I love a lot in your approach is that you are able to link the whole approach with the PEP Product environmental passport. So you are using grounded data that are really referred to. Very fascinating I would say. From my from my point of view what just can be improved, but it's anyway, it's a very good start. It's this aspect you know that that the real use of machine is sometimes difficult. We tried also to implement the same perspective but in a different way in terms of top-down approach we mean that we just collect information from sensors within the plant in order to understand what is the real impact and not in terms of single sensors, but in terms of the whole environmental impact of as an example, consumption of energy of a machine.
What is the difference in the two approaches in the top-down approach that is not the best I would say because maybe last trustable I would say you are not able to catch as an example which is the part of the CPS that it's working good or bad. But the good approach in the top-down approach is that you can also catch things that cannot figure out in a bottom-up approach I would say like things that are related to the way in which is actually used the production system. It's a strange thing because it's something that we realised that the examining the energy user at plant level. But sometimes companies are not really aware on the way they use energy in a plant. I mean that they are not able as an example we see this in in the [...] case. Do you remember [Respondent 9] case? They have a path of energy flow that is crazy I would say and are not simply to be explained.
And also by using their information of the production plant in as an example, you can use the production planning of the plant in order to understand okay, this could be the environmental impact, but if you really monitor in dept the plant the tracking is not consistent with what they expect.
This is a problem and this is related to the actual user of the of the plant. Anyway, I mean that that's to approach can be for sure implemented. And this approach like this can provide a very good insight on a hotspot in terms of what are the element that is and the possible configuration that could work in a better way.

Another interesting thing that I see is that as I mentioned before.
That sometimes you can also have, as an example, We realised that some environmental product declaration for some machine and the problem of the machine is that you use the machine in Europe or instead in India the environmental impact change dramatically, because the energy mix changes and at the same time some companies within the same year. In particular in [country], try to buy energy. Um cleaner energy, in order to reduce the environmental footprint and this approach really is effective. It's expensive and it's becoming more and more expensive because the renewable energy is not infinite, and furthermore, to the remaining mix at the national level, it's become dirtier and dirtier. So, the companies using the national energy mix are becoming more and more impacting also, if they don't change anything in the production plant while the companies that buy this kind of certificate are becoming more and more clean. So, this is another interesting thing to analyse. It depends on the context in which you use this tool. I mean if you consider that the energy mix is fixed, and you have a certain configuration that is quite consistent with the effective use of CPS within the company. I think under this assumption to the tool is very effective and very useful and provide a very good insights.
[Respondent 9] do you have a comment on this view or other ideas.

Respondent (9) 26:02
No, no, no. I believe you said everything that had to be said. Actually, I believe that there are some differences with the approach that we usually have used. [top-down] Many complications that come from our approach and in some ways are solved by using a bottom-up approach and but there are also maybe some complications that can be solved using a top-down approach so but I believe this is a really interesting approach. As I said, it's a very well-done work.

Interviewer: Felix Schöllhammer 26:48
Thank you.

Respondent (8) 26:48
And another thing that I also just thought in this moment is that in order to be effective, you should have a proper tracking of all the sensors and not all sensors have [declarations]. And this is a current limit. But if you consider that in the future

the environment, the European Commission is implementing more and more the tracking the passport for each product, particularly energy using product, I think that this is the proper approach. The proper approach Felix so complements it's something that could be very effective.

Interviewer: Felix Schöllhammer 27:27
Very nice. Thank you so much for your opinion and your insights here. I must follow my structure here, so maybe you have to repeat some things. Do you have some general questions.

Respondent (8) 27:55
No, it is OK, I think if we start with the question, we can take some time because if we, we could go very deep detail. Yeah, but it's interesting if we have another hour, I would ask a little bit more but anyway maybe we can show also the video also to a colleague and if we have some questions and we can send you by e-mail if you agree because also in order to be sure that we have understood it properly.

Respondent (9) 28:37
Yes good idea.

Interviewer: Felix Schöllhammer 28:37
Yeah of course.

Respondent (8) 28:40
Anyway.

Interviewer: Felix Schöllhammer 28:40
What I wanted to say with the energy mix and what we're doing in the tool we are taking the energy mix of the country into account.

Respondent (8) 28:50
Yeah, for sure. We have to do.

Interviewer: Felix Schöllhammer 28:51
We only take the average of a country into account. So, we say, OK, let's say Italy has

this energy mix. So, we don't see if a certain company is buying green energy that that we don't do at the moment. But I mean that could be also an improvement for the future.

Respondent (9) 29:12
Ok.

Respondent (8) 29:14
Ohh OK.

Respondent (9) 29:16
No, but I believe [Respondent 8] point was more related to the recent developments that we found by, let's say, renewing certifications that we've done, it is a general consideration to be taken into account because as you said, the residual energy mix is getting, let's say dirtier and dirtier by the day because certification and certified energy of renewable energy has a huge market, so it's been almost all of it been taken by the corporations that want to have good environmental performances and as a result not the average energy mix, but the residual energy mix that is mandatory for many Type 3 Certifications must be taken into account also for the future. And this enforced the use of the residual energy mix, if there is no certification. So, there is a huge part of usually of manufacturing of a product so.
That is something that should be taken into account. I know that at the level of your tool, I believe it's already an outstanding result, the one that you are delivering as of now.

Interviewer: Felix Schöllhammer 31:13
OK. Thank you.

Respondent (8) 31:13
OK if.

Respondent (9) 31:13
But that was just more of a general note I believe.

Interviewer: Felix Schöllhammer 31:16
Yeah.

Respondent (8) 31:16
If I can add a little bit, no, it depends from my point of view it more in the perspective you use the tool. If you consider the tool in the perspective of the producer of CPS, you have to use the energy mix. I mean that is something that you cannot change because you don't know how the CPS is used.

Respondent (9) 31:25
For the use phase, of course. This problem is less important.

Respondent (8) 31:27
It's more if you adopt this kind of tool within a specific factory, as I would say, in that case, you can also have a deeper analysis. I'm thinking about an integrated system. In that case, if there is a specific CPS that is applied in a specific factory, it's in that case probably the factory makes use of some certificate things like that. Anyway, it's not a problem the perspective just to provide more options in the energy use, I would say it's not. It's not so different it's you have to choose a specific input of energy and by changing this kind of input is the environmental impact change for what we have seen the energy environmental impact is not so much it's so important that it's quite difficult that the material part of production we can consistently we can comparable, but there are some specific scenarios in which under specific very low impact energy, the material part that the production of the CPS is becoming important but under very specific consumption. I would say if you are in Finland things like that or you use solar energy, things like that in or use very green energy. But it's not the case. This is not the case in general.

Interviewer: Felix Schöllhammer 33:27
Okay, thank you.
How would you describe your overall impression of the tool and what are it's strength and weaknesses?

Respondent (8) 33:39
Okay [Respondent 9] do you want to start or I can provide?

Respondent (9) 33:44
No, no, you just talked. And then maybe if there if there is something that I mean you're missing, maybe I will add it.

Respondent (8) 33:46
OK. Overall impression. As I said before, it's very positive it's I think that is something that we can really make different in particularly the strength point of this tool is related to the possible use in the planning of a CPS within a specific company. I would say in order to understand before what will the planning of environmental impact along the years, things like that and this could be very interesting because. That can also help people with CPS projects by identifying possible alternative option. I will say or possible alternative option. But in terms of selection or parts or selection of configuration, possible configuration. Furthermore, a very strength point of it I have seen is the direct reliability of information in terms of direct reference to the specific models of the CPS that it's, this is quite important. A weak point, if I have to mention some weak point.
It's probably related to the fact that the applicability of the tool is possible just for modules that are able to be tracked and the second week point is related to the fact that sometimes there are some intangible aspects that cannot be foreseen in the beginning, and so this is not a problem. I see it's not a weakness, it's more a perspective of implementation.
I mean, once you are able to match the top-down modelling with the bottom-up modelling you can understand how it's important that part. It is an initial part of work and I can see really important progresses. And I'm also curious in seeing how it will be applied and for our point of view we also can share your experience because it's very interesting also within our institute.

Interviewer: Felix Schöllhammer 36:22
Thank you.

Respondent (8) 36:26
You want to add something [Respondent 9]

Respondent (9) 36:31
No, no, believe that analysis was very complete.

Interviewer: Felix Schöllhammer 36:37
Thank you. OK, then the next questions I have.
Here you can answer on a scale from 1-5. A Likert scale. I gonna go over some features of the tool and you can say how useful you find the different features. 1 would be it's not useful and then 5 would be it's extremely useful.

Respondent (8) 36:57
Okay.

Respondent (9) 36:57
Okay.

Interviewer: Felix Schöllhammer 37:05
The first question is.
To what extent is it useful to specify different configurations of a cyber physical system?

Respondent (8) 37:17
I would say 5.
But [Respondent 9], but we can make an average our response. [Respondent 9].

Interviewer: Felix Schöllhammer 37:19
OK.

Respondent (9) 37:27
Yeah. No, I believe it's very important 4 or 5 because I believe that that gives the power to the user to make a decision actually, so that's pivotal.

Respondent (8) 37:34
Okay.

Interviewer: Felix Schöllhammer 37:42
Thank you.
The second question is to what extent is it useful to compare the environmental impacts of different CPS configurations?

Respondent (8) 37:54
5.
It's again.

Respondent (9) 37:55
Yeah, the same the same as before. 5
Direct consequence.

Interviewer: Felix Schöllhammer 38:02
And OK and short. Why is that a 5?

Respondent (8) 38:09
Uh, because. In that case you don't have some variability to be managed, it's just planning. So it's very precise. I mean it's the way you think the system should work. So in that case it's in the planning perspective, there is no, no uncertainty. I would this for this reason my point is 5.

Interviewer: Felix Schöllhammer 38:42
OK. Thank you.

Respondent (9) 38:42
Uh, believe already said it before, so in the previous answer so. So 5.

Interviewer: Felix Schöllhammer 38:49
Thank you. And to what extent is it useful to automatically extract information from the product environment profile documents?

Respondent (8) 39:03

You say in terms of using information to in order to, from, from PEP things like that you're saying?

Interviewer: Felix Schöllhammer 39:13
So like to what extent is it useful to automatically extract information instead?

Respondent (8) 39:18
No, it's very effective. That part, that feature probably the most interesting, what impressed me most because I never seen something like that and the goal in the in the direction of automation of LCA and all of this because it's my area of work. So, five also in this case.

Respondent (9) 39:40
For me too.
The point is that there is little to no integration with these databases as of now in the available software, so this is a really strong point of the of the tool.
Actually, I would like to ask you maybe a couple of things and on how you retrieve this data automatically if you have like a background database or if you have an API or something like that.

Interviewer: Felix Schöllhammer 40:00
Thank you.
Yes sur.
Yeah, let's go to the questions. Uh, just after this, but then we can talk about this.

Respondent (9) 40:21
Yeah, but that goes, yeah, over the over the hour. So as we said before it's not the time not the place but maybe we'll ask you for an e-mail.

Interviewer: Felix Schöllhammer 40:23
You can ask some questions after this, let's just finish the questions, but I'm available after the meeting. To what extent is it useful to visualise environmental impacts?

Respondent (9) 40:35
Yeah.

Respondent (8) 40:39
Okay.
Okay in that case I cannot be so precise, but I would say 4.
But for that specific reason I mean that from my perspective, what is very important is to be related to a specific standard, and I've seen all the relevant impact category, but there is some specific choice for that impact category or some specific reference for that environmental impact. So, the reference to the standard maybe could be I'm not sure because I've seen very rapidly, but for what I understood, but maybe I might be wrong, it's a there is no direct link to a specific scheme for representation of environmental impact, and this could be quite important. I mean also you know that that schemes are different. You know there are the PEP there are the EPD.
So, I would suggest to define just the specific outcome and to motivate to give a reason for that specific representation on the environmental impact, or just provide some option in in representing environmental impact. Anyway, this is an improvement I'm I would say we are. I'm placing the at the higher level my expectation because your work is very good and in this perspective is four, okay.

Respondent (9) 42:30
I believe it's five actually, because the visualisation of the environmental impacts is very useful to for the end user, it's actually more of a matter of usability than the underlying principle for the calculation is something that I believe is not part of the feature. The feature just the visualisation. So, the visualisation is one of the most important parts of a tool like this because it helps decision makers in the sense of maybe the end user to intuitively and to see and understand the magnitude of the differences between various configurations much more than a number may do, so I believe it's 5.

Respondent (8) 43:25
So it's a 4 and a 5 I would say.

Interviewer: Felix Schöllhammer 43:26
Thank you.
Amazing. Thank you.
And to what extent is it useful to calculate the amount of data generated by the CPS?

Respondent (8) 43:42
It's a tricky question.

Respondent (9) 43:43
I'm sorry, could you repeat, please? I think I missed some words.

Interviewer: Felix Schöllhammer 43:46
Yeah, to what extent is it useful to calculate the amount of data generated by the CPS so it's about the data volume?

Respondent (8) 43:57
By the steps of our order of magnitude, I would say.
I would say 4.5 I mean the remaining part is that we are not sure that is the real environmental data that will be developed. The remaining part is just related to the fact that as we mentioned before, there is also a top-down approach in the real use of the CPS and but if you want if you are working in a planning perspective, it's five. I mean if we work in the perspective of understanding the real quantity, I would say 4 because we are not sure that the data.

Interviewer: Felix Schöllhammer 44:43
Ok.

Respondent (8) 44:47
[Respondent 9]

Respondent (9) 44:47
Yeah.
Honestly it is not really clear to me the significance of the size the amount of data that has been calculated by the CPS.
Because it could be useful in order to understand other indexes. The environmental impact per GB per, so they could be useful in that way.
In in that sense it is useful for maybe some specific applications.
So I would say it's either four or three. It's not as important, I would say as the other two, because I believe the previous functions because they are I believe the core.

Yeah, the core functions of your tool, but I think they could be useful. I think they are very interesting from much more technical standpoint I believe.

Interviewer: Felix Schöllhammer 46:03
And thank you to the next question is very much related to the one before: To what extent is it useful to calculate the environmental impacts of that generated data from a cyber physical system.

Respondent (8) 46:14
This is basically exactly the same point that I mean if you work in the planning perspective is five if you wort in the actual use of its four, I mean that there is also a little slice of information that we do not have and but anyway if we.
You didn't make any. OK, it's later question. Sorry. It's OK. This is my point.

Respondent (9) 46:54
You know it's a bit, I believe it's. I actually agree with [Respondent 8]. So, I believe it's 4 to 5.

Interviewer: Felix Schöllhammer 47:02
Perfect. Thank you.
And last question here would be to what extent is it useful to take the components location related carbon intensity for electricity consumption into account?

Respondent (9) 47:17
From my perspective five, as we said before, it's very important to do this because it's.

Respondent (8) 47:24
So sorry Felix could you repeat the question. I didn't catch it somewhere.

Interviewer: Felix Schöllhammer 47:27
Yeah, it's a. It's a very a long one. It's about the energy mix. To what extent is it useful to take the components location related to carbon intensity for electricity consumption into account, yeah.

Respondent (8) 47:38

OK, this is the same, OK, same is always the same from 4 to 5. It depends on. I mean in reality it's probably no. It's 4 to 5 because also by the identifying the location, so the energy mix is fixed. You still need some information on what is used, how CPS is actually used within a company.

Respondent (9) 48:08

I believe that the location for the for the determination of the specific energy at the impact of this specific energy mix, it's important that there is a difference. It is important to add the difference that there is between, as we said before, between China and I don't know Spain.

The difference can be two to three times. The impact could be two to three, two to three times higher for China, for example. So that is pretty important. It's one of the things that we take into account when we think about as we apply our applications as [Respondent 8] said before. For example, for a machine, if it is placed in a country or if it is used in the country rather than another, it's it makes a very large difference, at least for the use phase.

Respondent (8) 49:07

What is interesting is if you want to make comparison the usability of the tool is improved. I mean that the energy mix affects the environmental impact in the same way in different configuration. The problem when you want to.

To identify a number for a specific configuration, this is the.

Respondent (9) 49:28

Yeah. OK. Yeah, yeah. No, no, I no understand that because if the configuration, the configurations you are comparing are all always in the same place. If the point is to make a comparison between those configurations, then choosing a specific energy mix does not make a difference. If you are comparing the same configuration but in different places, that could be very useful. So yeah.

In a sense, I in this sense I believe if you are comparing configurations.

Then it is not that useful. Uh, if you're come, if you want to compare the use phase for same CPS in different countries in different situations and configurations but different places that is a very important parameter, so it really depends. I would say.

Yeah, it's a very specific, but it's a very, I don't know, it's a.
At the time, that is really not commonly used and I believe it's a good thing that it is used or I would tend to 4 to 5 just because of the specificness and particularly of it.

Interviewer: Felix Schöllhammer 50:58
OK. Thank you. Very nice.
The next question would then be and now you don't have to answer on one to five anymore.
So now the question is, would the environmental impacts of the CPS influence your design decisions?

Respondent (8) 51:18
Okay, we currently we know not design. We just monitor so.
Okay from my point of view, it is something that is more and more in a key focus from machine producer or plant. For what we understood currently there is more cost driver or functional drivers. I mean you want to have a similar level of productivity, or you would just have some saving in terms of cost and these are the most important drivers in designing plants, it's so CPS It's is, um, but. For what we understood, it's not. It's not, but maybe the having an environmental monitoring of the CPS in studies are real important feature that we see as a really effective, really important from the producer is not our point of view, it's our experience with producer.

Respondent (9) 52:40
Yeah, from a user standpoint, CPS will always at least the industrial user.
I believe that the impact of a CPS of CPS will always be marginal with respect to their actual operation, so I believe that will not change much their decision. But from a producer standpoint, the fact that they can boost the fact that their CPS has that kind of performance could be very useful because it could lead to, some new marketing uh, and some growth or some interesting points for the producer and for the marketing of the of the product. But from a user standpoint, especially if it is an industrial user, I believe that it won't change. Because they will look more at the functionality of the CPS rather than the environmental impact.

Interviewer: Felix Schöllhammer 53:48
OK, very good. Thank you.

Respondent (8) 53:48
Also, if I can add just a little note it also depends on the user. I mean that we have seen that there are some users that have some machine that are completely linked and they have a lot of data for these companies that are frontline companies monitoring and it's so important that can also affect also the design phase, but that's companies are very few. I mean in for both, I mean in terms of [country] production, I would say commonly the big companies are more related to still to old problems like productivity costing, things like that.

Interviewer: Felix Schöllhammer 54:36
Okay, thank you.
And next question is, if you were using the tool, which of the four impact indicators would you pay most attention to?
I can send it in the chat. The indicators are first footprint, global warming and freshwater usage, water pollution and then acidification of water and soil.

Respondent (8) 55:10
I would say I don't know [Respondent 9] there, but from my point of view the hierarchy is quite good.
Uh, I mean, that's CO2. It's, uh, it's probably we say you know that in LCA we say that we have a carbon tunnel problem that we focus just on CO2 but it's also the focus of the producer sometimes CO2 is quite important also because it's related to energy use in particular.

Respondent (9) 55:40
Yes. And because it is the language that is spoken as of now by industrial partners, so that they see Global warming and CO2 Kilogrammes. But they usually don't see behind it. And so, it's our way to breakthrough their barriers, let's say, and to show them other impact categories, other indicators. So, I believe it's important to have a focus on CO2, but it's also really, really important to have other indicators, especially water related indicators as you as you mentioned.

Respondent (8) 56:30
What are using something that is very, very more and more and more in the perspective that European Commission, but also there is some new like biodiversity, but it's something that will be implemented in the future is not already present. I would say in my personal perspective that after CO2, the main important.
Yeah, I'm not sure at the same level of fresh Water usage is actually acidification because it is something is quite similar to CO2 footprint a lot of gases that produce acidification also have an impact of global warming. And this is something that commonly is quite related to the energy use. So if the problem is the energy use, basically you should choose some impact category that is more related to the energy use and the according to my experience, the most important are acidification, but also the freshwater use because you know that freshwater use is something that used in particular in renewable energy and things like that, not directly.
Not directly within the company because you know that it commonly, particularly where you have some assembly, there is no water use and in this sense the freshwater use is more related to Lifecycle not to the plant. And in this perspective could be not understood by the producer, I would say. So, I would say that the first two are CO2 footprint and acidification then freshwater usage and then water pollution.

Interviewer: Felix Schöllhammer 58:17
Perfect thank you.
OK. The last question here would be, would you use the tool to calculate environmental footprints of southern physical systems?

Respondent (8) 58:35
Possibly yes. Possibly. Yeah, if we can. If we can apply. We have a specific use case. We will be happy to use that. Yes. The absolutely yes and also to test we are very, very curious las a researcher. We are curious for everything and every time that we can test new approaches, we are very happy.

Respondent (9) 58:50
More than happy.

Respondent (8) 59:05

And furthermore, I'm particularly happy to use this tool because it's many years ago, I wrote an initial paper on this and for me a pleasure to see a project work on this. So, there are two different valuable reason for using the tool one personal and second it could be useful, but it depends on the context. If we have the possibility to use a real configuration. That means that we should find the specific sensors specific model that are actually used, and this is the only limit. But anyway, we can also explore at academic level what is the perspective. So, my replies yes. So, to sum up, yeah.

Interviewer: Felix Schöllhammer 1:00:00

Very nice. OK. And then the last question is, would you like to receive the final taper of the project and get access to the tool as soon as it's finished, and the project is over?

Respondent (8) 1:00:14

Yeah. Yeah, thanks. It's it would be a pleasure. It would be interesting to make a double comparison I would say of planning but also see seeing what is the difference of an environmental impact by a top down and bottom up approach. This could be quite interesting in order to fix what is the weight of intangible aspect? As an example, we have seen that sometimes machine production machines and things like that are leaved in a standby position. Don't know why for a lot of times and just waiting for some items, things like that and in this perspective, it's there is no, there is no proper planning, but there is no specific reason for doing this and we are also able to catch this aspect by looking to the bill of energy bill of energy and all tracking energy in during the year. And so, it could be quite interesting to see, OK, this is the planned the ideal consumption that we expected consumption, and this is the actual consumption and then the environmental impact for sure.

Interviewer: Felix Schöllhammer 1:01:45

Yeah, it's a, it's this is very, very super interesting part to make this comparison. I think in in this research that will be a bit too much because it's mainly focused in actually on the tool and the method. So, we are not, we're not no, but for the next for the future, very interesting cause. I mean it we go at the moment and say, OK. We don't care what your CPS is, but you can use our tool to find out the environment

footprint. But then in the future, maybe they can be like a case study where we see, OK, this is the planning and what is actually the impact in the end, which would be very, very nice to do.

Respondent (8) 1:02:12
Okay OK. Okay.

Interviewer: Felix Schöllhammer 1:02:29
Maybe in the future, in the future research, but yeah, very nice thanks you for that insight, yeah.

Respondent (9) 1:02:34
You're welcome!
Respondent (8) 1:03:51
If you need some help contact us for sure. Okay.

Respondent (9) 1:05:12
Thank you. Bye.

Respondent (8) 1:05:14
Bye.
Interviewer: Felix Schöllhammer stopped transcription

Appendix C

Activity and Concept tables

TABLE C.1: LCA for CPS As-Is Activity Table

Module	Task	Name	Description
1		**Defining CPS**	Task of describing the CYBER_PHYSICAL_SYSTEM (CPS) of the study.
1	1.1	Specifying CPS	Define the basic information about the CYBER_PHYSICAL_SYSTEM, including description, name and the intended lifetime. The task of describing the CYBER_PHYSICAL_SYSTEM (CPS) of the study.
1	1.2	Specify component type	Defines the COMPONENT_TYPE, with its name and category of it.
1	1.3	Specify CPS components	Defines the COMPONENTS with their multiplicities and numbers.
2		**Analysing Configurations**	Defining different kinds of CONFIGURATIONS of COMPONENTS of a CPS.
2	2.1	Define configuration	The information about the configuration results in CONFIGURATION and includes the name of the configuration.
2	2.2	Look up PEP existence	Examine if the considered component has available environmental declarations, in the form of a Product Environmental Profile (PEP).
2	2.3	Find energy consumption	Find energy consumption information for the use phase and total life-cycle in the Product Environmental Profile (PEP) of the COMPONENT_TYPE.
2	2.4	Calculate energy consumption	Examine the energy consumption by taking the before-defined information into account.
3		**Analysing CO2 emissions**	Analysing the CO2 emissions of CPS Configurations, by taking the previously defined information into account.
3	3.1	Define CPS region	State the region's name where the CPS is located. This information is important to access the CO2 emissions of the region's electricity mix.
3	3.2	Check region electricity mix data	Access the region's electricity mix information. This is done via the data of the electricity map. (www.electricitymaps.com) Check if the data is existent if yes the emissions can be calculated in the next step
3	3.3	Calculate CO2 emissions	This step calculates the CO2 emissions. Energy consumption data and the region of the to-be-analysed CPS are taken into account to calculate the CO2 emissions.
4		**Analysing data footprint**	Analysing the amount of data that's being created due to the CPS.
4	4.1	Choose sampling approach	Define the sampling technique/approach that is used by the COMPONET_TYPE. It can be periodic, event-based or non-sampling.
4	4.2	Choose sampling rate	In the case of a periodic or event-based sampling approach, the sampling rate or sampling frequency is determined. The measuring unit is hertz.
4	4.3	Calculate data usage	This step quantifies the amount of data that a certain COMPONENT_TYPE is producing.
5		**Analysing System Functionalities**	This task is not further defined.

TABLE C.2: LCA for CPS As-Is Concept Table

ID	Name	Description
C_AI.1	CYBER_PHYSICAL_SYSTEM (CPS)	CYBER PHYSICAL SYSTEM (CPS), is a system that seamlessly blends physical and digital elements, allowing for real-time monitoring, control, and automation in various domains. The CPS is the object that is being analysed.
C_AI.2	CONFIGURATION	A COMPONENT is a single hardware device that performs specific functions, such as sensing, calculating, and controlling physical processes within the system.
C_AI.3	CONFIGURATION_COMPONENTS	Information about multiplicities and whether the same COMPONENT is being used multiple times in the viewed CPS.
C_AI.4	COMPONENT	A COMPONENT is one specific device/ part of a CPS. It can be for example a sensor or a computer.
C_AI.5	COMPONENT_TYPE	The COMPONENT_TYPE is a kind of COMPONET that groups multiple COMPONENTS with the same properties.
C_AI.6	MANUFACTURER	MANUFACTURER contains information about the producer that manufactures the COMPONENT.
C_AI.7	ELECTRICITY_MAP_REPOSITORY	This is an online accessible data storage that provides information about the ELECTRICITY MIX INFORMATION of different regions.
C_AI.8	ELECTRICITY_MIX_INFORMATION	The ELECTRICITY MIX INFORMATION provides information about the CO2 emissions from energy production in the CPS' region.
C_AI.9	ELECTRICITY_BY_SOURCE	Provides Information about the exact energy production source of the region's energy mix. e.g.: how much electricity was produced by wind, coal or gas.
C_AI.10	PRODUCT_ENVIRONMENT_PROFILE _REPOSITORY	Provides online accessible information about the environmental information of a variety of products in the form of a PRODUCT ENVIRONMENTAL PROFILE. It is an ISO 14025:2006 Type III environmental declaration.
C_AI.11	PRODUCT_ENVIRONMENT_PROFILE	This is an official document that communicates the environmental impact and performance of a COMPONENT_TYPE based on a Life Cycle Assessment (LCA).
C_AI.12	DATA_APPROACH	DATA_APPROACH encompasses data-related details about a COMPONENT_TYPE. It includes information about whether the COMPONENT samples data, its sampling approach and the data sampling rate. This DATA APPROACH determines how much data for example a sensor sends to a processing unit like a computer.
C_AI.13	A4H_DATASET	ContextAct@A4H is a real-life daily living dataset collected in the Amiqual4Home smart apartment. It contains data from sensors in the apartment, collected while a person was living there. Data-related information about Components are derived from this dataset.

TABLE C.3: LCA for CPS To-Be Activity Table

Module	Task	Name	Description
1	**1**	**Defining CPS**	Task of describing the CYBER_PHYSICAL_SYSTEM (CPS) of the study.
1	1.1	Specify CPS details	Defining details about the studies' CPS. The name and description of the CYBER_PHYSICAL_SYSTEM (CPS) are stated.
1	1.2	Specify CPS functional lifetime	The functional lifetime which is the period of time expressed in years the CYBER_PHYSICAL_SYSTEM (CPS) is intended to operate is specified.
2	**2**	**Defining Components**	Task of describing each component of the CPS.
2	2.1	Create CPS component list	Every component of the studies CPS is listed. In COMPONENT_TYPE the information about the COMPONENT is stated.
2	2.2	Find and link environmental declarations	ENVIRONMENTAL_DECLARATIONS result from an ENVIRONMENTAL_DECLARATION_REPOSITORY. They have to be available for each COMPONENT_TYPE or a very similar COMPONENT has to be used for the analysis. The ENVIRONMENTAL_DECLARATIONS has to be linked to each COMPONENT_TYPE.
2	2.2.1	Find similar component	Every COMPONENT_TYPE has to have an ENVIRONMENTAL_DECLARATIONS. In case no declarations can be found, an alternative, similar, alternative COMPONENT which has existing ENVIRONMENTAL_DECLARATIONS has to be found and used in the analysis.
	2.3	Retrieve environmental information	Environmental information is retrieved from the ENVIRONMENTAL_DECLARATIONS and integrated into COMONENT_TYPE_DETAILS.
3	**3**	**Defining Configurations**	A CONFIGURATION represents one way of designing a CPS and has multiple COMPONENTS.
3	3.1	Specify configuration details	The information about each configuration results in CONFIGURATION and includes the name and ID of a configuration.
3	3.2	Choose components for each configuration	Each CONFIGURATION has multiple components, this Task includes selecting the before-defined COMPONENTS.
3	3.3	Choose quantity of component in configuration	This task is to select the number of the same COMPOMEMT_TYPE in each CONFIGURATION that is used simultaneously.
3	3.4	Specify location of component in configuration	The LOCATION is stated, which is the place given as the country name where the COMPONENT is located.
4	**4**	**Defining Data-related information**	This activity involves detailing the data-related properties of each COMPONENT_TYPE.
4	4.1	Specify number of years of usage of CPS	The amount of years of usage of the CPS is stated. Typically it's the same value as functional lifetime.
4	4.2	Specify sampling properties	The sampling properties are stated in DATA_INFORMATION.
4	4.3	Specify CO2-emission for one GB of Data	The data related CO2-emissions for one GB of Data is stated in CYBER_PHYSICAL_SYSTEM (CPS).
5	**5**	**Analysing method results**	This task is to specify how to analyse the results of the method.
5	5.1	Choose calculation mode	Here the calculation mode is defined. Which influences if the results are presented in total over the entire lifetime or per year.
5	5.1.1	Select p.a.	If p.a. is selected the CONFIGURATION_DETAILS (P.A.) with its impacts per year for each configuration are displayed.
5	5.1.2	Select total	If total is selected the CONFIGURATION_DETAILS (total) with its impacts as the sum over the entire lifetime for each configuration are displayed.
5	5.2	Compare general footprints of configurations	Here the results for the general footprints for each configuration are compared with each other.
5	5.3	Compare data-related footprints of configurations	Here the results for the data-related footprints for each configuration are compared with each other.

TABLE C.4: LCA for CPS To-Be Concept Table p.1

ID	Name	Description
C_TB.1	CYBER_PHYSICAL_SYSTEM (CPS)	CYBER PHYSICAL SYSTEM (CPS), is a system that seamlessly blends physical and digital elements, allowing for real-time monitoring, control, and automation in various domains. The CPS is the main object of study.
C_TB.2	CONFIGURATION	A CONFIGURATION describes the setup of components. In the context of CPS, multiple Configurations can be perceived as alternative configurations, each representing a different arrangement of components (devices) and settings. The number of components as well as the number of components over time is defined.
C_TB.3	CONFIGURATION_LINE	CONFIGURATION_LINE has information regarding the quantity of identical COMPONENT_TYPE within a CONFIGURATION.
C_TB.4	CONFIGURATION_IMPACTS_TOTAL	CONFIGURATION_IMPACTS_TOTAL represent the total environmental impacts as a cumulative over the full functional lifetime associated with each configuration.
C_TB.5	CONFIGURATION_IMPACTS_P.A.	CONFIGURATION_IMPACTS_P.A. represent the yearly environmental impacts associated with each configuration.
C_TB.6	COMPONENT	A COMPONENT is a single hardware device that performs specific functions, such as sensing, calculating, and controlling physical processes within the system.
C_TB.7	COMPONENT_TYPE	The COMPONENT_TYPE is a kind of COMPONET that groups multiple COMPONENTS with the same properties.
C_TB.8	COMPONENT_TYPE_DETAILS	The COMPONENT_TYPE_DETAILS provide a concise overview of information regarding COMPONENT_TYPES. This includes details about the manufacturer, expected lifetime, and information about the materials used in the components.
C_TB.9	COMPONENT_IMPACTS (TOTAL)	The COMPONENT_IMPACTS (TOTAL) compiles the cumulative environmental impacts throughout the manufacturer's lifetime. It provides an overview of the total environmental effects resulting from all lifecycle stages.
C_TB.10	COMPONENT_IMPACTS (MANUFACTURING)	COMPONENT_IMPACTS (MANUFACTURING) refers to the environmental impacts solely related to the manufacturing stage of the component's lifecycle. It includes emission factors such as raw material extraction, energy consumption, and production processes during manufacturing.
C_TB.11	COMPONENT_IMPACTS (DISTRIBUTION)	COMPONENT_IMPACTS (DISTRIBUTION) refers to the environmental impacts solely related to the distribution stage of the component's lifecycle. It includes factors such as transportation, packaging and logistics during distribution.
C_TB.12	COMPONENT_IMPACTS (INSTALLATION)	COMPONENT_IMPACTS (INSTALLATION) refers to the environmental impacts solely related to the installation stage of a component's lifecycle. It includes factors such as energy consumption, waste generation and resource utilisation during installation.
C_TB.13	COMPONENT_IMPACTS (USE)	COMPONENT_IMPACTS (USE) refers to the environmental impacts solely during the use stage of a component's lifecycle. It includes factors such as energy consumption, emissions and waste generation.
C_TB.14	COMPONENT_IMPACTS (END OF LIFE)	COMPONENT_IMPACTS (END OF LIFE) includes the environmental effects related to the disposal or end-of-life phase of a component's lifecycle. It encompasses factors such as recycling, waste management and emissions during disposal.

TABLE C.5: LCA for CPS To-Be Concept Table p.2

C_TB.15	MANUFACTURER	MANUFACTURER contains information about the producer that manufactures the COMPONENT.
C_TB.16	LOCATION	LOCATION contains information about the physical location or region of a COMPONENT.
C_TB.17	CARBON_INTENSITY_ELECTRICITY	CARBON_INTENSITY_ELECTRICITY provides information about the CO2 emissions associated with energy production in specific geographical locations, taking into account the electricity mix of the region.
C_TB.18	CARBON_INTENSITY_REPOSITORY	CARBON_INTENSITY_REPOSITORY is an online accessible archive that provides information about CARBON_INTENSITY of energy production of different regions and countries. It provides insights into the CO2 emissions associated with different energy sources and their geographical location.
C_TB.19	ENVIRONMENTAL_DECLARATIONS	ENVIRONMENTAL_DECLARATIONS are official documents and reports that stem from a Life Cycle Assessment (LCA). They provide information about the environmental impact of a COMPONENT. These declarations include data on all impact factors across the lifecycle stages.
C_TB.20	ENVIRONMENTAL_DECLARATIONS _REPOSITORY	ENVIRONMENTAL_DECLARATIONS_REPOSITORY is an online archive that stores and organises ENVIRONMENTAL_DECLARATIONS.
C_TB.21	DATA_INFORMATION	DATA_INFORMATION encompasses data-related details about a CONFIGURATION_LINE. It includes information about whether the COMPONENT samples data, its sampling approach and the data sampling rate.

Appendix D

Requirements

TABLE D.1: Requiremnts for LCA for CPS Method p.1

Epics and user stories				Parent epic (if user story)			Status Idea	Prioritisation	Status implementation		Source
ID	**Description**	**Explanation**	**Type**	**ID**	***Description***	**Status**		**Scale 1-5**	**Status**		**category**
1	to structure the analysis in a systematic and structured way.	The analysis in the tool should be done in a systematically and structured way, e.g. taking lifecycle stages as a structuring approach into account.	Epic			Agreed			5 Implemented		team
1.1	to consider the LCA phases (Phases of conducting an LCA) defined in the ISO Standard	The used LCAs should take the phases of the ISO Standards into account. It should split the analysis in Phases. 1. Goal and Scope Definition 2. Inventory Analysis 3. Impact assessment 4. Interpretation	User story	1	*to structure the analysis in a systematic and structured way.*	Agreed			5 Implemented		literature
1.2	to also consider a phase/stage named "maintenance"	The method should, next to ISO LCA stages, also consider the stage Maintenance.	User story	1	*to structure the analysis in a systematic and structured way.*	Rejected			3 Backlogged		team
1.3	the analysis should be divided into the Life cycle stages.	The method should be able to structure the analysis into the lifecycle phases. Accourding to the main LC phases: - Manufacturing - Distribution - Installation - Use - End of Life	User story	1	*to structure the analysis in a systematic and structured way.*	Agreed			5 Implemented		literature
2	to specify different locations/ regions within a CPS	The method/tool should be able to track/ specify different locations/ regions of components of a CPS.	Epic			Agreed			4 Implemented		team
2.1	to be able to choose a location/ region for every component	Method should be able to set location information for every component of a CPS. By doing so it can be ensured that the accurate impact can be calculated, because different energy mix carbon offsetts of different region can be taken into account.	User story	2	*to specify different locations/ regions within a CPS*	Agreed			3 Implemented		team
3	to analyse the CO2 footprint	The method should analyse the CO2 footprint of a CPS	Epic			Agreed			5 Implemented		team
3.1	per component, time moment, LCA stage, and region, when the data is available	The method should be able to analyse the CO2 footprint of a CPS. By calculating each component's footprint with the inputs of the region, time Period, Environmental Profile, Energy Mix information, and Data Usage information.	User story	3	*to analyse the CO2 footprint*	Agreed			5 Implemented		literature
3.2	analyse CO2 footprint based on electricity consumption, taking location of CPS component into account. Location-based electricity consumption only focuses on the use phase.	The method should be able to calculate the CO2 footprint of every CPS component, by taking location-based electricity-production CO2 emissions into account. Hereby the information on the energy consumption in the use phase and the location-based energy mix CO2 emissions are used for the calculation.	User story	3	*to analyse the CO2 footprint*	Agreed			4 Implemented		team
3.3	to be able to calculate the CO2 footprint of a distributed CPS	The method should be able to calculate the CO2 footprint of CPS, also when components have different locations/ are in different regions. Distributed CPS have components in different regions, and these regions can have different energy mixes therefore also a different carbon footprint per kWh.	User story	3	*to analyse the CO2 footprint*	Agreed			4 Implemented		team
3.4	to be able to compare the footprint of different configurations	The method should give the user the ability to compare the environmental footprint of different CPS configurations.	User story	3	*to analyse the CO2 footprint*	Agreed			5 Implemented		team
4	to analyse other environmental impact factors	The method should be able to also analyse other environmental impacts next to the CO2 footprint.	Epic			Agreed			4 Implemented		team
4.1	to be able to calculate the impact of the used materials on the environment	The method should be able to calculate the impact of the used materials on the environment and calculate the amount	User story	4	*to analyse other environmental impact factors*	Rejected			3 Partially implemented		team
4.2	to be able to calculate the water usage of a CPS	The method should also be able to analyse the water footprint of CPS	User story	4	*to analyse other environmental impact factors*	Agreed			3 Implemented		literature
4.3	to be able to calculate the water pollution of CPS	The method should be able to calculate the water polution potential a CPS has	User story	4	*to analyse other environmental impact factors*	Agreed			3 Implemented		literature
4.4	to be able to calculate the overall global warming impact in CO2-equivalents	The method should be able to calculate the overall CO2 and Global warming impact of CPS.	User story	4	*to analyse other environmental impact factors*	Agreed			4 Implemented		team
4.5	to be able to calculate the Acidification of soil and water	The method should calculate the acidification soil and water, and use this factors in calculation. Source is LCA	User story	4	*to analyse other environmental impact factors*	Agreed			3 Implemented		literature

TABLE D.2: Requiremnts for LCA for CPS Method p.2

Epics and user stories				Parent epic (if user story)		Status Idea	Prioritisation	Status implementation	Source
ID	**Description**	**Explanation**	**Type**	**ID**	***Description***	**Status**	**Scale 1-5**	**Status**	**category**
5	to be able to define and analyse different functionalities	Method should be able to describe functionalities and tasks that a CPS can fulfill.	Epic			Rejected	2	Backlogged	team
5.1	to specify different functionalities, that can be implemented with a various set of components	We desire to allow the definition of functionalities that could be implemented in different ways (e.g. with a single component that us very versatile, or with 2 simpler components)	User story	5	*to be able to define and analyse different functionalities*	Rejected	2	Backlogged	team
5.2	to be able to analyse the importance of functionalities	Method should be able to help user to calculate/ assess the importance of functunalities of a CPS. Different dimentions shoud be taken in to account,. Focus is on environmental impact and usefulness of the CPS itself.	User story	5	*to be able to define and analyse different functionalities*	Rejected	2	Backlogged	team
5.3	to be able to analyse the CO2 footprint of different functionalities of CPS	Method should be able to specify different functionalities of a CPS and also choosing which functionalities are being used/considered to calculate CO2 footprint	User story	5	*to be able to define and analyse different functionalities*	Rejected	3	Backlogged	team
6	to consider mobile devices in the evolution of the CPS	to consider mobile devices in the evolution of the CSP	Epic			Agreed	2	Implemented	team
6.1	to be able to also include mobile devices in the CPS architecture	The method should be able to also include mobile devices that.	User story	6	*to consider mobile devices in the evolution of the CPS*	Agreed	2	Implemented	literature
7	to consider how data evolves along time	We desire to take into account the fact that the energy consumption during the year (ex. summer vs winter)	Epic			Agreed	4	Implemented	team
7.1	to be able to take different averages of the electricity mix to minimise sesonal / daily differences	the method should be able to not only take the available energy mix information for a certain timestamp but should also be able to build averages of the energy mix. This will increase validity. This will avoid the effects that seasons and weather differences etc. have on the energy mix. Sesonal averages	User story	7	*to consider how data evolves along time*		4	Implemented	team
8	that the method and tool comply with some good practices	The method should comply with some good practices of method design. It should be situational and should be conform with ISO standards	Epic			Agreed	5	Implemented	team
8.1	that the method refers to the ISO standard	This means that the method uses terminology compliant with ISO.	User story	8	*that the method and tool comply with some good practices*	Agreed	5	Implemented	team
8.2	that the method is situational	The method should be adaptable to the context, ambitions and capabilities of the CPS engineering team. This could mean that some activities are optional, but also that we offer suggestions on when to use some method fragments or not. Or offer possible pathways through the activities.	User story	8	*that the method and tool comply with some good practices*	Agreed	3	Implemented	team
9	to be able to specify lifetime of CPS/ component	The method and tool should specify a lifetime for each component type and the whole CPS. The lifetime can be the functional lifetime which is the intended lifetime of the CPS or the manufacturer lifetime which is the lifetime for each component type.	Epic			Rejected	4	Backlogged	team
9.1	differentiation between functional lifetime and manufacturer lifetime	The method should differentiate between the real expected lifetime of the user and the one the manufacturer are mentioning. They often differ. User shoudl be able to decide on lifetime	User story	9	*to be able to specify lifetime of CPS/ component*	Rejected	4	Backlogged	team
9.2	to be able to advice about the environmental cost of the replacement	The method should be able to take environmental costs of repalcing components into account.	User story	9	*to be able to specify lifetime of CPS/ component*	Rejected	3	Backlogged	team
									team
10	to be able to define components and configurations in detailed way and define attributes	Method should be able to define componets in a detailed way. Especially in terms of architecture.	Epic			Agreed	3	Implemented	team
10.1	to be able to specify different architectures in detailed and versatile way	We may need to define architectures more in detail and with more versatility; so we can have components of different granularity (e.g. a door that has a panel, 2 sensors and an engine; or the whole smart house)	User story	10	*to be able to define components and configurations in detailed way and define attributes*	Agreed	3	Implemented	team

TABLE D.3: Requiremnts for LCA for CPS Method p.3

Epics and user stories				Parent epic (if user story)			Status Idea	Prioritisation	Status implementation		Source
ID	Description	Explanation	Type	ID	Description	Status	Scale 1-5	Status			category
10.2	to be able to represent configurations in a detailed way.	The method should be able to specify different CPS configurations. Each configuration should have information about components, location, quantity, manufacturer information, etc. It should be possible to have multiple configurations for the same CPS.	User story	10	*to be able to define components and configurations in detailed way and define attributes*	Agreed		4	Implemented	team
11	to be able to describe the CPS in a graphical way	The method should also help by visualising the CPS graphically in a diagram or model.	Epic			Rejected			Backlogged	team
11.1	to produce a graphical version of the CPS architecture	The method should also help by visualising the CPS graphically in a diagram or model.	User story	11	*to be able to describe the CPS in a graphical way*	Rejected		2	Backlogged	team
11.2	be able to display explicability of the system (a component is needed due to another component)	It might be helpful to display graphically the dependances between components. This might help the user to understand correlation between component and therefore, easily explain the system and env. impact.	User story	11	*to be able to describe the CPS in a graphical way*	Rejected		2	Backlogged	team
12	to be able to declare and offer information about trustworthiness reliability and validity of outcome/ calculation and interpretation of method and used data	data source and publisher of information about components can influence its trustworthiness. Product information published by manufacturers varies from information published by third parties.	Epic			Agreed		4	Partially implemented	team
12.1	to be able to take the data quality requirements of ISO into account	The method should follow the requirements of ISO 4.2.3.6.2 The data quality requirements: e.g time-related coverage, sources of the data	User story	12	*to be able to declare and offer information about trustworthiness reliability and validity of outcome/ calculation and interpretation of method and used data*	Agreed		4	Implemented	literature
12.2	to be able to state limitations and assumtions that the method has.	The method and assumption that are being done inside the method should be explicitly stated. Limitations about the method need to be stated to the trustworthiness of the result.	User story	12	*to be able to declare and offer information about trustworthiness reliability and validity of outcome/ calculation and interpretation of method and used data*	Agreed		4	Implemented	literature
12.3	to be able to state the trustworthiness of the used data. Give information about sources that are used for calculation.	data source and publisher of information about components can influence its trustworthiness. Product information published by manufacturers varies from information published by third parties.	User story	12	*to be able to declare and offer information about trustworthiness reliability and validity of outcome/ calculation and interpretation of method and used data*	Agreed		4	Implemented	team
12.4	to be able to state how trustworthy the LCA data is used for the calculation	The tool should calculate how much data is manually inputted and how much is automatically derived from PEP	User story	12	*to be able to declare and offer information about trustworthiness reliability and validity of outcome/ calculation and interpretation of method and used data*	Rejected		2	Backlogged	team
14	to be able to specify a detailed architectural configuration	To be able to define a CPS architecture in a detailed way. Including restrictions and dependencies.	Epic			Rejected		1	Backlogged	team
14.1	to clarify configuration specification concerning components and types	to clarify the order in which the definition of the number/type component is done in the configuration	User story	14	*to be able to specify a detailed architectural configuration*	Rejected		1	Backlogged	team
14.2	to be able to define component's dependency	to be able to define component dependance on other components	User story	14	*to be able to specify a detailed architectural configuration*	Rejected		1	Backlogged	team
15	To be able to graphically in form of a model display the method	The tool should be able to graphically / visually represent the method flow	Epic			Agreed		5	Implemented	team
15.1	to be able to show the method in a model, inform of a PDD	A PDD - model should describe the Method in a graphical way for better understandability.	User story	15	*To be able to graphically in form of a model display the method*	Agreed		5	Implemented	literature
15.2	to be able to see the evolement of the method in form of PDDs	The evolvement/ development of the Method in form of PDDs. AS-IS and TO-BE	User story	15	*To be able to graphically in form of a model display the method*	Agreed		5	Implemented	team
15.3	to be able to show the method in form of a object diagram	Certain instances/ examples of the usage of the method should be shown in form of a Object model.	User story	15	*To be able to graphically in form of a model display the method*	Agreed		2	Implemented	team

TABLE D.4: Requiremnts for LCA for CPS Method p.4

Epics and user stories				Parent epic (if user story)			Status Idea	Prioritisation	Status implementation		Source
ID	Description	Explanation	Type	ID	Description	Status	Scale 1-5	Status		category	
16	to be able to calculate the data footprint of CPS	The method should help calcuate the data volume that a CPS generates and also calculate the data-related environmental impacts.	Epic			Agreed		4	Partially implemented	team	
16.1	to be able to calculate the data the components create.	The method should be able to quantify/calculate the quantity of data that every CPS component creates. Hereby different data approaches influence the quantity. The user should be able to choose the sampling rate and data approach for every individual component.	User story	16	*to be able to calculate the data footprint of CPS*	Agreed		3	Implemented	team	
16.2	to be able to calulate the energy consumtion of the created data	The method should be able to calculate the approximate energy consumption that is needed to process store transmits the data thats created because of the component.	User story	16	*to be able to calculate the data footprint of CPS*	Rejected		1	Backlogged	team	
16.3	to be able to calulate the environmental impacts/ emissions that the data has	The method should be able to calculate the emissions that occur due to data creation of a component	User story	16	*to be able to calculate the data footprint of CPS*	Agreed		4	Implemented	team	
16.4	the method should take into account a data approaches (factoring of data4approach for different configurations)	The method should consider different data approaches when calculating the data footprint. Data approaches can drastically affect the data volume.	User story	16	*to be able to calculate the data footprint of CPS*	Agreed		4	Implemented	team	
17	to be able to automatically fetch data from online data sources	The method /tool should be able to automatically retrieve as much data as possible from online sources. By doing so manual entries to the tool can be kept to a minimum.	Epic			Agreed		4	Implemented	team	
17.1	to be able to fetch LCA data of used components from websites/ deposites when possible	The method should be able to access and fetch LCA data about components automatically in the tool, without manually input.	User story	17	*to be able to automatically fetch data from online data sources*	Agreed		3	Implemented	team	
17.2	to be able to autmatically fetch electricity carbon intesisty information	The method should be able to access and fetch carbon intensisty information for different locations/countries.	User story	17	*to be able to automatically fetch data from online data sources*	Agreed		2	Implemented	team	
18	Tool should automatically should have automated functions	The tool should make use of automated customised function that make tis use easier. They can be done in Java script.	Epic			Agreed		4	Implemented	team	
18.1	Tool should automatically create new sheet for each componet type with overview of predefinded impact factors	Tool should automatically create new sheet for each componet type with overview of predefinded impact factors	User story	18	*Tool should automatically should have automated functions*	Agreed		5	Implemented	team	
18.2	Tool should show the status of completeteness of component type sheets.	The tool should automatically indicate with a status collum, how complete data was fetched form websides This helps the user to see how much manual input needs to be done	User story	18	*Tool should automatically should have automated functions*	Agreed		2	Implemented	team	
18.3	Every component should have a unique ID, Input should be controlled and error should come up when ID is already taken	Every component should have a unique ID, Input should be	User story	18	*Tool should automatically should have automated functions*	Agreed			Implemented	team	
19	to be able to be easy to use	The tool should be self explanatory, decriptions should guide the user thorough the process	Epic			Agreed		3	Implemented	team	
19.1	the tool should be self explanatory, descriptions on every sheet should guide the user.	the tool should be self explanatory, descriptions on every sheet should guide the user. On the title page sheet, contact person and authors of relevant papers should be given. Additionally links to relevant data sources, like PDD, electricity info, PEP database, PDDs.	User story	19	*to be able to be easy to use*	Agreed		3	Implemented	team	
19.2	The user should see what fields need to be filled out and which not.	The tool should show the user where to put entries and where not, this can be done by Color coding and conditional formating.	User story	19	*to be able to be easy to use*	Agreed		3	Implemented	team	
19.3	The user should get a warning when trying to override a function or doing a wrong input	The tool should only allow the users to make entries where entries should be made to not damage calculations or other important functions. This is possible by using protected areas in the sheets.	User story	19	*to be able to be easy to use*	Agreed		3	Implemented	team	
19.4	The user should easily find back to main sheets	the tool should be easy to use. With the help of links, different sheets can be accessed with the help of links.	User story	19	*to be able to be easy to use*	Agreed		3	Implemented	team	
20	to show represent results visually	method should show results visually	Epic			Agreed		4	Implemented	team	
20.1	the tool should be able to show the comparison of different configuratiosn visually	the tool should be able to show the comparison of different configuratiosn visually. By making use of charts and diagrams	User story	20	*to show represent results visually*	Agreed		4	Implemented	team	

Appendix E

Traceability of Artefacts

TABLE E.1: Traceability Table of Requirements and Artefacts p.1

Requirements / Traceability			
ID	**Description**	**Related Concept ID**	**Realted Feature ID**
1	to structure the analysis in a systematic and structured way.		
1.1	to consider the LCA phases (Phases of conducting an LCA) defined in the ISO Standard	C_TB.9 C_TB.10 C_TB.11 C_TB.12 C_TB.13 C_TB.14	
1.3	the analysis should be divided into the Life cycle stages.	C_TB.9 C_TB.10 C_TB.11 C_TB.12 C_TB.13 C_TB.14	
2	to specify different locations/ regions within a CPS		F7
2.1	to be able to choose a location/ region for every component	C_TB.16	F7
3	to analyse the CO2 footprint		F2
3.2	analyse CO2 footprint based on electricity consumption, taking location of CPS component into account. Location-based electricity consumption only focuses on the use phase.	C_TB.16 C_TB.17	F7
3.3	to be able to calculate the CO2 footprint of a distributed CPS	C_TB.16	
3.4	to be able to compare the footprint of different configurations	C_TB.4 C_TB.5	F1 F2
4	to analyse other environmental impact factors		
4.1	to be able to calculate the impact of the used materials on the environment	C_TB.8	
4.2	to be able to calculate the water usage of a CPS	C_TB.4 C_TB.5 C_TB.8 C_TB.9 C_TB.10 C_TB.11 C_TB.12 C_TB.13 C_TB.14	
4.3	to be able to calculate the water pollution of CPS	C_TB.4 C_TB.5 C_TB.9 C_TB.10 C_TB.11 C_TB.12 C_TB.13 C_TB.14	

TABLE E.2: Traceability Table of Requirements and Artefacts p.2

4.4	to be able to calculate the overall global warming impact in CO2-equivalents	C_TB.4 C_TB.5 C_TB.9 C_TB.10 C_TB.11 C_TB.12 C_TB.13 C_TB.14	F2
4.5	to be able to calculate the Acidification of soil and water	C_TB.4 C_TB.5 C_TB.9 C_TB.10 C_TB.11 C_TB.12 C_TB.13 C_TB.14	
7	to consider how data evolves along time		
7.1	to be able to take different averages of the electricity mix to minimise sesonal / daily differences	C_TB.17 C_TB.18	
9	to be able to specify lifetime of CPS/ component		
9.1	differentiation between functional lifetime and manufacturer lifetime		
9.2	to be able to advice about the environmental cost of the replacement		
10	to be able to define components and configurations in detailed way and define attributes		
10.1	to be able to specify different architectures in detailed and versatile way	C_TB.1 C_TB.2 C_TB.3 C_TB.6 C_TB.7 C_TB.15	
10.2	to be able to represent configurations in a detailed way.	C_TB.1 C_TB.2 C_TB.3 C_TB.6 C_TB.7 C_TB.15	
16	to be able to calculate the data footprint of CPS		F5 F6
16.1	to be able to calculate the data the components create.	C_TB.21	F5
16.2	to be able to calulate the enegry consumtion of the created data		
16.3	to be able to calulate the environmental impacts/ emissions that the data has	C_TB.4 C_TB.5 C_TB.21	F6
16.4	the method should take into account a data approaches (factoring of dataApproach for different configurations)	C_TB.21	F5

TABLE E.3: Traceability Table of Requirements and Artefacts p.3

17	to be able to automatically fetch data from online data sources		F3
17.1	to be able to fetch LCA data of used components from websites/ deposites when possible	C_TB.19 C_TB.20	F3
17.2	to be able to autmatically fetch electricity carbon intesity information	C_TB.18	
20	to show represent results visually		F4
20.1	the tool should be able to show the comparison of different configuratiosn visually		F4

Appendix F

Ethics and Privacy Scan

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Section 1. Research projects involving human participants

P1. Does your project involve human participants? This includes for example use of observation, (online) surveys, interviews, tests, focus groups, and workshops where human participants provide information or data to inform the research. If you are only using existing data sets or publicly available data (e.g. from Twitter, Reddit) without directly recruiting participants, please answer no.

○ No ◉ Yes

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Recruitment

P2. Does your project involve participants younger than 18 years of age?

◉ No ○ Yes

P3. Does your project involve participants with learning or communication difficulties of a severity that may impact their ability to provide informed consent?

◉ No ○ Yes

P4. Is your project likely to involve participants engaging in illegal activities?

◉ No ○ Yes

P5. Does your project involve patients?

◉ No ○ Yes

P6. Does your project involve participants belonging to a vulnerable group, other than those listed above?

◉ No ○ Yes

Ethics Warning.  **As you are dealing with vulnerable participants (yes to one (or more) of P2-P6) a fuller ethical review is required.** Please add more detail on your participants here:

This question was not displayed to the respondent.

P7. Do you intend to be alone with a research participant or have to take sole responsibility for the participants at any point during your research activity?

This question was not displayed to the respondent.

Ethics Warning.  **As you will be alone with or solely responsible for vulnerable participants (yes to P7) a fuller ethical review is required. You may also need a Certificate of Conduct (Dutch: VOG) from the government.** Please add more detail here:

This question was not displayed to the respondent.

P8. Does your project involve participants with whom you have, or are likely to have, a working or professional relationship: for instance, staff or students of the university, professional colleagues, or clients?

- (●) No
- ( ) Yes

P9. Is it made clear to potential participants that **not** participating will in no way impact them (e.g. it will not directly impact their grade in a class)?

This question was not displayed to the respondent.

Ethics Warning.  **As participants may think that not participating may harm them (yes to P8 and no to P9), participation may no longer be voluntary. Hence, a fuller ethical review is required.** Please provide more information here:

This question was not displayed to the respondent.

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Informed consent

PC1. Do you have set procedures that you will use for obtaining informed consent from all participants, including (where appropriate) parental consent for children or consent from legally authorized representatives? (See suggestions for information sheets and consent forms on the website.)

- ( ) No
- (●) Yes

PC2. Will you tell participants that their participation is voluntary?

○ No ◉ Yes

PC3. Will you obtain explicit consent for participation?

○ No ◉ Yes

PC4. Will you obtain explicit consent for any sensor readings, eye tracking, photos, audio, and/or video recordings?

○ No ◉ Yes ○ Not applicable

PC5. Will you tell participants that they may withdraw from the research at any time and for any reason?

○ No ◉ Yes

PC6. Will you give potential participants time to consider participation?

○ No ◉ Yes

PC7. Will you provide participants with an opportunity to ask questions about the research before consenting to take part (e.g. by providing your contact details)?

○ No ◉ Yes

Ethics Warning. **Given your responses to the informed consent questions (a no on any of PC1-PC7), a fuller ethical review is required.** Please provide more information regarding the questions that are causing this here:

This question was not displayed to the respondent.

PC8. Does your project involve concealment or deliberate misleading of participants?

◉ No ○ Yes

Ethics Warning. **As you plan to use concealment or misleading (yes to PC8), and this may impact participants' rights to informed consent, a fuller ethical review is required.** Please provide more information on the concealment/misleading here:

This question was not displayed to the respondent.

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Section 2. Data protection, handling, and storage

The General Data Protection Regulation imposes several obligations for the use of **personal data** (defined as any information relating to an identified or identifiable living person) or including the use of personal data in research.

D1. Are you gathering or using personal data (defined as any information relating to an identified or identifiable living person)?

- (•) No
- ( ) Yes

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High-risk data

This question was not displayed to the respondent.

DR1. Will you process personal data that would jeopardize the physical health or safety of individuals in the event of a personal data breach?

This question was not displayed to the respondent.

DR2. Will you combine, compare, or match personal data obtained from multiple sources, in a way that exceeds the reasonable expectations of the people whose data it is?

This question was not displayed to the respondent.

DR3. Will you use any personal data of children or vulnerable individuals for marketing, profiling, automated decision-making, or to offer online services to them?

This question was not displayed to the respondent.

DR4. Will you profile individuals on a large scale?

This question was not displayed to the respondent.

DR5. Will you systematically monitor individuals in a publicly accessible area on a large scale (or use the data of such monitoring)?

This question was not displayed to the respondent.

DR6. Will you use special category personal data, criminal offense personal data, or other sensitive personal data on a large scale?

This question was not displayed to the respondent.

DR7. Will you determine an individual's access to a product, service, opportunity, or benefit based on an automated decision or special category personal data?

This question was not displayed to the respondent.

DR8. Will you systematically and extensively monitor or profile individuals, with significant effects on them?

This question was not displayed to the respondent.

DR9. Will you use innovative technology to process sensitive personal data?

This question was not displayed to the respondent.

Privacy Warning. **As high-risk data processing seems involved (yes to any of DR1-DR9), a fuller privacy assessment is required.** Please provide more information on the DR1-DR9 questions with a yes here:

This question was not displayed to the respondent.

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Data minimization

This question was not displayed to the respondent.

DM1. Will you collect only personal data that is strictly necessary for the research?

This question was not displayed to the respondent.

DM2. Will you only collect not strictly necessary personal data because it is (1) technically unfeasible not to collect it when collecting necessary data, or (2) needed as a source of necessary data?

This question was not displayed to the respondent.

DM3. Will you (1) extract any necessary data as soon as possible from the collected not strictly necessary data and (2) delete the not strictly necessary data immediately after any required extraction?

This question was not displayed to the respondent.

DM4. Will you anonymize the data wherever possible?

This question was not displayed to the respondent.

DM5. Will you pseudonymize the data if you are not able to anonymize it, replacing personal details with an identifier, and keeping the key separate from the data set?

This question was not displayed to the respondent.

Privacy Warning. **As you do not seem to minimize data collection (no to any of DM2-DM5), a fuller privacy assessment is required.** Please provide more information on the DM2-DM5 questions with a no here:

This question was not displayed to the respondent.

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Using collaborators or contractors that process personal data securely

This question was not displayed to the respondent.

DC1. Will any organization external to Utrecht University be involved in processing personal data (e.g. for transcription, data analysis, data storage)?

This question was not displayed to the respondent.

DC2. Will this involve data that is not anonymized?

This question was not displayed to the respondent.

DC3. Are they capable of securely handling data?

This question was not displayed to the respondent.

DC4. Has been drawn up in a structured and generally agreed manner who is responsible for what concerning data in the collaboration?

This question was not displayed to the respondent.

DC5. Is a written contract covering this data processing in place for any organization which is not another university in a joint research project?

This question was not displayed to the respondent.

Privacy Warning. **As you do not seem to have appropriate processes in place for sharing data with collaborators or contractors (no to any of DC3-DC5), a fuller privacy assessment is required.** Please provide more information on the DC3-DC5 questions with a no here:

This question was not displayed to the respondent.

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International personal data transfers

This question was not displayed to the respondent.

DI1. Will any personal data be transferred to another country (including to research collaborators in a joint project)?

This question was not displayed to the respondent.

DI2. Do all countries involved in this have an adequate data protection regime?

This question was not displayed to the respondent.

DI3. Is a legal agreement in place?

This question was not displayed to the respondent.

Privacy Warning. **As you do not seem to have appropriate safeguards in place for international data transfers (no to DI2 and DI3), a fuller privacy assessment is required.** Please provide more information on intended international data transfers here:

This question was not displayed to the respondent.

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Fair use of personal data to recruit participants

This question was not displayed to the respondent.

DF1. Is personal data used to recruit participants?

This question was not displayed to the respondent.

DF2. Have potential participants provided this personal data voluntarily to be contacted about the research?

This question was not displayed to the respondent.

DF3. If contact details have been provided by a third party, would participants expect their details to be passed on to the university and to be used in this way?

This question was not displayed to the respondent.

DF4. If contact details have been gathered for a purpose other than research, would participants expect their details to be used in this way?

This question was not displayed to the respondent.

Privacy Warning.  **As there seem to be issues with your use of personal data for recruitment (no to one or more of DF2-DF4), a fuller privacy assessment is required.** Please provide more information on the intended use of personal data for recruitment here:

This question was not displayed to the respondent.

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Participants' data rights and privacy information

This question was not displayed to the respondent.

DP1. Will participants be provided with privacy information? (Recommended is to use as part of the information sheet: For details of our legal basis for using personal data and the rights you have over your data please see the University's privacy information at www.uu.nl/en/organisation/privacy.)

This question was not displayed to the respondent.

DP2. Will participants be aware of what their data is used for?

This question was not displayed to the respondent.

DP3. Can participants request that their personal data be deleted?

This question was not displayed to the respondent.

DP4. Can participants request that their personal data be rectified (in case it is incorrect)?

This question was not displayed to the respondent.

DP5. Can participants request access to their personal data?

This question was not displayed to the respondent.

DP6. Can participants request that personal data processing is restricted?

This question was not displayed to the respondent.

DP7. Will participants be subjected to automated decision-making based on their personal data with an impact on them beyond the research study to which they consented?

This question was not displayed to the respondent.

DP8. Will participants be aware of how long their data is being kept for, who it is being shared with, and any safeguards that apply in case of international sharing?

This question was not displayed to the respondent.

DP9. If data is provided by a third party, are people whose data is in the data set provided with (1) the privacy information and (2) what categories of data you will use?

This question was not displayed to the respondent.

Privacy Warning. **As there seem to be issues with the data rights of your participants or the provision of privacy information (no to one or more of DP1-DP6, DP8, DP9, or yes to DP7), a fuller privacy assessment is required.** Please provide more detail regarding data rights and/or privacy information here:

This question was not displayed to the respondent.

.

Using data that you have not gathered directly from participants

This question was not displayed to the respondent.

DE1. Will you use any personal data that you have not gathered directly from participants (such as data from an existing data set, data gathered for you by a third party, data scraped from the internet)?

This question was not displayed to the respondent.

DE2. Will you use an existing dataset in your research?

This question was not displayed to the respondent.

DE3. Do you have permission to do so from the owners of the data set?

This question was not displayed to the respondent.

DE4. Have the people whose data is in the data set consented to their data being used by other researchers and/or for purposes other than that for which that data set was gathered?

This question was not displayed to the respondent.

DE5. Are there any contractual conditions attached to working with or storing the data from DE2?

This question was not displayed to the respondent.

DE6. Does your project require access to personal data about participants from other parties (e.g., teachers, employers), databanks, or files?

This question was not displayed to the respondent.

DE7. Do you have a process in place to gain informed consent from these participants?

This question was not displayed to the respondent.

DE8. Are there any contractual conditions attached to working with or storing the data from DE6?

This question was not displayed to the respondent.

DE9. Does the project involve collecting personal data from websites or social media (e.g., Facebook, Twitter, Reddit)?

This question was not displayed to the respondent.

Privacy Warning. **As there may be issues with the use of existing data (no to DE3, DE4, DE7 or yes to DE9), a fuller privacy assessment is required.** Please provide more detail regarding the use of existing data here:

This question was not displayed to the respondent.

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Secure data storage

This question was not displayed to the respondent.

DS1. Will any data be stored (temporarily or permanently) anywhere other than on password-protected University authorized computers or servers?

This question was not displayed to the respondent.

DS2. Does this only involve data stored temporarily during a session with participants (e.g. data stored on a video/audio recorder/sensing device), which is immediately transferred (directly or with the use of an encrypted and password-protected data-carrier (such as a USB stick)) to a password-protected University authorized computer or server, and deleted from the data capture and data-carrier device immediately after transfer?

This question was not displayed to the respondent.

DS3. Does this only involve data stored with a collaborator or contractor?

This question was not displayed to the respondent.

DS4. Excluding (1) any international data transfers mentioned above and (2) any sharing of data with collaborators and contractors, will any personal data be stored, collected, or accessed from outside the EU?

This question was not displayed to the respondent.

Privacy Warning. **As there may be issues with secure data storage (no to DS2 and DS3, or yes to DS4), a fuller privacy assessment is required.** Please provide more detail regarding data storage here:

This question was not displayed to the respondent.

Q27.

Section 3. Research that may cause harm

Research may cause harm to participants, researchers, the university, or society. This includes when technology has dual-use, and you investigate an innocent use, but your results could be used by others in a harmful way. If you are unsure regarding possible harm to the university or society, please discuss your concerns with the Research Support Office.

H1. Does your project give rise to a realistic risk to the national security of any country?

- (●) No
- ( ) Yes

H2. Does your project give rise to a realistic risk of aiding human rights abuses in any country?

- (●) No
- ( ) Yes

H3. Does your project (and its data) give rise to a realistic risk of damaging the University's reputation? (E.g., bad press coverage, public protest.)

- (●) No
- ( ) Yes

H4. Does your project (and in particular its data) give rise to an increased risk of attack (cyber- or otherwise) against the University? (E.g., from pressure groups.)

- (●) No
- ( ) Yes

H5. Is the data likely to contain material that is indecent, offensive, defamatory, threatening, discriminatory, or extremist?

- (●) No
- ( ) Yes

H6. Does your project give rise to a realistic risk of harm to the researchers?

- (●) No
- ( ) Yes

H7. Is there a realistic risk of any participant experiencing physical or psychological harm or discomfort?

- (●) No
- ( ) Yes

H8. Is there a realistic risk of any participant experiencing a detriment to their interests as a result of participation?

- (●) No
- ( ) Yes

H9. Is there a realistic risk of other types of negative externalities?

- (●) No
- ( ) Yes

Ethics Warning. **As you replied yes to one (or more) of H1-H9, a fuller ethical review is required.**
Please provide more detail here on the potential harm, and how you will minimize risk and impact:

This question was not displayed to the respondent.

.

Section 4. Conflicts of interest

C1. Is there any potential conflict of interest (e.g. between research funder and researchers or participants and researchers) that may potentially affect the research outcome or the dissemination of research findings?

- (●) No
- ( ) Yes

C2. Is there a direct hierarchical relationship between researchers and participants?

- (●) No
- ( ) Yes

Ethics Warning. **As you replied yes to C1 or C2, a fuller ethical review is required.** Please provide more information regarding possible conflicts of interest and how you mitigate them here:

This question was not displayed to the respondent.

Section 5..

Section 5. Your information.

This last section collects data about you and your project so that we can register that you completed the Ethics and Privacy Quick Scan, sent you (and your supervisor/course coordinator) a summary of what you filled out, and follow up where a fuller ethics review and/or privacy assessment is needed. For details of our legal basis for using personal data and the rights you have over your data please see the University's privacy information. Please see the guidance on the ICS Ethics and Privacy website on what happens on submission.

Z0. Which is your main department?

- (●) Information and Computing Science
- ( ) Freudenthal Institute
- ( ) Pharmacy
- ( ) Other, namely: [ ]

Z1. Your full name:

[Nils Felix Schöllhammer]

Z2. Your email address:

[n.f.schollhammer@students.uu.nl]

Z3. In what context will you conduct this research?

- ( ) As a student on a course with course coordinator: [ ]
- ( ) As a student for my bachelor thesis, supervised by: [ ]
- (●) As a student for my master thesis, supervised by: [Sergio España]
- ( ) As a PhD student, supervised by: [ ]
- ( ) As an independent researcher (e.g. research fellow, assistant/associate/full professor)

Z4. Bachelor programme for which you are doing the thesis

This question was not displayed to the respondent.

Z5. Master programme for which you are doing the thesis

- ○ Applied Data Science
- ○ Artificial Intelligence
- ◉ Business Informatics
- ○ Computing Science
- ○ Data Science
- ○ Game and Media Technology
- ○ Human-Computer Interaction
- ○ Other

Z6. Email of the course coordinator or supervisor (so that we can inform them that you filled this out and provide them with a summary):

[redacted]

Z7. Email of the moderator (as provided by the coordinator of your thesis project):

[redacted]

Z8. Title of the research project/study for which you filled out this Quick Scan:

A life-cycle assessment method to assess the environmental impacts of cyber-physical systems

Z9. Summary of what you intend to investigate and how you will investigate this (200 words max):

We have engineered a lightweight method with web-based tool support to assess the environmental impacts of Cyber-Physical Systems (CPSs) throughout their life cycles. The method aims to provide insights into the sustainability issues associated with CPSs, to improve decision-making for system designers. We are interested in validating the developed method by conducting expert interviews. We intend to investigate the usefulness and strength and weaknesses of certain features of the tool. All interviews are anonymised, and no personal data is collected.

Z10. In case you encountered warnings in the survey, does supervisor already have ethical approval for a research line that fully covers your project?

- ○ Yes
- ○ No

◉ Not applicable

Z11. Provide details on the ethical approval (e.g. ethical approval number)

This question was not displayed to the respondent.

Embedded Data
EthicsScore: 0
PrivacyScore: 0

Scoring Results	
Ethics	
Mean Score:	0.00
Weighted Mean of Items:	0.00
Weighted Standard Deviation of Items:	0.00
Items:	0.00
Privacy	
Mean Score:	0.00
Weighted Mean of Items:	0.00
Weighted Standard Deviation of Items:	0.00
Items:	0.00