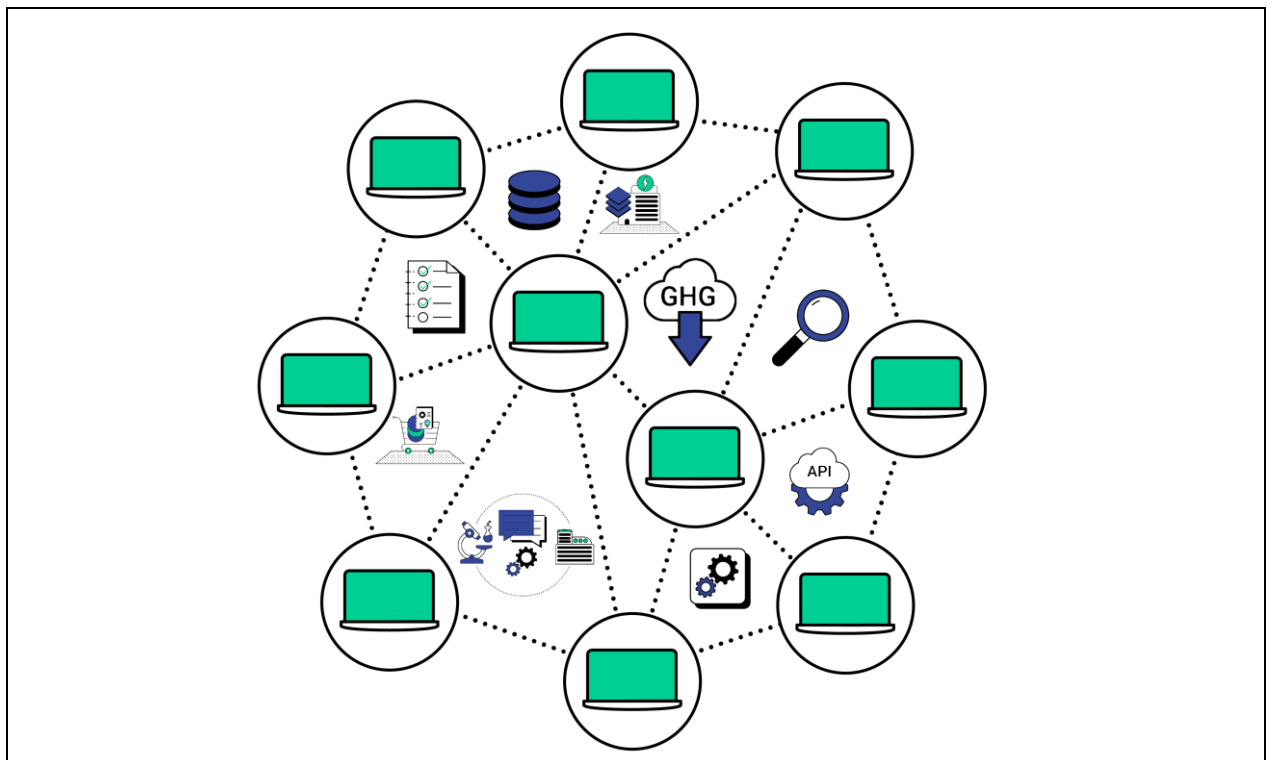


## Travail de Bachelor 2023

# Integration, Calculation, and Visualisation of CO2 Emissions Data



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## SOURCES OF ILLUSTRATION ON TITLE PAGE

[https://wiser-climate.com/wp-content/uploads/2023/04/WISER\\_Zusatz-Icons\\_RZ\\_Main-1-2048x2048.png](https://wiser-climate.com/wp-content/uploads/2023/04/WISER_Zusatz-Icons_RZ_Main-1-2048x2048.png)

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## SUMMARY

The decarbonisation goals of companies and organizations present a real challenge in calculation greenhouse gas emissions. Individuals lacking expertise in sustainability may find difficult to perform these calculations and utilize existing databases due to their diverse formats and incompatibilities as they are provided by different entities. Moreover, once these calculations are performed, it is often challenging or even impossible to trace the process, making CO2 emission results less transparent and reliable.

This thesis is in collaboration with the WISER project whose goal is to build a digital ecosystem to connect different sustainability data sources. The goal of this Bachelor's thesis is to create a web application that integrates diverse data sources from WISER to aid end-users to visualise CO2 emissions calculations effectively. To achieve this objective, the study begins with research on the existing solutions, with the purpose of finding their downsides and position the WISER project. Subsequently, an analysis of the different technologies is conducted, followed by the implementation of the tools in order to demonstrate the findings. Finally, the web application is presented, and future improvements are discussed, followed by an overview of the results.

Key words: data centres, greenhouse gas, emissions, sustainability, life cycle assessment

## FOREWORD

This project marks the culmination of my educational journey at HES-SO Valais Wallis, where I have pursued a Bachelor's degree in Business Information Technology. As the final semester of a rigorous three-year full-time course, this thesis was undertaken from May 1st to July 28th, with the aim of assessing the skills acquired by future graduates during their training.

The subject of this work was submitted by Professor Jean-Paul Calbimonte in collaboration with the WISER project. This project's goal is to assess and analyse CO2 emissions through the integration of calculation and visualization methods.

The findings presented in this report adhere to the APA 6 (American Psychological Association) formatting standard for scientific reports, ensuring adherence to guidelines pertaining to writing style, layout, figures and illustrations, references, and other essential components.

## ACKNOWLEDGEMENTS

First and foremost, I would like to thank Professor Jean-Paul Calbimonte for proposing this Bachelor thesis and providing invaluable guidance and support throughout the entire process. His expertise and insights have been instrumental in shaping the direction of this research.

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I would like to thank Mr. Didier Beloin-Saint-Pierre and Alexander Kirsten from EMPA for their valuable input in showcasing Data Centre CO2 emissions. Their expertise in the field has greatly enriched this project.

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## ABBREVIATION LIST

<b>GHG:</b>	Greenhouse Gas
<b>LCA:</b>	Life Cycle Assessment
<b>LCIA:</b>	Life Cycle Impact Assessment
<b>LCI:</b>	Life cycle inventory
<b>URP:</b>	Unit Process
<b>GUI:</b>	Graphical User Interface
<b>ICT:</b>	Information and Communication Technology

# 1. Introduction

## 1.1. Subject

Climate change is a real problem nowadays. There are existing laws to help fight against it such as the Swiss emissions neutrality from here to 2050 (DETEC, n.d.). To follow those laws, some companies are implementing multiple solutions with the goal of reducing their Green House Gas emissions.

Most of the current programs and solutions for greenhouse gas (GHG) emissions calculations, implemented by companies work like black boxes. This means that they are not transparent and the calculations for CO<sub>2</sub> emissions are in many cases difficult to trace and are not always the same. For example, to reduce GHG impacts, managers at different companies undertake the task of gathering relevant information and translating it into actionable measures. However, they encounter various obstacles along the way.

These challenges include finding suitable data sources, ensuring compatibility between different data sources, selecting, and understanding a suitable life cycle assessment (LCA) methodology, integrating all the information into a comprehensive evaluation, and creating a user-friendly display to present to management.

## 1.2. WISER project

This Bachelor thesis is in collaboration with the WISER project<sup>1</sup>. The WISER project is a flagship of InnoSuisse<sup>2</sup> and its goal is to create an open and transparent digital ecosystem to streamline GHG assessments that helps public and private actors implement data-driven decarbonization strategies to enable a systemic change. The WISER Consortium consists of multiple organizations for research such as EMPA and HES-SO.

Their vision is to conduct a reliable, transparent, and uniform assessment of GHG emissions via value chains<sup>3</sup>. The companies can formulate their climate strategy by identifying the best options to reduce the emissions of GHG. In fact, nowadays companies can find different procedures that display various results. Unfortunately, these results are not easily comparable due to some inconsistencies. To fight this problem, WISER created a digital ecosystem containing open-source web services which, in turn, leads to a simpler and consistent GHG assessment procedure. (Wiser-Project Research, n.d.)

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<sup>1</sup> <https://wiser-climate.com/>

<sup>2</sup> Innosuisse is the Swiss Innovation Agency. It promotes SMEs and start-ups in their Research and Development activities.

<sup>3</sup> It's a series of activities and procedures that a company goes through to deliver a product.

What differentiates the WISER project from other existing tools is the ecosystem and the way that multiple reliable sources from different organizations are connected via the Wiser Service which works as an API (Application Programming Interfaces). WISER compares and utilizes various reliable data sources, adapts value chain models to multiple GHG assessments with the objective of having more accurate evaluations. (Wiser-Project Research, n.d.).

The digital ecosystem is composed of data providers, assessment practitioners and information and communication technology specialists. This ecosystem facilitates the efficient transfer of knowledge to stakeholders, demonstrates the usefulness of the digital ecosystem and its web services to implementation partners, and enhances the flexibility and transparency of GHG assessments, thereby streamlining the collaboration between partners.

#### **1.2.1. Wiser Scope**

Within the WISER project, the focus lies on the development of three primary dashboards: SP5, SP6, and SP7. Each one of these dashboards serves a distinct purpose in facilitating sustainability assessments and promoting environmentally conscious decision-making.

The main goal of these dashboards is to give users the power to choose and arrange different tools that help them find and organize the most important greenhouse gas emission factors. These factors come from various sets of information, and consider different situations like countries, standards, and years. The dashboards help users find and prioritize the most important GHG emission factors for their specific needs by allowing them to choose their own criteria and requirements.

#### **1.2.2. SP5**

The SP5 dashboard is designed to assist companies in evaluating the GHG emissions of their manufacturing sites. By utilizing this dashboard, companies can analyse and quantify the environmental impact of their manufacturing processes, enabling them to identify areas for improvement and implement sustainable practices.

#### **1.2.3. SP6**

In the case of SP6, the dashboard aims to support the procurement of Information and Communication Technology (ICT) equipment in cities. It provides a comprehensive platform for evaluating the environmental footprint associated with the procurement process, allowing cities to make informed decisions based on the GHG emissions and sustainability performance of the ICT equipment under consideration.

#### **1.2.4. SP7**

This Bachelor's thesis studies the SP7 dashboard, which is used to monitor the electricity consumption in data centres. Data centres play a significant role in the digital society, and their energy consumption is a critical factor in environmental sustainability. The SP7 dashboard aims to provide users with a detailed understanding of the GHG emissions associated with electricity usage in data centres. Through this dashboard, users can assess and benchmark the environmental performance of data centres, enabling them to make informed choices and implement energy-efficient measures.

### **1.3. Objectives of this thesis**

#### **1.3.1. Primary Objective**

The primary objective of this Bachelor's project is to develop a transparent, traceable, and intuitive web tool capable of seamlessly integrating the diverse data sources proposed by WISER. By employing a calculation algorithm for integration, the application will empower end-users to visualize accurate and reliable CO2 emissions calculations. This user-friendly tool provides valuable insights, facilitating decision-making and promoting sustainable practices in the context of climate change mitigation.

#### **1.3.2. Sub-goals**

In addition to the main project's objectives, we also aim to implement various topics that have been covered throughout the Bachelor's courses. Among these objectives, the adoption of methodologies for project management is a priority, as well as enhancing our coding skills.

For this thesis, our client is Mr. Didier Beloin-Saint-Pierre, a scientist at EMPA. By using a well-organized project management approach, we work closely with our client and stay flexible to meet their requirements. Improving our coding skills is also crucial to create a high-quality web application that's user-friendly and efficient.

### **1.4. Use Case : Decarbonization of Data Centres**

The use case for this Bachelor's project is the calculation of emissions for data centres. In fact, our goal is to support the decarbonization of the data centres by calculating their emissions within a set time period and provide detailed results which can help stakeholders take decisions and identify the best options to reduce GHG emissions. Additionally, we aim to provide a web service for forecasting carbon footprint using relevant datasets and implement an evaluation tool whose task is to present the results on a dashboard.

## 1.5. Project Limitations

We can find some limitations in this project that we need to consider. Firstly, there is a strict time constraint, which means we must adhere to the given deadline. This influences our technology and task decisions during the implementation. Lastly the integration of our dashboard with the existing WISER dashboards is a significant consideration that we need to address.

## 1.6. Method

In this report, a methodical approach was adopted to address the objectives of the study, ensuring a comprehensive understanding and achievement of the thesis' goals.

The first section starts by exploring the concept of Life Cycle Assessment (LCA), providing an explanation of its principles and significance in evaluating the environmental impact of products or services. This foundational understanding of LCA sets the stage for the following analysis. Additionally, a comparative analysis of existing LCA programs and tools is then conducted to contextualize the project and identify its unique contributions.

Then, in the pursuit of selecting the most suitable technologies to support the project's objectives, an in-depth analysis of various technologies is undertaken. This evaluation allows us to identify and choose the best tools in order to optimize the web application's functionality.

The practical implementation of findings follows. The report details the step-by-step progress, challenges faced, and the application's architecture and functionalities, ensuring an effective environmental impact assessment tool. Also, in this section we explain the collaboration with experts from EMPA, who acted as valuable clients.

The report concludes with a comprehensive analysis of the work done. Key findings and insights obtained throughout the project are summarized, showcasing the contributions made by this bachelor thesis. Acknowledging the limitations and challenges faced, the report also looks towards the future, outlining areas for improvement and further development to refine and enhance the application's capabilities.

## 2. State Of the Art

In this section, we explore various topics, commencing with the definition and comprehension of life cycle assessment, delving into its phases, and gaining insights into a product or service's life cycle. Next, we conduct a comparative analysis of existing LCA software. Subsequently, we review the diverse datasets to be analysed, selecting the most suitable one for this project.

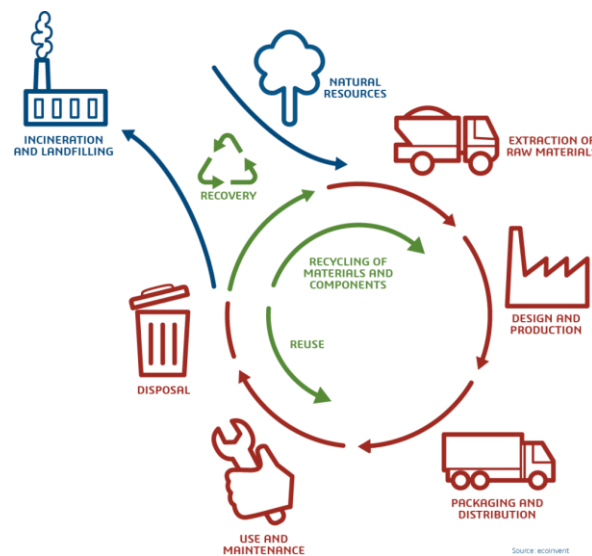
### 2.1. Life Cycle Assessment

A Life Cycle Assessment (LCA), sometimes referred to as Life Cycle Analysis, is the study and estimation of the environmental impacts of services and products during their entire life cycle, from its production to waste or recycling. (Encyclopedia of Toxicology (Third Edition), 2014)

#### 2.1.1. Product or Service Life Cycle

The **life cycle of a product** or service includes five main steps: getting the materials, making it, moving it, using or selling it, and getting rid of any leftover waste. It is important to understand and assess the environmental effects of each of these steps in order to promote sustainable practices and reduce the overall impact on the environment. (European Commission - Joint Research Centre, 2010)

Figure 1: Life Cycle Assessment



(Ecoinvent LCA, n.d.)



## **Raw Material Extraction**

The beginning of a product or service's life cycle is when raw materials are extracted from natural resources. This step includes minerals, metals, wood, or agricultural crops. The effects on the environment currently involve damaging habitats, ruining land, using up energy and water, and the chance of harmful substances being let out. Using sustainable sourcing and extraction methods, being efficient with resources, and responsibly mining can help reduce the impact on the environment when getting raw materials. (Environmental emissions and energy consumptions assessment of a diesel engine from the life cycle perspective, 2013)

## **Manufacturing**

The manufacturing phase is when raw materials are turned into finished products using different types of industrial processes. This step often requires energy, water, and chemicals, which can cause greenhouse gases to be emitted, water pollution, and generate waste. Focusing on using less energy, producing less waste and pollution, and using materials and technologies that are environmental-friendly are key ways to reduce the harm caused by manufacturing. (Analyzing environmental sustainability methods for use earlier in the product lifecycle, 2018)

## **Transportation**

Transportation plays a significant role in the life cycle of a product or service. This phase is about moving materials, components, and finished products along the supply chain. This includes transportation from suppliers to manufacturers, between factories, and to stores or customers. The way we transport things has negative effects on the environment. These include using a lot of energy, creating air pollution from the gases that vehicles release, and ruining the environment by building roads and other structures. To lessen the negative impact of transportation on the environment, it is important to plan logistics efficiently, optimize routes, use cleaner modes of transportation, and encourage sustainable transportation systems. (A method to ecodesign structural parts in the transport sector based on product life cycle management, 2015)

## **Usage and Retail**

The stage when customers use or buy a product or service is called the usage and retail phase in its life cycle. This phase includes the energy and resources used throughout a product's lifespan, like electricity, water, and waste created. Using products and technologies that are less damaging for the environment, such as energy-efficient ones that last longer and are used and disposed responsibly, are important for reducing the environmental impact when buying and using products or services. (European Commission - Joint Research Centre, 2010)

## Waste Disposal

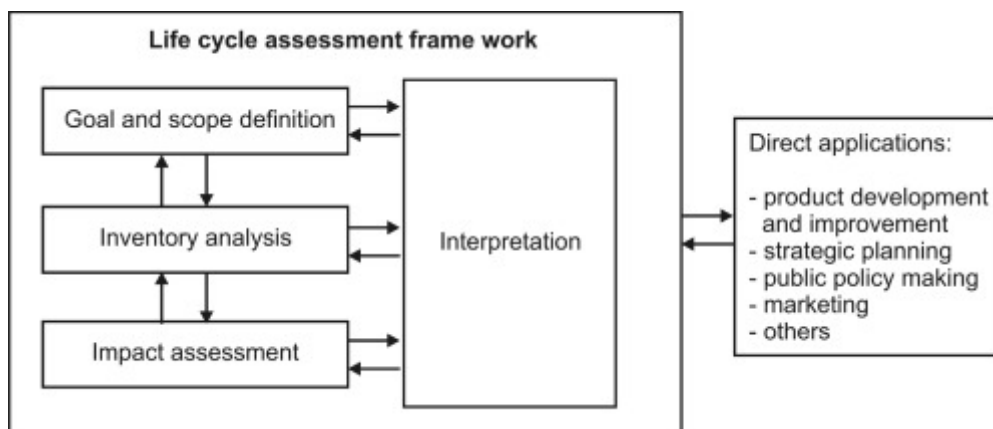
The last step in the life cycle of a product or service is waste disposal. During this stage, waste that is produced throughout the life cycle, including post-consumer and/or industrial waste, is managed and treated. Throwing garbage in the wrong places can cause pollution of the land, water, and air. It can also use up resources faster. Using effective ways to manage waste, like recycling, reusing, composting, and responsible disposal, is essential for reducing harm to the environment and following circular economy principles. (Industrial Ecology and global Change)

### 2.1.2. Life Cycle Phases

**Life cycle assessment** typically consists of four distinct phases: goal definition, inventory analysis, impact assessment, and interpretation. Each step is important for understanding and measuring the effects a product or system has on the environment. (Life cycle assessment, 2017)

It is important to understand and use these four phases of LCA in an effective way when conducting environmental assessments. By using a step-by-step and consistent method, LCA gives important information to help with sustainable development, eco-design, and decision making. The picture below, illustrates the LCA phases according to ISO 14040. (Environmental management, n.d.)

**Figure 2:** LCA phases according to ISO 14040



(Environmental management, n.d.)

## **Goal**

During the goal definition phase, the focus is on determining the study scope and objectives for the LCA study. The process begins by establishing the purpose behind conducting the assessment. Following this, the inclusions and exclusions for the assessment are defined. Subsequently, the specific system or unit under investigation is identified. Lastly, the intended audience for the assessment is specified. This phase plays a pivotal role as it establishes the foundation for subsequent stages and ensures that the assessment comprehensively addresses crucial environmental aspects. (Curran M. A., 2016)

## **Inventory Analysis**

During the inventory analysis phase, we gather and measure information about the entire life cycle of the product or system being researched. This entails finding and describing the inputs (such as materials, energy, and water) and the outputs (for example, emissions, pollution, and waste) at every step of the life cycle. We use different ways to collect information, like surveys, databases, and reading articles, to get the most accurate and complete data. The data is put together in a list called a life cycle inventory (LCI), which is used as a starting point for more detailed analysis. (Rebitzer, 2004)

## **Impact assessment**

The impact assessment phase involves evaluating the potential environmental effects identified in the inventory analysis. This involves employing various methods to quantify the environmental impact of specific actions, considering both inputs and outputs. During this step, the inventory data is assigned values and transformed into scores for different environmental categories, such as climate change, use of resources, and human health impacts. The impact assessment facilitates the comparison and integration of various environmental effects, providing an overall assessment of the system's sustainability. (Rebitzer, 2004)

## **Interpretation**

During the interpretation phase, we analyse and share the findings from the LCA study. This includes looking at how important and uncertain the results are, finding out the main causes of environmental harm, and doing tests to see how sensitive the results are. The interpretation phase also includes sharing the results with stakeholders like government officials, people who work in the industry, and customers. Understanding and discussing the results about the results of LCA helps make smart decisions and find ways to make the product or system better. (Curran M. A., 2013)

### 2.1.3. Life Cycle Inventory

Life Cycle Inventory (LCI) represents one component of LCA and involves the compilation and quantification of multiple inputs, outputs, and environmental impacts. LCI helps to identify and quantify the energy, the emissions, and other important and relevant factors in association with every stage of a product or service's life cycle. (Christoforou, 2022)

Thanks to a detailed inventory of the consumed resources, produced waste and generated emissions, valuable information can be gathered for studying and analysing the environmental impact. (Christoforou, 2022)

### 2.1.4. Life Cycle Impact Assessment

Life Cycle Impact Assessment (LCIA) conducts the evaluation of the potential environmental impact that was identified during the LCI stage. This allows the researchers and decision makers to have a better understanding of the damages caused by the emissions. With the results provided by the LCIA, the decision makers can detect the domains to enhance and make decisions to improve the environmental performance (Liu, 2021)

## 2.2. Existing LCA Programs

In this bachelor thesis, conducting a comprehensive comparison of existing tools and solutions is crucial for establishing the position of our new solution. The comparative analysis will focus on the following key aspects:

- **Usability:** evaluating the user-friendliness and ease of use of each solution.
- **Price:** assessing the cost structure, including monthly or yearly fees, and identifying whether the tool is available free of charge.
- **Database:** analysing the quality and reliability of the underlying data utilized by each solution.
- **Transparency:** investigating the transparency and traceability of the data sources used by the tools.
- **Updates:** considering the frequency and regularity of updates provided by each solution.

By closely examining and putting the items in contrast, valuable insights can be gained about the strengths and weaknesses of each tool. The examination will help in identifying the unique aspects of the new solution and identifying areas for improvement.

### 2.2.1. OpenLCA

OpenLCA is an open-source and free to use LCA tool. Users can download and install the software without any direct costs. Thanks to the active community, regular updates and improvements on the software can be found. Regarding the data, OpenLCA supports various databases and data formats such as Ecoinvent and GaBi, both known for their high-quality LCI data. By providing users with options to document and reference the data used, OpenLCA promotes transparency, and it allows researchers to trace the origins of the data as well as its relevance and reliability. (openLCA, n.d.)

However, to use OpenLCA, it requires some familiarity with LCA and sustainability concepts. Our main objective is to create a user-friendly platform that can be accessed by everyone. By asking the user to import data sets can be a challenge for less experienced ones and they may not know which data set to use.

Even though OpenLCA supports various databases and formats, the data sets must be imported, it does not include its own database. This can lead users to upload data from less reliable and transparent sources which can compromise the accuracy and credibility of the assessment. The image below displays the OpenLCA interface, indicating that it may not be very user-friendly and may require some level of expertise to perform assessments effectively.

**Figure 3:** OpenLCA application step where the user can see impact factors for an assessment.

**Impact factors: 1'-Hydroxyestragole**

Impact assessment method	Impact category	Impact factor	Unit
ILCD 2011 Midpoint	Human toxicity, cancer effects - ILCD 2011 Midpoint	5.02E-7	CTUh / kg
ILCD 2011 Midpoint+	Human toxicity, cancer effects - ILCD 2011 Midpoint+	5.02E-7	CTUh / kg
IMPACT 2002+	Carcinogens - IMPACT 2002+	2.574373766	kg C2H3Cl eq / kg
ReCiPe 2016 Endpoint (E)	Human carcinogenic toxicity - ReCiPe 2016 Endpoint (E)	4.07E-6	DALY / kg
ReCiPe 2016 Endpoint (H)	Human carcinogenic toxicity - ReCiPe 2016 Endpoint (H)	4.07E-6	DALY / kg
ReCiPe 2016 Endpoint (I)	Human carcinogenic toxicity - ReCiPe 2016 Endpoint (I)	0.0	DALY / kg
ReCiPe 2016 Midpoint (E)	Human carcinogenic toxicity - ReCiPe 2016 Midpoint (E)	1.23	kg 1,4-DCB / kg
ReCiPe 2016 Midpoint (H)	Human carcinogenic toxicity - ReCiPe 2016 Midpoint (H)	1.23	kg 1,4-DCB / kg
ReCiPe 2016 Midpoint (I)	Human carcinogenic toxicity - ReCiPe 2016 Midpoint (I)	0.0	kg 1,4-DCB / kg
ReCiPe Endpoint (E)	Freshwater ecotoxicity - ReCiPe Endpoint (E)	0.0	species.yr / kg
	Human toxicity - ReCiPe Endpoint (E)	1.18E-6	DALY / kg
	Marine ecotoxicity - ReCiPe Endpoint (E)	0.0	species.yr / kg
	Terrestrial ecotoxicity - ReCiPe Endpoint (E)	0.0	species.yr / kg
ReCiPe Endpoint (H)	Freshwater ecotoxicity - ReCiPe Endpoint (H)	0.0	species.yr / kg
	Human toxicity - ReCiPe Endpoint (H)	1.18E-6	DALY / kg
	Marine ecotoxicity - ReCiPe Endpoint (H)	0.0	species.yr / kg
	Terrestrial ecotoxicity - ReCiPe Endpoint (H)	0.0	species.yr / kg
ReCiPe Endpoint (I)	Freshwater ecotoxicity - ReCiPe Endpoint (I)	0.0	species.yr / kg
	Human toxicity - ReCiPe Endpoint (I)	0.0	DALY / kg
	Marine ecotoxicity - ReCiPe Endpoint (I)	0.0	species.yr / kg
	Terrestrial ecotoxicity - ReCiPe Endpoint (I)	0.0	species.yr / kg

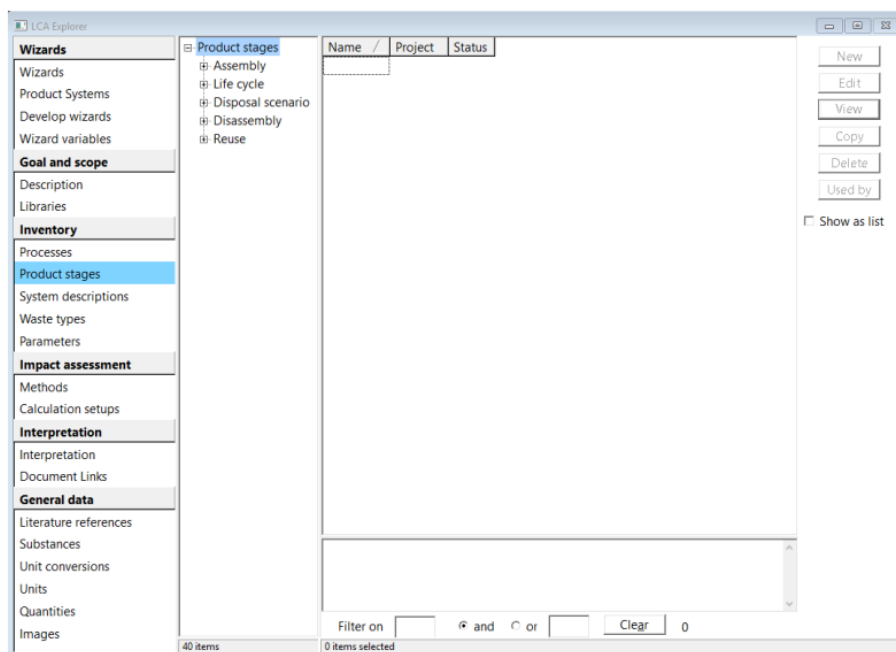
General information | Flow properties | **Impact factors**

(Jonas., 2019)

### 2.2.2. SimaPro

SimaPro is a cost-effective LCA software. To use SimaPro, users are required to purchase a license, and the pricing is determined by the type of license, number of users, and the modules or databases utilized. SimaPro was designed to be user-friendly by implementing an appealing interface backed by comprehensive documentation to assist its users. Due to its relevance, SimaPro is updated periodically. Like the other LCA pieces of software, SimaPro offers access to multiple databases such as Ecoinvent. By allowing users to document their assessments, this program ensures transparency and traceability (SimaPro, 2023). As OpenLCA, this program requires LCA and sustainability knowledge as well. Also, the user interface may not be considered the most user-friendly.

**Figure 4:** SimaPro where the user can enter information in order to start an assessment.



(PRé Sustainability, 2023)

### 2.2.3. Comparison with WISER

When analysing the two LCA applications mentioned earlier, a notable drawback is their reliance on user knowledge of LCA and sustainability concepts, which can be challenging for non-experts. One application requires users to provide their own data sets, further complicating tasks for inexperienced users. Their reliability and transparency cannot be verified. In contrast, WISER offers an ecosystem with multiple reliable data sets like Ecoinvent, providing users with all the necessary tools and simplifying their tasks without requiring expertise in LCA or sustainability domains. The objective of this thesis, in collaboration with WISER, is to offer a centralized and easy-to-use web application where users do not need to search for external resources as everything is provided.

### 2.3. Durability Data Set

In the field of sustainability analysis, data plays a vital role in offering valuable insights and aiding well-informed choices. A data set refers to a collection of information or data employed for analysis and research in a particular domain (What is a Data Set, n.d.). In the sustainability domain, a wide variety of data sets are available, including LCI databases like Ecoinvent, utilized for conducting LCA.

The accessibility and availability of such data sets empower stakeholders to make decisions and drive sustainability efforts. Accurate and up-to-date data sets are essential for guiding sustainable practices across various sectors and promoting progress towards a more sustainable future. For this thesis, it is very important to have reliable data sets so we can provide the best results to users in a reliable and transparent way.

#### 2.3.1. Ecoinvent Database

The Ecoinvent database is a globally recognized life cycle inventory (LCI) database that supports a wide range of sustainability assessments. With its extensive collection of datasets, it enables researchers to evaluate the environmental impact of products and processes throughout their life cycle. One of the key strengths of the Ecoinvent database lies in its emphasis on transparency and traceability. Each dataset is accompanied by detailed documentation, providing users with access to individual unit process data and clear explanations of the underlying methodologies. This ensures that researchers can confidently analyze and interpret the information provided by the database. (Ecoinvent, 2013) (Wernet, et al., 2016)

In addition to comprehensive data on inputs and outputs, the Ecoinvent database offers a wealth of supplementary information. This means that the information about the products, their qualities, measurements, and calculations are available for users to understand the details of the systems being analysed.

#### 2.3.2. ENTSO-E

ENTSO-E is an acronym for the European Network of Transmission System Operators for Electricity. It is an association that represents the transmission system operators (TSO) of Europe. ENTSO-E was established to promote collaboration and coordination among TSO for the reliable and efficient operation of the European electricity system. (ENTSO-E, 2021)

This association plays a crucial role in facilitating cross-border electricity exchanges, coordinating network planning and development, and supporting the integration of renewable energy sources. It works towards the interconnection of Europe's electricity transmission network. Furthermore, the organization actively develops and promotes the implementation of network codes and guidelines to ensure consistent operational practices. (ENTSO-E, 2021)

ENTSO-E extends its efforts to research and development initiatives, with the goal of enhancing the technical capabilities of the European electricity transmission system. These initiatives explore innovative technologies and practices. Through its platform, ENTSO-E provides transparency and access to real-time and historical electricity market data in Europe.

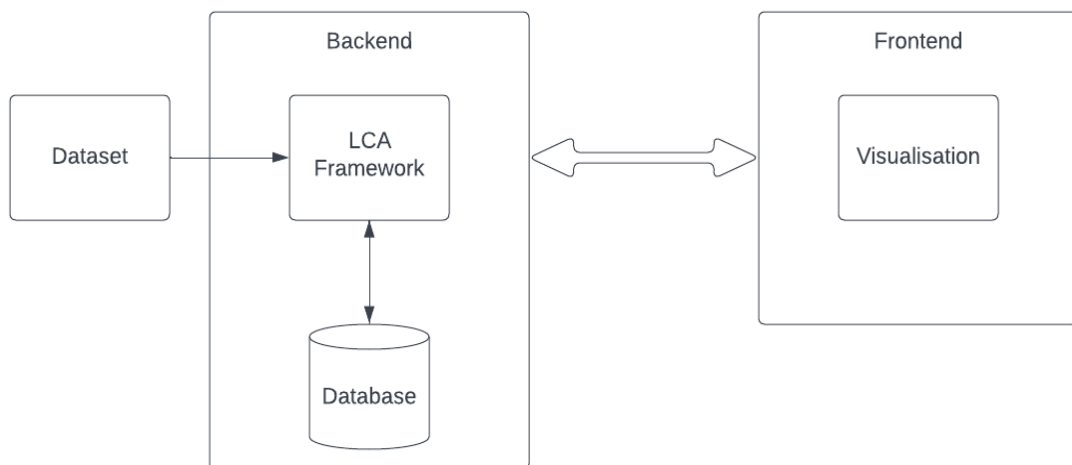
### 2.3.3. Data Set Choice

In our thesis, we utilize two essential data sets: Ecoinvent and ENTSO-E, specifically designed to support sustainability analysis. Ecoinvent is a well-known LCI database, enabling life cycle assessments, while ENTSO-E focuses on electricity transmissions and consumption data. Both data sets prioritize transparency and reliability, with Ecoinvent offering comprehensive documentation and ENTSO-E providing access to real-time and historical electricity market data in Europe. By leveraging these data sets, our thesis achieves a key goal: delivering reliable, transparent, and traceable results.

## 3. Analysis of Required Technologies

In this section we discuss and compare various technologies to identify the optimal choices for our project. Then, we conclude by discussing data visualization, emphasizing its significance and relevance for this undertaking.

As a reminder, the goal of this thesis is to develop a web application capable of integrating various data sources and visualizing CO2 emissions calculations for end-users. To help us to better understand the required tools for this project, the diagram below illustrates the different technological components discussed in this section:



**Figure 5:** Technological components diagram that shows each technology importance and role.

(author's source)



- **Dataset:** this component serves as the source of data to be used in the application. It provides the necessary information for emissions calculations and analysis. It is important to have reliable data in order to provide the best results.
- **Backend:** the backbone of the application, this technology is responsible for implementing the calculations and managing the database. It ensures smooth data processing and storage. By acting as a server, it makes the link with the frontend component and receive the request from the user and treat them.
- **LCA Framework:** an integral part of the project, this framework handles emissions calculations and data retrieval transparently, using reliable methods and processes.
- **Database:** the data repository plays a vital role in storing all relevant information, ensuring data availability and integrity. It is important to possess a type of database that can store any data type and be able to handle large amounts of it.
- **Frontend:** hosting the web application, this component enables direct user access. It empowers users to select specific parameters, input data, and visualize the results through a user-friendly dashboard featuring interactive graphs.

In order to justify our choices, some tables are used where each column identifies a specific technology or piece of software, and each row represents a criterion. The evaluation scale employs the symbols "-", "+", "++", and "+++" with the following meanings:

- “-”: represents that the criterion is not met
- “+”: represents that the criterion is partially met
- “++”: represents that the criterion is met to a significantly
- “+++”: represents that the criterion is fully met

### 3.1. LCA Frameworks

In the context of this thesis, the choice of an appropriate LCA framework is crucial. The accuracy and reliability of the calculated emissions form the foundation of this project, aiming to provide the user with the most reliable and informative results possible.

An essential consideration when selecting a framework is its transparency, effectiveness, data processing and calculation methods. These aspects play a significant role in ensuring the reliability and accuracy of the results obtained.

#### 3.1.1. Brightway2

Brightway2<sup>4</sup> is an open-source software framework for Life Cycle Assessment (LCA) and related environmental modelling. It is designed to support researchers and developers in conducting transparent and customizable LCA studies. Brightway2 is built on the Python programming language, providing a flexible and powerful platform for creating and analysing life cycle inventory (LCI) models. It offers a wide range of features and tools to support the entire LCA process, from data collection and model creation to impact assessment and interpretation. (Brightway Software Framework – Brightway documentation., n.d.)

Key features of Brightway include an extensive database support, and the ability to perform uncertainty and sensitivity analysis. It offers a wide range of built-in methods and tools to model complex life cycle systems accurately. With its flexible and modular architecture, Brightway allows users to customize and expand functionalities to suit specific project requirements. It facilitates data integration from various sources and supports multiple impact assessment methods. Furthermore, Brightway promotes transparency and reproducibility by providing detailed documentation and version control features.

Overall, Brightway empowers users to make decisions by delivering reliable and comprehensive life cycle assessment results. Its continuous development and active community support ensure up-to-date methodologies.

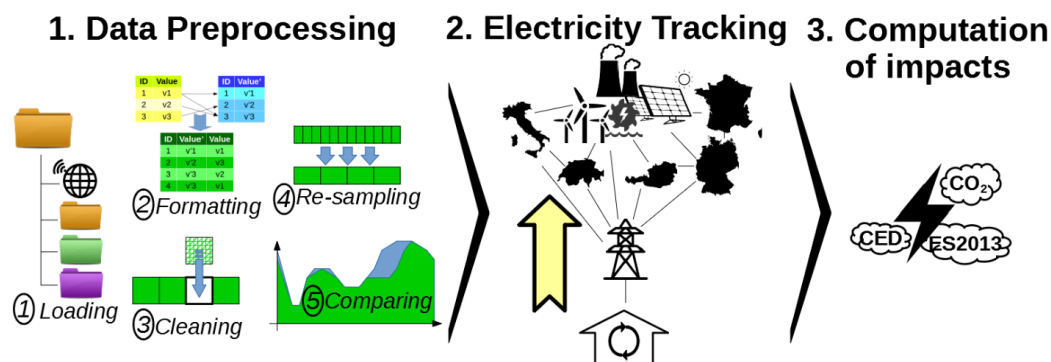
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<sup>4</sup> <https://github.com/brightway-lca>

### 3.1.2. EcoDynElec

EcoDynElec<sup>5</sup> is a Python package that facilitates the convenient and straightforward computation of environmental impacts associated with European electricity. This powerful tool enables the tracking of electricity flows across various European countries, employing a methodology similar to that of Life Cycle Assessment (LCA). By utilizing data from ENTSO-E and its member countries, EcoDynElec ensures the accuracy and reliability of the information used for impact assessment. This comprehensive dataset includes detailed information on electricity generation, cross-border transactions, and consumption patterns within the European region. (Overview – ecodynelec 1.0 documentation, n.d.)

Figure 6: EcoDynElec Data Process



(ecodynelec structure, n.d.)

The EcoDynElec software is organized in 3 modules (as shown above):

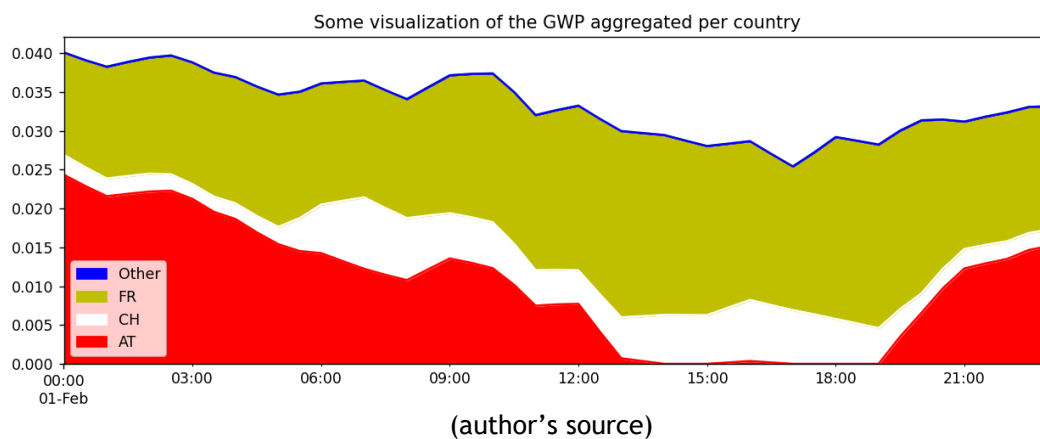
- 1. Data Preprocessing:** This module focuses on finding relevant data, performing necessary data cleaning procedures, and adjusting the data to ensure its quality and consistency. By treating the data with care, this module lays the foundation for accurate and reliable assessments.
- 2. Electricity Tracking:** With this module, EcoDynElec enables the tracking of electricity from its source to its end consumption. It allows for the analysis of generation patterns, cross-border transactions, and the identification of the various pathways through which electricity flows within and between countries.
- 3. Computation of Impacts:** The final module of EcoDynElec is dedicated to calculating the overall environmental impacts associated with electricity generation. It incorporates relevant impact assessment methods and models to quantify the effects on various environmental categories, such as greenhouse gas (GHG) emissions, resource depletion, and ecosystem

<sup>5</sup> <https://gitlab.com/fledee/ecodynelec>

damage. EcoDynElec can provide up to 5 years of historical data than can be used to train algorithms in forecasting environmental impacts up to 48h.

Below, there is an example of the outputs that can be generated using EcoDynElec. This output offers valuable insights into emissions data, allowing users to conduct in-depth analysis of emissions based on countries and/or sources. By leveraging these outputs, users gain the ability to explore and evaluate emissions patterns and trends. The example below showcase the emissions breakdown by countries, every thirty minutes for a day.

**Figure 7:** Emissions by Country for one day



### 3.1.3. Framework Choice

The chosen framework for emissions calculation in this thesis is EcoDynElec. This module has been previously utilized in another project and was specifically requested by the Product Owner for implementation in this thesis. The decision to use EcoDynElec was primarily driven by its compatibility with ENTSO-E. Also, the algorithm is in constant development which ensures an up-to-date module. However, Brigway2 can be implemented in the future as an additional framework for emission calculation.

### 3.2. Data Schema and ontologies for the CO2 emissions

#### 3.2.1. Type of Database

In this bachelor thesis, it is very important to choose a database capable of handling large data volumes and in various formats. Our decision will be guided by several key factors:

- **Flexibility:** The chosen database should support data storage in various formats, types, and structures. It should also allow for future modifications and adaptations as our data needs evolve.
- **Performance:** It is essential for the database to efficiently handle significant amounts of data and execute queries swiftly. A fast and responsive performance is necessary to ensure timely retrieval and analysis of data.

By considering these aspects, we aim to identify a database solution that not only accommodates our current requirements but also possesses the scalability and speed necessary to support future data growth and analytical needs in our research. For this we are going to study two types of databases: relational and non-relational.

#### 3.2.2. Relational Database

A relational database organizes data into tables with rows and columns. The relationships between the tables are defined through keys. It uses tables to store information, sometimes they share it which is called a relationship. In a table we can find columns that are used to define the information and rows where the data is stored. A column can be used in other tables thanks to the primary key, which is a unique value. (Oracle, n.d.)

One of the biggest advantages of a relational database is its reliability. In fact, every relational database implements the ACID principle (Atomicity, Consistency, Isolation and Durability) which guarantees the reliability of the transactions. This means that if one change fails, the transaction will fail, and the database's state will not change. (MongoDB, n.d.)

However, this type of databases uses a rigid schema. Indeed, it requires a certain level of planning because the structure, columns, must be defined upfront. Moreover, the data must perfectly fit the categories and predefined rules such as a maximum number of characters for a phone number. Relational databases don't handle large amounts of unstructured data correctly. As the unstructured data changes, it means all the data should change and be updated. Also, this decreases performance, and due to its complexity, the queries may take more time. (MongoDB, n.d.)

### 3.2.3. Non-relational database

A non-relational database, commonly known as NoSQL, is a database type that does not rely on tables with predefined relationships. Unlike traditional relational databases, NoSQL databases offer the advantage of flexibility. They do not enforce rigid structures, allowing them to handle data in any format. Additionally, non-relational databases are well-equipped to manage large volumes of data while delivering high performance. (oracle, n.d.)

There are various types of non-relational databases (explained later in this document), each designed to address specific data management needs:

- Document Databases
- Key-value Database
- Graph Databases
- Wide-Colum Databases

Non-relational databases are particularly suitable for managing unstructured big data. Their flexibility allows for storing multiple data types without requiring significant changes to the database schema. This adaptability proves advantageous when dealing with evolving data requirements and accommodating dynamic data formats.

### 3.2.4. Database Type decision

**Table 1:** comparison between relational and non-relational database

	Non-Relational	Relational
<b>Performance</b>	+++	+
<b>Flexibility</b>	+++	-
<b>Big data volumes</b>	+++	++

(author's source)

Based on the evaluation of the above criteria, we have opted to utilize a non-relational database for this bachelor thesis. The choice is driven by the inherent flexibility of non-relational databases, which allow for handling large volumes of data while maintaining optimal performance.

Unlike relational databases, non-relational databases provide the necessary adaptability to accommodate evolving data structures and formats, ensuring a more robust and efficient solution for our project.

### 3.3. Criteria for choosing the non-relational database

When evaluating non-relational databases for our project, we need to consider several key factors that impact their suitability:

- **Simplicity:** We must test the ease of setup, configuration, and ongoing maintenance of the database. A simple and user-friendly database will streamline our development process.
- **Performance:** The performance of the database is crucial, especially when dealing with large volumes of data. We need to evaluate factors such as read/write speeds, scalability, and the ability to handle high data throughput efficiently.
- **Flexibility:** The flexibility of the database plays an important role in adapting to evolving data requirements. We should examine how well the database supports changes in schema design and data modelling, allowing us to easily accommodate new data types and structures without significant disruptions.
- **Relationship Handling:** As our project may involve complex relationships between data entities, we need to assess the database's capabilities in managing these connections. The ability to efficiently handle links and associations between data entities is essential for maintaining data integrity and enabling comprehensive analysis.

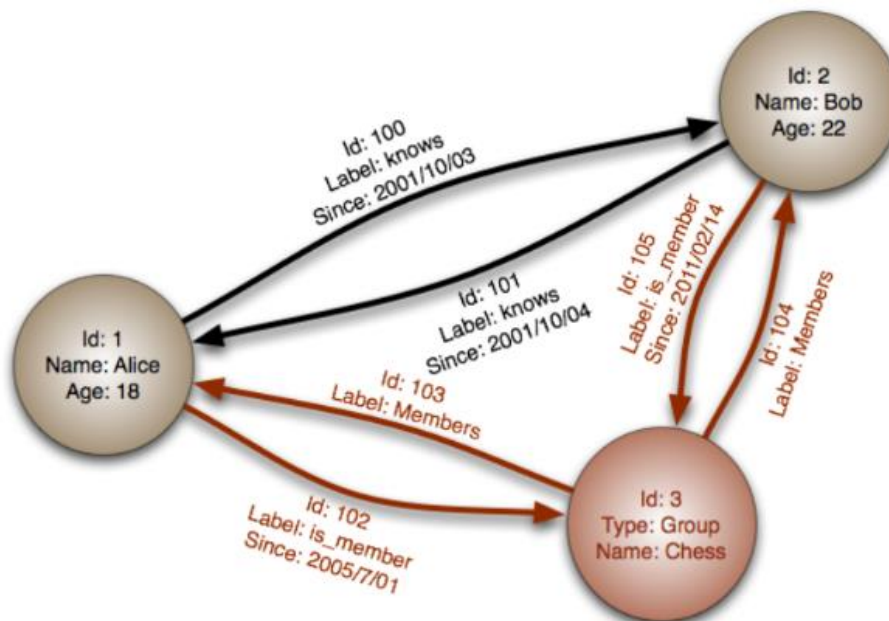
By carefully considering these factors, we can make a decision regarding the most suitable non-relational database for our project. This decision will significantly impact the efficiency, scalability, and overall success of our application.

#### 3.3.1. Graphical Database

A graph-oriented database is a type of NoSQL database that stores and searches data relationships using graph theory. Unlike traditional relational databases, which rely on complex JOIN operations, graph databases prioritize direct relationships between data elements (nodes). This makes traversing and querying interconnected data faster and more efficient. (Graph-Database, n.d.) (neo4j, n.d.)

By utilizing a graph database, we can benefit from several advantages. Firstly, it allows for more intuitive and efficient traversal of interconnected data, enabling faster and more precise querying of complex relationships. Secondly, the flexible nature of graph databases enables easier modification and expansion of the data model without significant schema changes, providing greater adaptability to evolving data requirements. (neo4j, n.d.)

**Figure 8:** Example of relationship for a graphical database



(influxdata, 2021)

### 3.3.2. Key Value Database

In this NoSQL database, the data is stored in two parts, key, used to fetch information from the database that returns a value. One of the main advantages of this database is its simplicity, because everything is stored as a unique key. Its simplicity can also be a disadvantage because more complex data cannot be supported. (mongodb, n.d.)

### 3.3.3. Document Database

Document databases, as their name suggests, store data in documents. These documents have a structure that resembles JSON's. It supports multiple data types, like strings, objects and nested documents. Like the Key value database, the data is stored in pairs. (mongodb, n.d.)

The advantages of this non-relational database type are the easiness to read and understand data by a user and its flexibility. Since this database does not employ schemas, we can use documents of different shapes. (mongodb, n.d.)



#### 3.3.4. Wide Column Database

The wide-column databases are very similar to relational ones. They store data in tables, organized by rows and columns. However, the names and format of the columns can differ, as the columns can be stored across multiple servers. They are similar to key-value because they organize and access data using a combination of rows and column references. Like the key-value databases, wide-column databases are fast and can handle big and unstructured data in a performant way because of their flexibility. (scylladb, n.d.)

#### 3.3.5. Choice

For this bachelor thesis, we decided to use a Graphical database due to its useful features including relationship criteria and flexibility. These attributes make it well-suited for handling unstructured data, which is prevalent in our case, particularly with the Ecoinvent and ENTSO-E datasets.

Furthermore, the flexibility offered by a Graphical database enables us to accommodate and adapt to the dynamic nature of the Ecoinvent and ENTSO-E datasets. As these datasets may undergo updates and additions over time, our chosen database will provide a scalable and agile solution to handle the evolving data requirements of our thesis.

### 3.4. Backend Technologies

The backend or “server-side of the application” refers to the essential parts of a program that operate behind the scenes and are not directly accessible by users. It effectively manages data, executes operations, and ensures the proper functioning of the client side of the application. As this portion of software is not in direct contact with users, backend designers develop features and characteristics that are indirectly accessed through a frontend application like creating API’s. Often referred to as the data access layer of software or hardware, the backend plays an important role in facilitating seamless communication between the user interface and databases, ensuring efficient data storage, retrieval, and manipulation. (Fitzgibbons, 2019)

For the study and choice of the back-end technology, various factors will be considered, including:

- **Syntax and Verbose:** Evaluating the programming language’s syntax means looking at how the language is organized, how easy it is to read, and how easy it is for developers to write and understand code. Minimizing verbosity can enhance development speed and improve the overall quality of the backend technology.
- **Compatibility:** Evaluating the compatibility of the language with other libraries, frameworks, and systems is crucial. This assessment includes considering how well the language integrates with existing technologies, the availability of relevant libraries and frameworks, and whether it aligns with the project’s overall architecture. For our project, this factor is important because we need to implement external sources for LCA.
- **Development speed:** This criterion involves evaluating the language’s productivity features, such as the availability of frameworks, tools, and libraries that can accelerate development, reduce coding effort, and improve time-to-market. It is very important for our thesis given the restrained time to the implementation.

#### 3.4.1. Python

The Python programming language is one of the best for backend development because of its user-friendly and easily understandable syntax. Due to its great community, there is an extensive amount of documentation and forums where the user can find the needed information. Also, python is open source which means that there is an extensive selection of libraries and modules. (Coursera Articles, n.d.)

Python is often used in rapid application development, but also largely used in scripting or as a glue language to connect existing components together. Programmers also choose Python in data science, machine learning or artificial intelligence. Overall, Python is a high-level language, and it supports object-oriented programming. (python, n.d.) Moreover, Python is the second fastest growing

programming language, which means it is used by more and more by companies. Therefore, will be less compatibility problems. (Coursera Articles, n.d.)

There are plenty of advantages when using python. First of all, Python has a simple and easy to learn syntax. It makes every program syntax readable and so, reduce costs regarding maintenance and programming. Second, there is a thriving community. Thanks to that, programmers can find a wide range of libraries and documentation. (pros and cons of python, n.d.)

However, there are some downsides when using Python. The main one is that Python is slower than most programming languages. Moreover, Python is not optimized to reduce memory and as it is not compiled until runtime, it is harder to avoid runtime errors. (pros and cons of python, n.d.)

### 3.4.2. Java

Java is a multi-platform, free to use and object-oriented programming language. It uses java language API, which is the frontend part that connects the developer and the java platform. It also uses java virtual machine (JVM) which is the backend communication between the java platform and the hardware. (java, n.d.)

One of the advantages of java is that it is an object-oriented programming language. It means that the programmer can create classes, methods and use other concepts to create modular and reusable code. Java is considered a secure language. In fact, it runs inside JVM, also known as sandbox. It uses a byte-code verifier and provides library-level safety. (javatpoint advantages-and-disadvantages-of-java, n.d.)

Due to the great community of developers that use java, users can find an extensive set of documentation on the internet that is maintained and updated regularly. Users can also find a large choice of libraries. (javatpoint advantages-and-disadvantages-of-java, n.d.)

Nevertheless, we can find some downsides when using java. In fact, java has a highly complex syntax. It may take more time to develop because of the verbose and complex code. Also, java has a high memory consumption level due to the java virtual machine which can be costing because of its requirements. (javatpoint advantages-and-disadvantages-of-java, n.d.)

### 3.4.3. Comparison Matrix Java vs Python

**Table 2:** Characteristics of the back-end languages

Feature	Java	Python
<b>Syntax</b>	Strict and verbose	Readable
<b>Code Readability</b>	More verbose syntax	Cleaner and more concise syntax
<b>Performance</b>	Generally faster execution speed	Slower execution speed
<b>Libraries and Frameworks</b>	Vast selection of libraries and frameworks	Extensive range of libraries and frameworks
<b>Community and Support</b>	Large and active community	Large and active community
<b>Development Speed</b>	Slower development process	Faster development process
<b>Platform Independence</b>	Platform-independent (JVM)	Platform-independent

(author's source)

### 3.4.4. Final Choice

**Table 3:** Comparison between Java and Python

	Java	Python
<b>Syntax</b>	++	+++
<b>Compatibility</b>	-	+++
<b>Development Speed</b>	-	+++

(author's source)

For this bachelor thesis, we selected Python for various reasons. Python is well-known for its simplicity and ease of use, making it accessible to developers of all levels. Its readability and syntax allow for faster understanding and implementation of code. This must be taken in consideration as the time to implement the solution is restrained.

Additionally, Python's compatibility with numerous libraries and APIs is a significant advantage, providing a wide range of useful tools for the project. For example, for this project, there is a high compatibility with the EcoDynElec module as it uses Python as development language which facilitates the implementation. Overall, Python's user-friendly nature, library compatibility, and fast development capabilities make it the ideal choice for this bachelor thesis.

### 3.5. Frontend Technologies

The frontend or “client side of the application” is the layer of the application the user can see and directly interacts with. It regroups multiple graphical user interface (GUI) components such as text, images, buttons, and navigation.

In order to identify the best front-end technology to use for the development of the application, we conducted a comparison between the two most used technologies for front-end web development. After careful evaluation, we decided to assess the technologies based on the following key criteria:

- **Performance:** Considering the requirement to render and handle large quantities of data, we prioritized the performance of the technology. It was crucial for the chosen technology to provide faster data display capabilities, ensuring an optimal user experience.
- **Community:** We recognized the importance of having a large and active community surrounding the chosen technology. A thriving community signifies updated documentation, active support forums, and a wide range of resources. This enables us to stay abreast of industry trends and leverage collective knowledge for effective development.
- **Flexibility:** Another critical factor we considered was the flexibility. We valued a technology that could seamlessly integrate with other technologies and libraries, allowing for efficient collaboration and extending the functionality of our application.

By evaluating frontend technologies based on these criteria, we aimed to make a rational decision that would yield a technology solution with superior performance, a strong community presence, and the necessary flexibility for successful integration.

### 3.5.1. React.js

React is a free open-source JavaScript library used for frontend web applications development. It was developed by Facebook and has a large community that maintains it along with it. Thanks to its great community, users can find a good supply of documentation. React is simple to learn due to the simplicity of its syntax. The components in a React application are responsible for rendering and displaying reusable pieces of code. (Joseph, 2022)

**Figure 9:** Example of code using React.js

```
class HelloMessage extends React.Component {  
  render() {  
    return <div>Hello {this.props.name}</div>;  
  }  
}  
  
root.render(<HelloMessage name="Taylor" />);
```

(React - A JavaScript library for building user interfaces)

Moreover, React.js uses a virtual DOM<sup>6</sup> (Document Object Model) which enhances performance. Unlike other libraries or frameworks that rely on the real DOM and update the entire page when there is an input or query, React's virtual DOM selectively updates specific elements instead of the entire DOM structure. (docs, n.d.)

However, even though React.js has various tools to develop frontend applications, it is not a framework. For example, it does not use the model-view-controller (MVC) architectural pattern, it only does the user interface. To create the model and the controller, the developers may have to use other tools. (Joseph, 2022)

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<sup>6</sup> programming interface for web documents that represents the structure of HTML or XML documents and allows dynamic access and manipulation of their content.

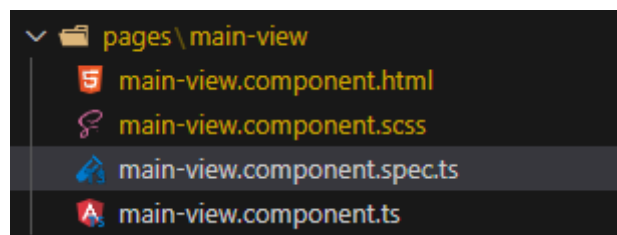
### 3.5.2. Angular

Angular is a free open-source web application framework based on Typescript created by Google. Being backed by Google is one of the main advantages because it will be maintained for the long-term and get updated often. Also, there is an excellent amount of documentation about Angular what makes it easier to use and solve bugs or problems. (alex, 2022)

Angular applications have a Model-View-Controller architecture which is a good practice when coming into web applications development. By implementing Two-Way data binding, it requires less time to develop the application because when there is a data change in the Model, the View does change too. It also uses plain HTML templates which makes it easy to develop. Angular is, overall, component based. Each component has its own responsibility and behaviour, designated for a specific task. In other words, a component is associated with an HTML piece of code that defines what is rendered on a page. (alex, 2022)

Although it is an easy-going language, Angular contains some limitations. One of the downsides is that Angular uses typescript, which contains very strict syntax. It contains some limited SEO capabilities. Another downside is the size and performance of the Angular framework that is relatively large, and it is not ideal for projects with strict performance requirements (alex, 2022). The picture below, illustrates all the documents needed to render one web page. This shows the heaviness of angular but also shows the organisation that it uses.

**Figure 10:** Example of Document Structure using Angular



(author's source)

### 3.5.3. Comparison Matrix Angular vs React.js

**Table 4:** Characteristics of the front-end languages

	Angular	React.js
<b>Language</b>	TypeScript	JavaScript
<b>Architecture</b>	Full-featured framework	JavaScript library with a component-based approach
<b>Performance</b>	Good performance, optimized for large applications	Excellent performance due to virtual DOM
<b>Community</b>	Large	Large and active
<b>Tooling</b>	Provides a complete set of tools and features	Rich ecosystem with many libraries and tools available
<b>Templating</b>	Uses declarative HTML templates	Uses JSX (JavaScript XML) for templating
<b>Data Binding</b>	Two-way	One-way
<b>Flexibility</b>	Opinionated framework with less flexibility	Highly flexible and adaptable

(author's source)



### 3.5.4. Final Choice

**Table 5:** Comparison between Angular and React.js

	Angular	React
<b>Performance</b>	++	+++
<b>Community</b>	+++	+++
<b>Flexibility</b>	-	+++

(author's source)

For this bachelor thesis, the React library will be used to develop the frontend. In fact, React.js is simpler and more flexible and thanks to the Virtual DOM implementation, the web application will have a better performance and fast rendering. Furthermore, React.js has a large and active community that provides a wide range of tools, libraries, resources, and up-to-date documentation which can be helpful. Moreover, the WISER SP5 dashboard utilizes React as the main frontend technology. By integrating this frontend technology to our web application, it increases compatibility with the other dashboards and facilitates the implementation for our project.

### 3.6. Data Visualization

Data visualisation plays a crucial role in transforming complex data into visually appealing representations, such as graphs and charts. These visualizations enable companies and organizations to improve their understanding of collected data and take decisions. (Tableau, n.d.)

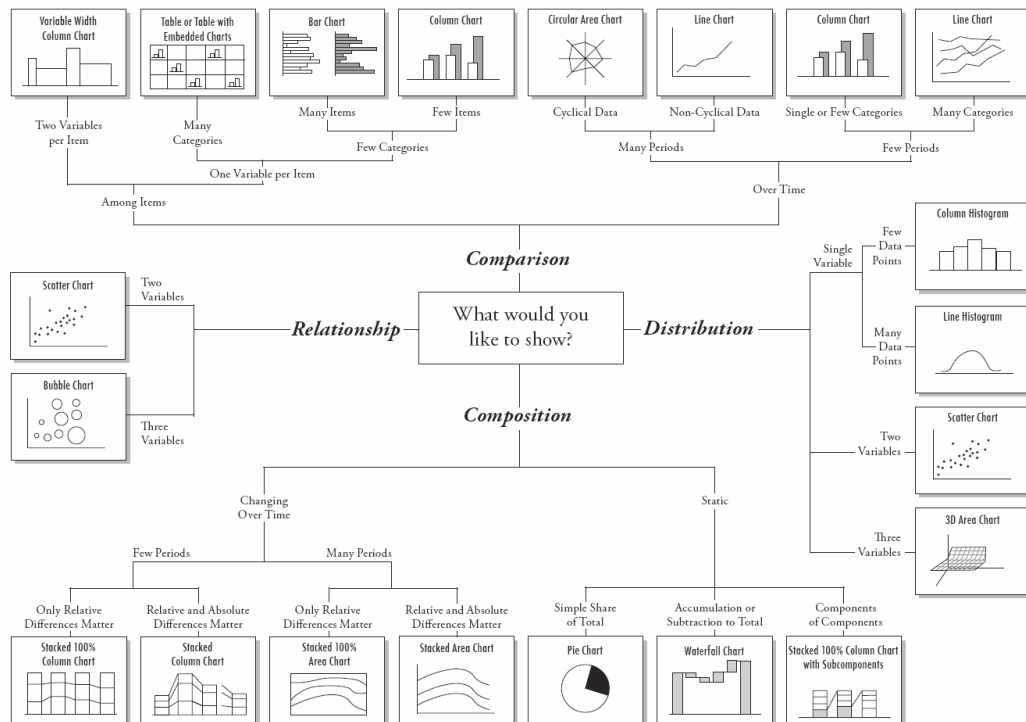
There are multiple types of visualizations such as:

- Dashboards
- Graphs
- Tables
- Charts

Each type plays its own part in conveying data effectively. After careful analysis of the data to be visualized, we have chosen the most suitable type of graph for this project to ensure optimal presentation and clarity.

As a reminder, our primary objective is to visually represent the emissions data over a specific period of time, allowing to have a comparison with previous time frames and provide forecasting representation. These types of analysis are crucial when addressing climate change and sustainability development. In order to make the best choice, we are going to study the diagram below:

**Figure 11: Chart Suggestion**



(Sandberg, 2013)

The Andrew V. Abela decision tree, helps to determine which type of graph is the most appropriate to use based on specific communication objectives and data characteristics. Every internal node represents a criterion relevant to the visualization goal, and each branch corresponds to the most suitable graph type to visualize data in the most effective way. (Sandberg, 2013)

As a reminder, our application aims to display the results in a way that the user can understand easily. For that the graph chosen to be displayed in the dashboard will play a crucial role.

As we can see on the decision tree, visual elements (what we are trying to communicate), are divided into four categories:

- **Relationship:** graphs that show the correlation between two or more variables
- **Comparison:** graphs that allow to compare one or more data sets and/or highlight differences over a period of time.
- **Distribution:** graphs that show how variables are distributed in order to identify trends
- **Composition:** graphs that display the evolution in a given period of time

Additionally, it is important to consider the characteristics of the data itself, such as:

- **Static:** type of data that does not change over time (not affected by temporal factors or updates)
- **Changing over time:** dynamic data that faces variations and updates over multiple time periods (Patterns over time).
- **Number of periods:** type of data that is collected and/or observed over a set time period (daily, weekly, etc).
- **Number of variables, items, or categories:** dimensions or attributes of the data.

By considering these data and following the decision tree, we were able to make our choice regarding the most suitable graph type for our visualization needs. We decided to use the line graph thanks to its multitude of advantages. This type of graph offers a clear representation of trends over time which allows us to identify patterns and variations in emissions. This helps assessing the emission reduction strategies effectively.

Also, line graphs facilitate comparison between different data. By using multiple lines on the same graph, we can analyse the results of different timelines, datasets, or sources for CO2 emissions. For example, by examining the impact over a specific timeframe, such as within a day, the data reveals insights about the electricity consumption patterns. This valuable information can guide decision-making, allowing users to identify periods of lower electricity utilization. Consequently, individuals can optimize their energy usage by choosing favourable time slots for activities such as household electricity consumption or electric vehicle charging. This proactive approach contributes to minimizing the environmental footprint associated with energy consumption. Furthermore, this type of graph is one of the best choices for forecasting. By extending the trend lines, we can estimate the trajectory of emissions.

In order to enhance result comprehension, the data will be presented in a line graph with various time intervals, such as hourly or monthly, along with the corresponding energy source quantity expressed in kilowatts (kW) or kilowatt-hours (kWh).

## 4. Architecture, Design and Methodology

In this section, we aim to gain a comprehensive understanding of the application development process. We start by exploring the Scrum methodology and its implementation in this project. Next, we delve into the Use Case and Activity Diagrams, which aid in understanding the application's features. Furthermore, we explain the architectures for data fetching and the overall application. Lastly, we examine how SP5 served as inspiration and present the mock-ups.

### 4.1. Methodology

Scrum is an Agile framework widely used for managing and organizing projects. It provides a flexible and iterative approach. This methodology allows us to adapt to changing requirements and deliver value incrementally. Scrum focuses on collaboration, transparency, and continuous improvement. (scrum, n.d.)

In Scrum, the team is composed as following:

- **Product Owner:** it is the person who represents the interests of the stakeholders and is the voice of the customer. For our project, M. Didier Beloin-Saint-Pierre fulfilled the role of Product Owner.
- **Development Team:** team of developers that are in charge of implementing features to fulfil the client's requirements. The development team for this project consisted of one person.
- **Scrum Master:** it is the person that ensures that the Scrum framework is followed by the team. For this project, SP7, there was no designated Scrum Master.

In a Scrum project we can find different events to be followed such as :

- **Sprint:** it is a time-boxed iteration of work. During the iteration, multiple tasks are accomplished. At the end of each sprint there is a developed product that is presented to the Product Owner.
- **Sprint Planning:** this event involves deciding which tasks will be undertaken during the upcoming sprint.
- **Sprint Review:** it is a meeting where the Product Owner and the Scrum team validate all the tasks completed during the sprint.
- **Daily Meeting:** a daily meeting held by the Scrum team to synchronize their work and plan activities for the day. Due to the limited size of the development team, the Daily Scrum meetings were not conducted in this project.

Within the Scrum framework, we can also find certain documents that are utilized, including:

- **Product Backlog:** list of user stories organized by priorities to be implemented throughout the project. It is defined by the Product Owner in collaboration with the development team. A user story is a brief description of a feature explained with the terms “As [actor], I want to [action]”.

The WISER team already had a product backlog with features for the projects SP5, SP6 and SP7. In fact, we adapted it to our project by organizing it based on the time available. The product backlog can be found in the appendices.

By applying the Scrum methodology, we were able to maintain a good project follow-up. Regular meetings with Mr. Beloin-Saint-Pierre and Mr. Calbimonte allowed us to progress by first targeting the requirements and secondly, detailing the goals for the application.

A first meeting to determine the problematic and the objectives of the project took place in the beginning of the project. Subsequently, several meetings were conducted involving key stakeholders, such as programmers and researchers from HEIG-VD, that helped us to design the application architecture. Additionally, a meeting with the Product Owner was held to define the SP7 Dashboard's features, which facilitated the design of mock-ups.

A dedicated meeting for sprint planning was held to determine the tasks that would be undertaken during each sprint. This meeting involved the collaboration of the development team and the Product Owner to identify the priorities and establish a clear plan of action.

Following the completion of each sprint, a sprint review session was conducted. This meeting provided an opportunity for the Product Owner and the Scrum team to come together and review the completed tasks as well as the developed product increment. The Product Owner provided valuable feedback, which played a crucial role in evaluating the progress and ensuring alignment with the project's objectives.

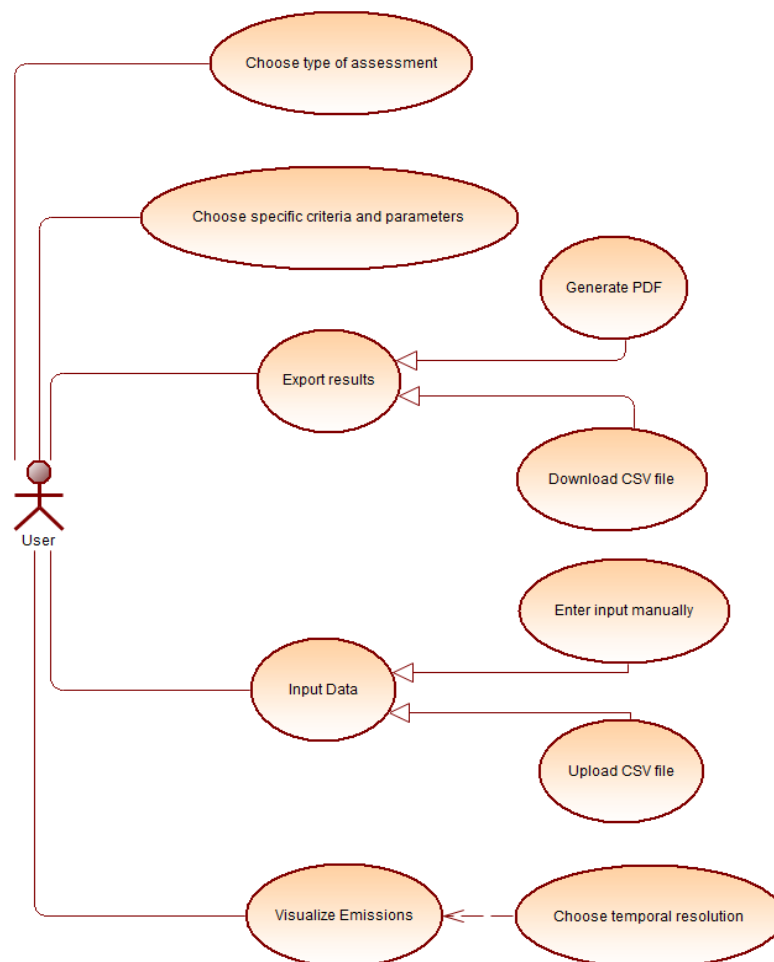
These meetings served as essential checkpoints in the project timeline, enabling effective communication, clarification of expectations, and validation of the work completed during each sprint.

## 4.2. Use Case Diagram

Use case diagrams serve as a way to model the behaviour of a system and capture its prerequisites. This type of diagram provides a brief representation of the system's high-level features and its scope. They also distinguish the interactions between the system and its actors. In use case diagrams, the actors and use cases illustrate the functionality of the system and how users can interact with it. However, these diagrams do not delve into the internal workings of the system. (IBM documentation, n.d.)

- **Use Case:** describes functions or actions that a system performs to fulfil the user's objective.
- **Actor:** it represents the various roles or entities that interact with the system.

Figure 12: Use Case



(author's source)

In the use case diagram for this project, the main actor is the "User", representing the individual interacting with the system. The system itself is represented as the "Application".

The main features of the system, as depicted in the use case diagram, include:

- **Choose an assessment type:** this allows the user to select the type of assessment they want to perform within the application.
- **Choose specific criteria and parameters:** the user can specify the specific criteria and parameters relevant to the assessment they are conducting.
- **Export the results into a PDF or CSV file:** this feature enables the user to export the assessment results into either a PDF or CSV file format for further analysis or sharing.
- **Input data, manually or by uploading a CSV file:** users can input data required for the assessment manually or choose to upload a CSV file containing the necessary data.
- **Visualize the results with the possibility of choosing a temporal resolution:** the system allows the user to visualize the assessment results through various graphical representations, with the option to select a specific temporal resolution, such as hourly, monthly, or yearly.

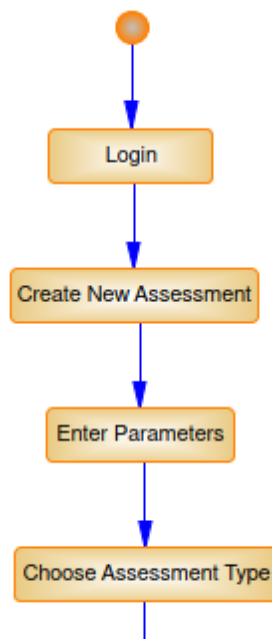
These main features outline the primary functionalities available to the user within the system, providing an overview of the actions they can take and the capabilities of the application.

### 4.3. Activity Diagram

Activity diagrams offer an insightful perspective into the system's behaviour by illustrating the sequential progression of actions within a process. They share similarities with flowcharts as they depict the flow between activities. However, activity diagrams go beyond simple flowcharts by enabling the representation of parallel or concurrent flows, as well as alternate flows. Within activity diagrams, the flow of control and data between actions is captured through the use of activity nodes and activity edges (IBM documentation diagrams activity, 2021). The entire diagram of activities for this project can be found in the appendices.

The activity diagram for the application commences with the user's login into the system. After a successful authentication, the user gets access to a range of functionalities. One of these features is the ability to create a new assessment, wherein the user can select the most suitable options based on their requirements. Subsequently, the user is presented with the option to choose an assessment type.

**Figure 13:** First phase of the Activity Diagram

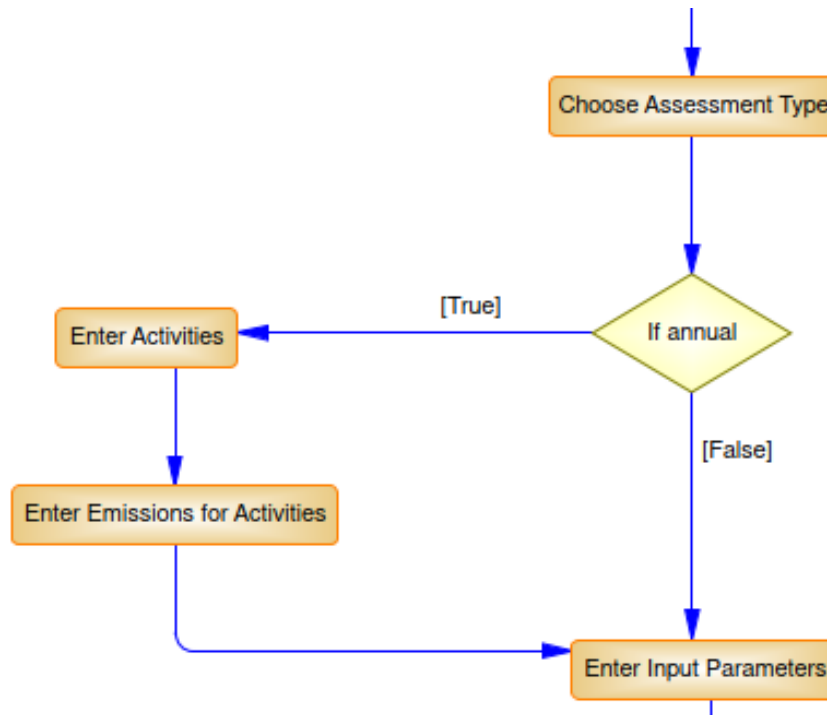


(author's source)



Based on the selected assessment, the user is presented with the opportunity to choose activities from a predefined list and input energy production values for each activity. Then, the user has the possibility to enter additional inputs.

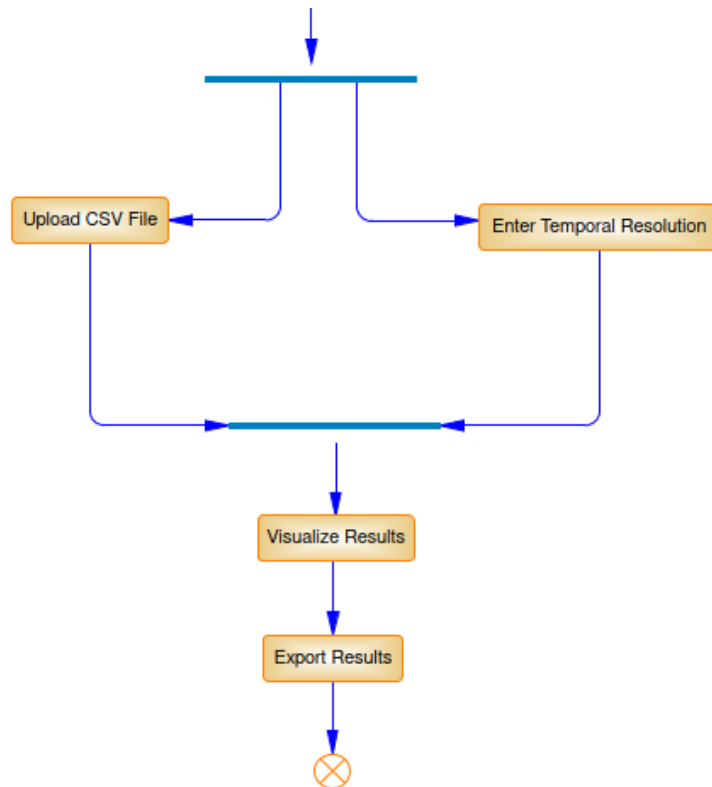
**Figure 14:** Second part of the Activity Diagram where the assessment selection is explained



(author's source)

The input parameters section of the application allows the user to perform synchronous tasks such as selecting the temporal resolution and uploading a CSV file containing relevant data. Following this step, the generated results can be visualized within the application and exported as desired.

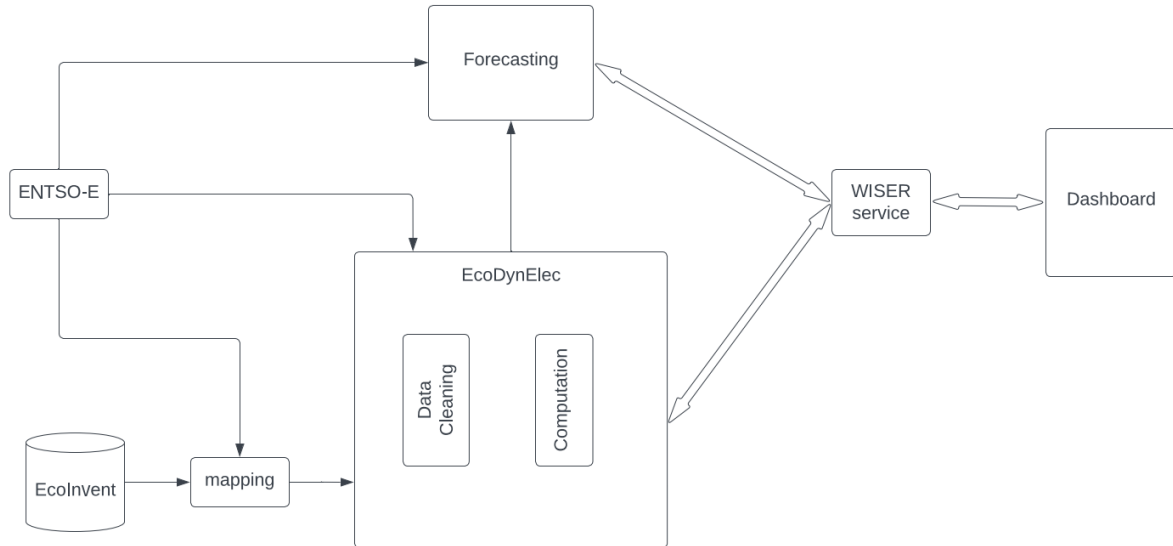
**Figure 15:** Third step of the Activity Diagram



(author's source)

#### 4.4. Architecture for fetching data

**Figure 16:** Architecture for data fetching



(author's source)

To facilitate the development of the software, the architecture illustrated above was designed. The architecture is divided into three parts: Data Sources, Computation and Dashboard.

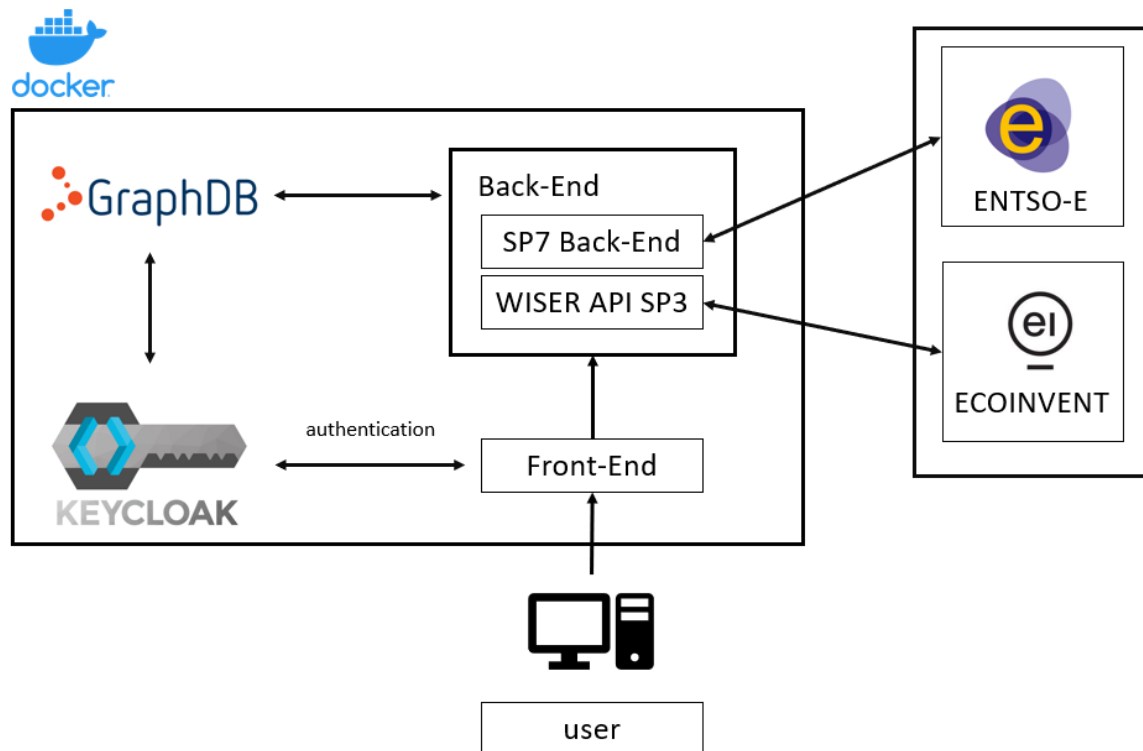
Regarding the data sources, for this application, we used ENTISO-E and the EcoInvent LCA database. Then, for the computation layer, we implemented the EcoDynElec library/module that was built to take ENTISO-E data as input. For the view layer, there is the Dashboard and the WISER service that calls the data processed and calculated with EcoDynElec.

In the first part, data is retrieved from ENTISO-E directly. All the data coming from EcoInvent cannot be computed directly by EcoDynElec module, so we must use a mapping spreadsheet. It uses a methodology to handle the differences or inconsistencies between the data retrieved from ENTISO-E and the LCA database. By doing so, it ensures that the impact calculations are accurate and consistent. Therefore, we can have a more reliable and comprehensive evaluation. Once the library has access to the data, it computes it thanks to the multiple modules available and outputs it to the WISER service.

The WISER service is an API used to make the link between backend and the frontend. In this case the backend is all the computation layer, and the frontend is the dashboard of WISER. On the dashboard the data is displayed following the configuration made by the user.

#### 4.5. Environment Set-Up

Figure 17: Architecture of the application



(author's source)

With the objective of ensuring the functionality of our application, we established a comprehensive setup environment that contains various components. The key elements are Docker, Keycloak, GraphDB, two backend servers (SP7 backend and SP3 WISER API), and a frontend server.

The frontend server works as the user interface, enabling users to interact the web application. To provide an authentication and authorization layer, the frontend was integrated with Keycloak. It ensured secure access to the application, protecting sensitive data and preventing unauthorized access.

GraphDB is used as a central repository for storing data, and thanks to its structure, it allows for an efficient organization of the data and facilitates the handling of it. The back-end servers work as the backbone of the application and played a pivotal role in processing and linking data with the front-end.

In the SP7 back-end, we implemented the EcoDynElec library which enables us to retrieve and process the data coming from ENTSO-E. The SP3 backend allows us to fetch data from Ecoinvent. These servers interact with GraphDB to retrieve or to update data.

Thanks to Docker, we encapsulated each component into separate containers. Docker ensures consistency across different environments and provides isolation between the different components, which prevents conflicts between them. This gives an isolated runtime environment to each container, and it means that if any component encounters an issue, the others are not affected. This enhances stability and reliability.

#### 4.6. Application design

To visualize the dashboard of SP7 effectively, we collaborated with the Product Owner to create mock-ups. After a meeting where the design of the final product was discussed, we designed the mock-ups to provide a clear representation of the desired interface. The mock-ups can be found in the appendices.

Our inspiration for these mock-ups came from studying the web application of SP5<sup>7</sup>. This allowed the Product Owner to easily communicate their requirements and expectations for the project. Additionally, having access to the source code of SP5 enabled us to analyse and understand its implementation, facilitating the process of adapting and integrating it into our own project.

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<sup>7</sup> <https://swiss-production.wiser.ehealth.hevs.ch/home>

## 5. Implementation

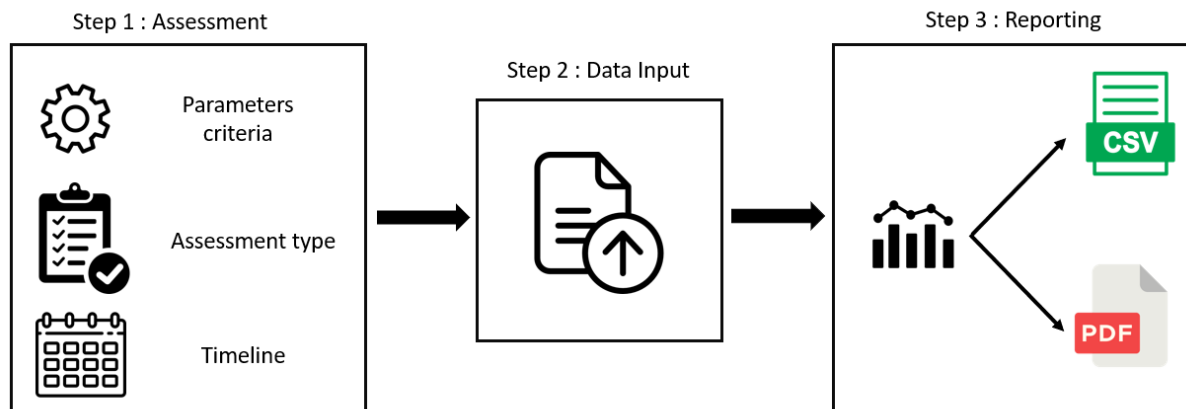
This section is dedicated to the explanation of the application. We start by explaining every feature implemented while justifying its purpose and relevance. Finally, we explore potential areas for future improvements, envisioning the application's growth and enhanced capabilities.

### 5.1. SP7 Dashboard

The home page of our application consists of three distinct steps: Assessment, Data Input, and Reporting.

- **Assessment:** this step serves as the starting point for users, providing an assessment framework where they can choose specific criteria and parameters.
- **Data Input:** in this step, users are presented with intuitive interfaces to input and manage data related to their analysis. They can enter data manually or import it from an external source.
- **Reporting:** the reporting step allows users to generate comprehensive reports and visualizations based on the data provided. Users can generate a PDF or a CSV file based on their needs and requirements.

Figure 18: Diagram to showcase the three steps of the web application



(author's source)

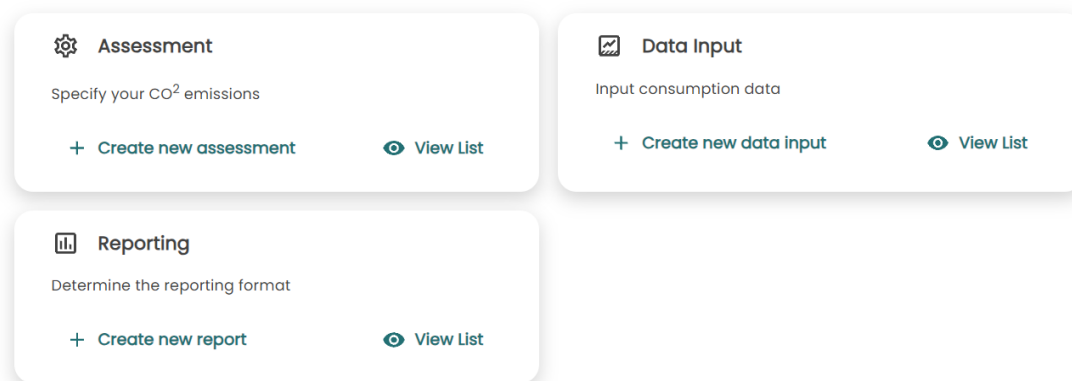
By dividing the application into these three steps, users can seamlessly navigate through the assessment process, input their data efficiently, and generate meaningful reports to drive actionable outcomes.

**Figure 19:** Web Application Home Page

Hi daniel

## Welcome to our experimental prototype

Experience a workflow to calculate your emissions



(author's source)

## 5.2. Step 1

The Step 1 interface, picture below, consists of three main sections: the Header, General Settings, and activities.

**Figure 20:** Step1 - First step of the application where user can choose different parameters

(author's source)

- **Header:** This section (in black), allows users to enter the name of the assessment and provides navigation options for easy movement between steps. Additionally, users can save the assessment progress using the save button, ensuring their work is securely stored.
- **General settings:** In this section (in red), users can choose various information such as the country involved in the assessment, or the specific type of assessment being conducted. These settings provide context and establish the parameters for the analysis.
- **Activities:** Within this section (in green), users can select different categories to analyse emissions. This feature focuses on specific aspects or sectors of interest, facilitating a more targeted and comprehensive evaluation.

By dividing Step 1 into these three parts, the interface provides a clear and organized structure for users to efficiently navigate and chose the necessary information for their assessment. This intuitive design enhances user experience and ensures a smooth progression through the assessment process.



One of the key elements in the general settings is the ENTSO-E countries dropdown list. This dropdown list restricts the selection options to only include countries that are part of the ENTSO-E network. By limiting the choices to ENTSO-E countries, users can easily and accurately specify the relevant countries for their assessment, ensuring that the analysis aligns with the intended scope and context.

The ENTSO-E countries dropdown list provides a streamlined and user-friendly interface, simplifying the country selection process and reducing the chances of errors or inconsistencies.

**Figure 21:** Step1 - Dropdown list for the selection of ENTSO-E countries



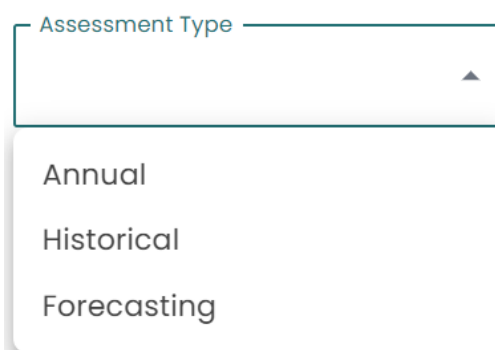
(author's source)

Within this dashboard, users have the option to choose from three types of assessments: Annual, Historical, and Forecasting. These assessment types are conveniently accessible through a dropdown list.

- **Annual Assessment:** This assessment type focuses on analysing emissions data for a specific year. Users can select a desired year from the dropdown list, allowing them to evaluate emissions trends and patterns over a defined annual timeframe. This assessment type is similar to the approach used in the SP5 dashboard, providing consistency and familiarity to users.
- **Historical Assessment:** The historical assessment allows users to analyse emissions data within a specific historical period. By selecting a start date and an end date from the dropdown list, users can examine emissions trends and fluctuations over a defined time range. This assessment type enables users to gain insights into the historical context of emissions data and identify long-term patterns or anomalies.
- **Forecasting Assessment:** With the forecasting assessment, users can generate emissions forecasts for the next 48 hours. This assessment type provides users with a forward-looking perspective, allowing them to anticipate and plan for potential emissions scenarios. By leveraging forecasting capabilities, users can make informed decisions and take proactive measures to manage emissions effectively.

By offering these three assessment types through a user-friendly dropdown list, the dashboard engages users to choose the most appropriate assessment method based on their requirements and objectives.

**Figure 22:** Step1 - Dropdown list to choose the assessment type

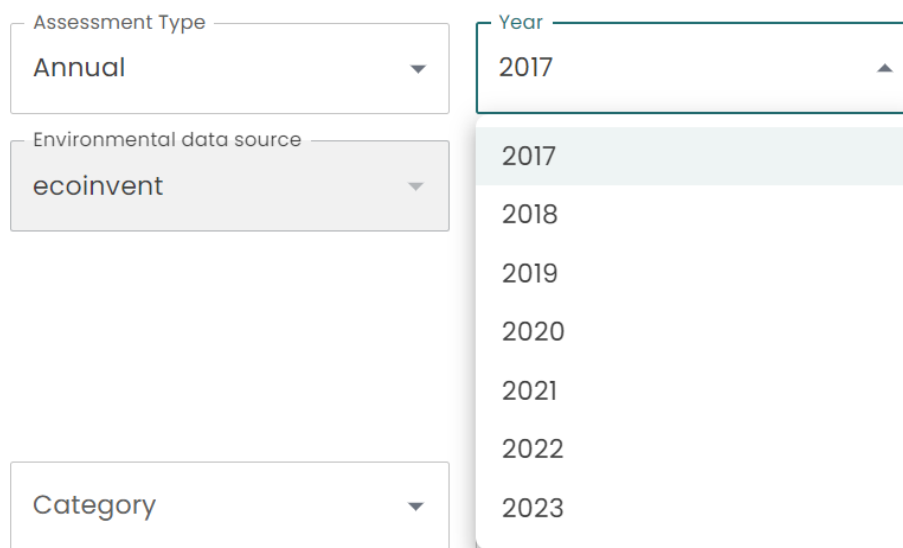


(author's source)

### 5.2.1. Annual Assessment

When selecting the annual assessment, the available years range from 2017 to 2023. This time frame aligns with the data provided by the ENTSO-E platform, ensuring that users can access and analyse emissions data within this specific period.

**Figure 23:** Step1 - Dropdown list to choose the year

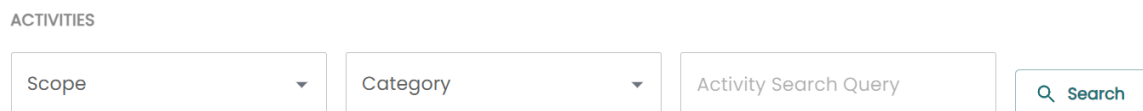


The screenshot shows a web form with three main sections. The first section has a dropdown menu labeled 'Assessment Type' with 'Annual' selected. The second section has a dropdown menu labeled 'Environmental data source' with 'ecoinvent' selected. The third section has a dropdown menu labeled 'Year' which is currently open, displaying a list of years from 2017 to 2023. The 'Year' dropdown is highlighted with a blue border and a blue arrow pointing up. The 'Assessment Type' and 'Environmental data source' dropdowns have a grey background and a blue arrow pointing down. The 'Category' dropdown is also visible below the 'Environmental data source' dropdown.

(author's source)

The product owner has requested that when choosing the annual assessment, the user should have the option to select activities, similar to the SP5 dashboard.

**Figure 24:** Step1 - Activities section



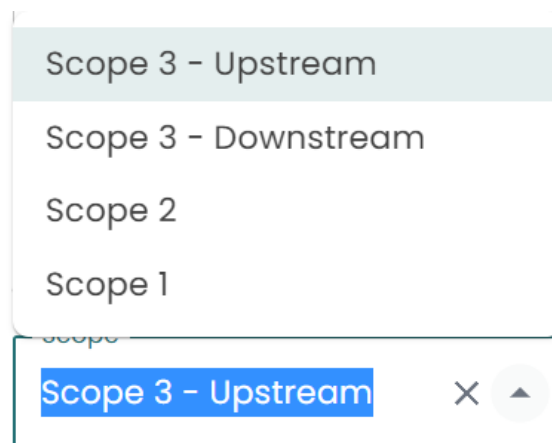
The screenshot shows the 'ACTIVITIES' section of the form. It contains four input fields: 'Scope' with a dropdown arrow, 'Category' with a dropdown arrow, 'Activity Search Query' with a text input, and a 'Search' button with a magnifying glass icon.

(author's source)

In the Scope dropdown list the user can choose different scopes that determine the boundaries within which the greenhouse gas emissions of the organization or product are assessed, with scope 1 being the narrowest boundary and scope 3 being the broadest. (youmatter, 2023)

- **Scope 1:** this scope represents direct emissions from sources that are owned or controlled by the organizations such as company-owned vehicles, on-site combustion of fuels and, industrial processes.
- **Scope 2:** this scope covers indirect emissions resulting from the generation of purchased electricity. Also, it is associated with the production of energy that the company consumes.
- **Scope 3:** this scope includes indirect emissions that result from the company's activities but are not directly controlled by the organization such business travel, purchased goods, waste disposal.

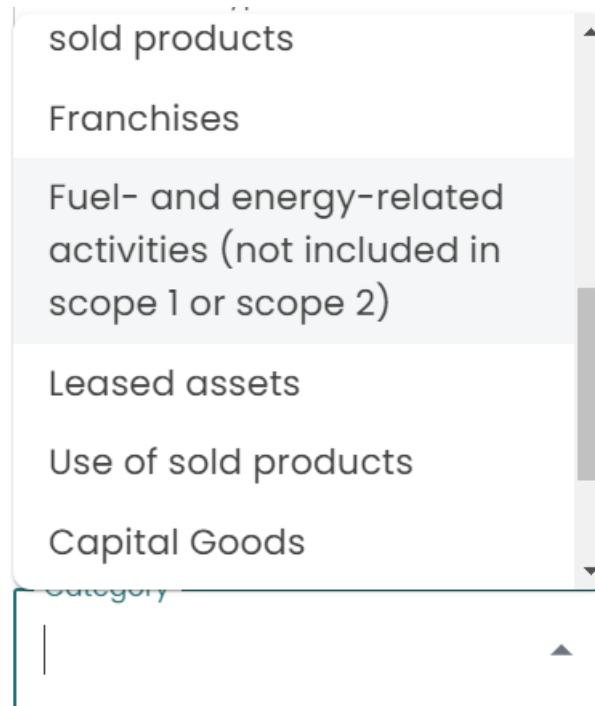
**Figure 25:** Step1 - Dropdown list in the activities section to choose the scope



(author's source)

The category dropdown list is dynamically linked to the selected scope. The available categories vary depending on the chosen scope. Users can select categories that range from fuel and energy-related activities to sold products or their usage. This linkage ensures that the available categories align with the specific scope chosen, allowing users to precisely classify and analyse the emissions associated with different aspects of their organization or product.

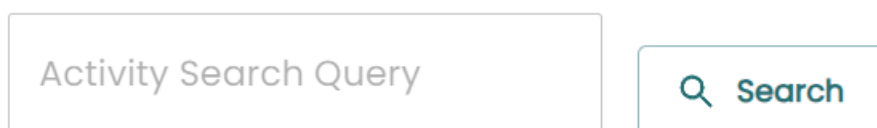
**Figure 26:** Step1 - Dropdown list of categories in the Activities section



(author's source)

The user has the option to enter a query or the name of the activity in order to search and then select one or multiple activities. When clicking on the search button, a list of activities that match the query will be shown. The user can, at that point, select one or multiple exercises from the list. This feature provides the user with a convenient and user-friendly option for selecting activities. This saves time and effort compared to manually scrolling through a long list.

**Figure 27:** Step1 - Activity search bar in the Activities section



(author's source)

### 5.2.2. Historical Assessment

When opting for the historical assessment, the user is provided with the choice to specify the start date and select the end date. It should be noted that the available years for selection range from 2017 to 2023, as explained previously.

**Figure 28:** Step1 - Parameters when choosing an Historical assessment

**GENERAL SETTINGS**


ENTSO-E Countries Switzerland ▼	Assessment Type Historical ▼
Date From 2017 ▼	Date To 2018 ▼

(author's source)

In accordance to the product owner's request, it was deemed necessary to implement a functionality which restricts access to the activities section, as we can see below, when selecting the historical assessment.

**Figure 29:** Step1 - Activities section when choosing an Historical assessment

**ACTIVITIES**

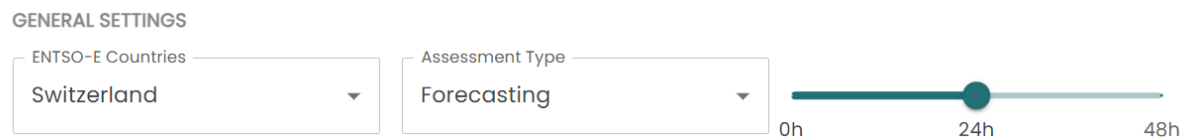
Scope ▼	Category ▼	Activity Search Query	 Search
---------	------------	-----------------------	--

(author's source)

### 5.2.3. Forecasting Assessment

When choosing the forecasting type assessment, a slider comes up. It contains the values, 0h, 24h and 48h. The user can select one of the 3 options.

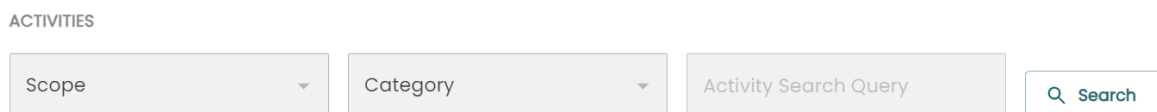
**Figure 30:** Step1 - Parameters when choosing a Forecasting assessment



(author's source)

Similar to the historical assessment, the activities section has been rendered non-selectable in accordance with the requirement specified by the product owner.

**Figure 31:** Step1 - Activities section when choosing a Forecasting assessment



(author's source)

### 5.3. Step 2

The data input management screen, referred to as step 2, is structured into three distinct sections: the navigation header, the current carbon footprint, and the list of activities and user inputs.

- **Navigation Header:** The navigation header serves the same purpose as in step 1, providing users with navigation options.
- **Current Carbon Footprint:** Within the current carbon footprint section, users are empowered to select the temporal resolution and upload a CSV file containing relevant data to facilitate their assessment.
- **List of Activities and User Inputs:** The list of activities and user inputs enables users to input consumption data for various activities, specifying the consumption units accordingly.

**Figure 32:** Step2 - Data Input Management

STEP 1  
Assessment Definition

STEP 2  
Data Input Management

STEP 3  
Reporting Definition

CURRENT CARBON FOOTPRINT

Temporal Resolution ▼

UPLOAD CSV FILE

Drag and drop, or  
click to select a  
CSV file

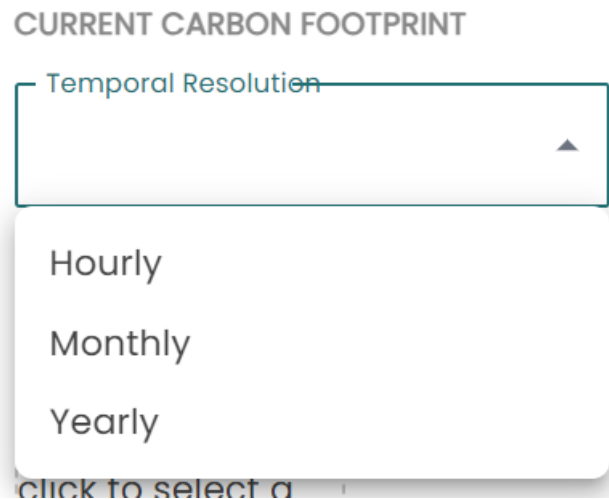
LIST OF ACTIVITIES AND USER INPUTS

(author's source)



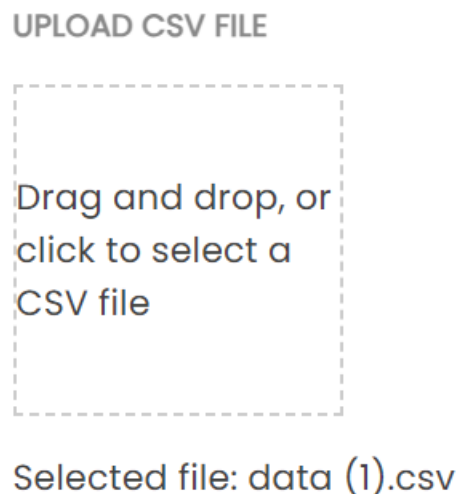
When selecting the temporal resolution, users are presented with three options: Hourly, Monthly, or Yearly. This choice plays a significant role in the subsequent step, step 3, as it determines how the data will be displayed in the graph.

**Figure 33:** Step2 - Dropdown list to choose the temporal resolution



As per the product owner's request, a key feature was implemented to allow users to upload a CSV file containing data related to their energy consumption into a dropbox that can be seen below.

**Figure 34:** Step2 - Section where the user can upload a CSV file



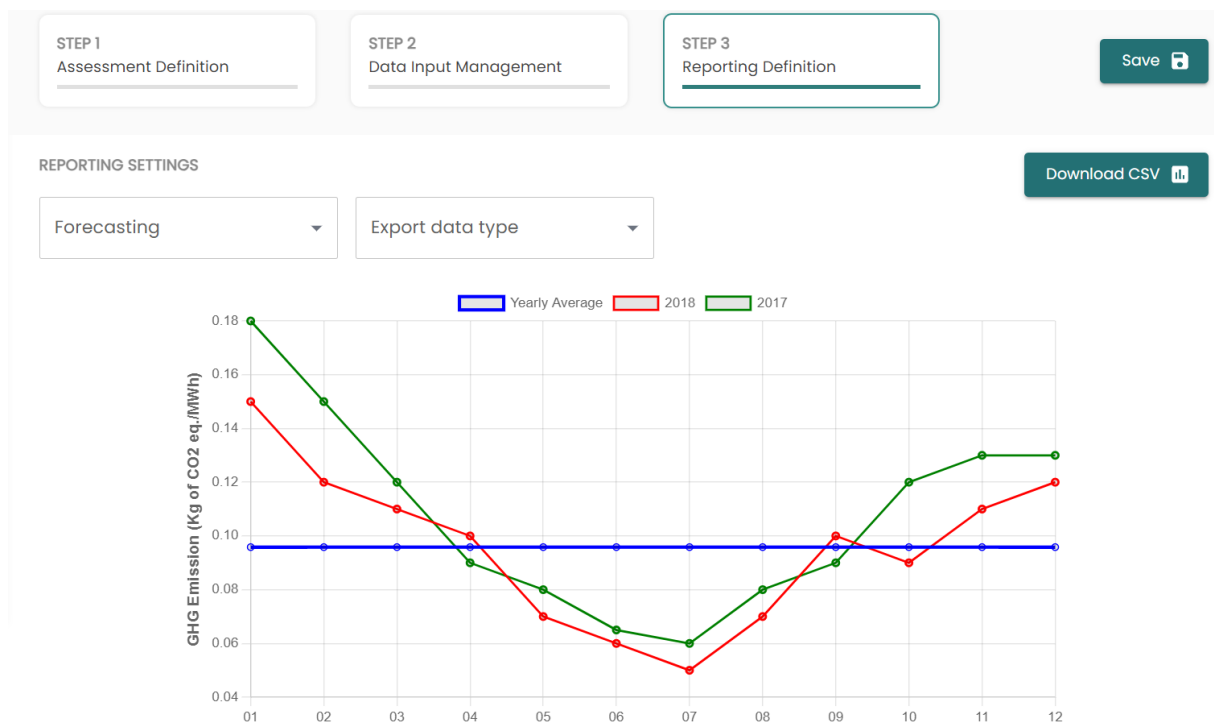
(author's source)

### 5.4. Step 3

The step 3, the reporting definition, is divided into 2 sections: The Navigation Header and the Reporting Settings.

- **Navigation Header:** The Navigation Header, similar to the previous steps, enables users to navigate through the different sections of the application.
- **Reporting Settings:** Within the Reporting Settings section, users are presented with various options. These include forecasting average settings and the ability to select the desired data export format. Additionally, a button is available to generate the report or download the data in CSV format. Users can also interact with the graphical representation of the results, allowing for a more comprehensive analysis.

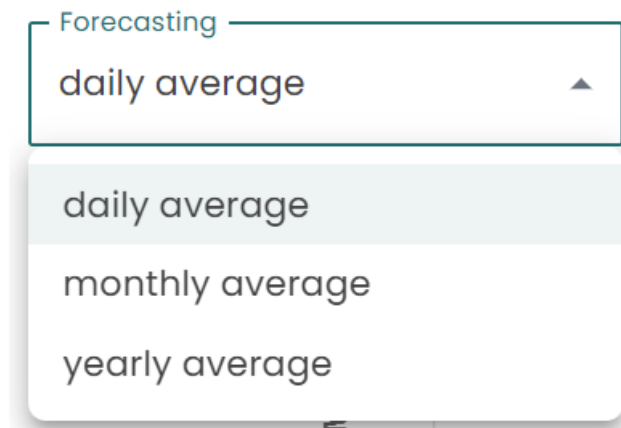
**Figure 35:** Step3 - Reporting Definition



(author's source)

The user is presented with multiple options, namely daily, monthly, and yearly averages. These options allow for a comprehensive analysis of the trend over different time periods.

**Figure 36:** Step3 - Dropdown list to choose the forecasting average



(author's source)

The user is provided with the flexibility to export data in various formats. Within the Export Data Type dropdown list, the user can choose to generate a comprehensive report in PDF format or export the data into a CSV file for further analysis and manipulation.

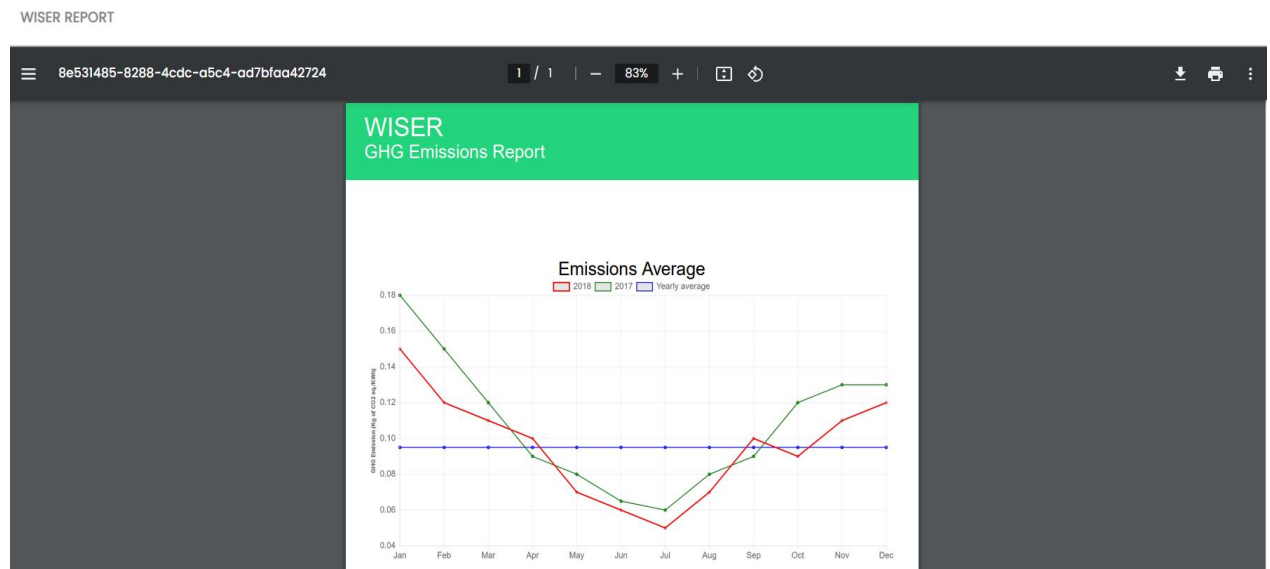
**Figure 37:** Step3 - Dropdown list to choose the export data file type



(author's source)

Below, an illustrative example of a PDF file that is generated can be found. This feature allows users to collaborate and communicate their findings with stakeholders and team members.

**Figure 38:** Example of generated PDF file



(author's source)

Below, an example of CSV file downloaded in which we can find the results based on the type of assessment chosen. In this case an historical assessment. Users can utilize this data to create custom graphs or analyse it using other software of their choice. This flexibility allows users to explore the data further and gain deeper insights for their specific needs.

**Figure 39:** Example of CSV downloaded

	A	B	C	D	E
1	Monthly	2018	2017	Average	
2	Jan	0.15	0.18	0.095	
3	Feb	0.12	0.15	0.095	
4	Mar	0.11	0.12	0.095	
5	Apr	0.1	0.09	0.095	
6	May	0.07	0.08	0.095	
7	Jun	0.06	0.065	0.095	
8	Jul	0.05	0.06	0.095	
9	Aug	0.07	0.08	0.095	
10	Sep	0.1	0.09	0.095	
11	Oct	0.09	0.12	0.095	
12	Nov	0.11	0.13	0.095	
13	Dec	0.12	0.13	0.095	
14					

(author's source)

## 6. Analysis of Results

This section is reserved to a self-evaluation about the application's development process and client's feedback. Here, we explain how the project progressed, our initial expectations, the encountered obstacles, and the strategies employed to overcome them. Additionally, we provide future improvements in order to enhance the application's functionality and meet all the client's wishes and needs.

### 6.1. Results Overview

The main goals of this project revolved around implementing reliable data sets for transparency, particularly ENTSO-E and Ecoinvent, and developing a user-friendly web application capable of conducting LCA calculations using EcoDynElec to fetch and process the necessary data. The ultimate aim was to contribute to the decarbonization of data centres.

To achieve these objectives, we first focused on integrating reliable data sets. We utilized ENTSO-E for gathering electricity consumption data across European countries and Ecoinvent data for conducting life cycle assessments. Merging these two data sets provided us with the essential information needed for accurate LCA calculations. This ensured that the data used in the project was transparent, reliable, and traceable.

Next, we integrated EcoDynElec, a robust LCA calculation tool. EcoDynElec skilfully fetched data from ENTSO-E and linked it with Ecoinvent, creating a seamless and transparent methodology for LCA calculations. By relying on reliable data sources, we ensured the credibility and accuracy of our assessments.

Finally, we focused on developing a user-friendly web interface. The interface was designed to provide easy navigation for users, offering various assessment options, including historical and annual assessments. Our aim was to empower users with an efficient and intuitive platform that displayed the results of their calculations through a visually appealing graph. This approach allowed users to analyse the outcomes effectively and draw meaningful insights from the data.

The current state of the application is a prototype, and it is not yet ready for deployment. Several areas still require improvement and further development to reach the desired level of functionality. As a prototype, it serves as a foundation for future iterations, allowing us to identify potential challenges, gather feedback from users, and refine the application based on their needs and expectations. Additional enhancements and refinements are necessary before the application can be considered deployment ready.

## 6.2. Future Improvements

Unfortunately, not all features that were originally expected could be implemented in the current version of the application. However, there are several key areas for future improvements that can be addressed to enhance the application's functionality and user experience. These include:

**Forecast Assessment Implementation:** one important aspect to consider is the implementation of forecasting capabilities. Due to time constraints, this feature was not fully implemented during the course of this project. However, incorporating forecasting functionality would greatly enhance the application's ability to provide valuable insights and predictions based on historical data. In the application, the frontend was implemented, but the link with the backend could not be made.

**Account Integration with ENTSO-E:** when creating user accounts, a valuable improvement would be to establish a direct link with ENTSO-E. In other words, when a user creates an account on WISER, an account could be also created automatically on the ENTSO-E platform. This integration would streamline the data retrieval process and ensure the availability of up-to-date and accurate information for assessments.

**Transition ENTSO-E data to a Database Storage Solution:** the data fetched from the ENTSO-E is downloaded in a CSV file. While the current implementation relies on storing data in a CSV file, a more ideal approach would involve utilizing a database for data storage, like we do with data coming from Ecoinvent. A database offers greater scalability, efficiency, and data management capabilities. Transitioning to a database-driven storage solution would enhance data organization, retrieval, and overall system performance, providing a more robust foundation for the application.

Addressing these future improvements would significantly enhance the functionality, usability, and overall value of the application, providing users with a more comprehensive and efficient experience.

### 6.3. Difficulties Encountered

During the implementation phase, we faced a few constraints. Some of them, contributed to the inability to fully implement certain aspects of the application, with the first obstacle being the configuration of the setup. A significant amount of time was dedicated to configuring and integrating the existing components of the application such as the Wiser SP3 API or Docker. We had to make sure that there were connections with external data sources like Ecoinvent or GraphDB as well the configuration of Keycloak. This involved ensuring proper compatibility in the system architecture. To overcome this challenge, along with the assistants at the research institute that work in the Wiser project, we were able to configure all the setup correctly and ensure every single component was working.

Another problem that we faced during the implementation was the complexity of integrating EcoDynElec into our system. It required careful consideration and technical expertise. As this module was being incorporated into the application for the first time, additional time was needed to thoroughly understand its functionalities, adapt it to the project's requirements, and resolve any potential integration challenges. A meeting with researchers from HEIG-VD took place, which allowed us to have a better understanding of the module. Also, a detailed documentation of EcoDynElec was provided which helped us to have a better understanding of the way it worked and how to implement it in our project.

Time was a limiting factor throughout the development process. Given the scope of the project and the available timeframe, it was not feasible to complete all the planned features and functionalities. The focus was primarily set on delivering a functional and usable application within the given time constraints.

### 6.4. Product Owner's Feedback

During the final stages of the project, a crucial sprint review was conducted, where we had the opportunity to present the developed web application to the Product Owner and people from EMPA. Their validation and feedback were essential in confirming that the application met their requirements and expectations. Even if all the wished requirements could not be implemented, the Product Owner expressed satisfaction with the functionality, user-friendliness, and transparency of the application, indicating that it aligned well with the envisioned goals.

## CONCLUSION

The objective of this bachelor thesis was to develop a web application that provides effective, reliable, and transparent results for assessing the emissions of energy produced by data centres. The project focused on implementing a robust computation algorithm and utilizing transparent data sources to ensure accurate and trustworthy outcomes. Through an in-depth analysis of existing solutions and comprehensive research, including meticulous data selection and thorough technology evaluation, the aim was to create a user-friendly and informative application.

By successfully implementing the chosen functionalities, the developed web application delivers the expected outcomes and empowers users to make informed decisions based on reliable emissions assessments. The application's ability to generate insightful results and enable trend analysis, particularly in the context of historical assessments, provides valuable insights for organizations in managing their environmental impact.

However, it is important to acknowledge that while the web application showcases significant progress, it is not yet ready for production. Some essential features, such as forecasting assessments and annual assessments, could not be fully realized due to time constraints and challenges encountered during the integration of the EcoDynElec module. These limitations present opportunities for future improvements and advancements.

Potential future developments include enhancing data management by storing the retrieved data using EcoDynElec directly in a database rather than relying on a CSV file. Additionally, establishing seamless integration between WISER and ENTSO-E accounts can further expand the application's capabilities. In fact, to be able to download data from ENTSO-E, the user must create an account in that platform.

In conclusion, the developed web application represents a significant step forward in facilitating emissions assessment for data centres. While further enhancements are possible, the application has successfully achieved its objectives by providing a valuable tool for organizations to analyse their emissions. The project serves as a solid foundation for future development and refinement, contributing to the broader goal of sustainability in the context of data centre energy consumption.



## PERSONAL EXPERIENCE

I thoroughly enjoyed working on this project as it provided me with an opportunity to explore a subject in great depth. The structured approach, extensive research, and thoughtful decision-making process were invaluable in my academic development. During my three years at HES-SO, I have been able to put every topic I learned into practice, and this project served as a culmination of that knowledge.

I had the chance to collaborate with experienced scientists who allowed me to gain valuable insights and expand my understanding of the subject matter. Working with a team from the research institute of HES-SO further gave me a glimpse into the workings of real-world companies.

Following the SCRUM methodology, I successfully organized my work and recognized the importance of effective communication during meetings. This allowed me to better comprehend the needs of clients and seamlessly integrate their requirements into our project.

Overall, this project has been a truly enriching experience, and I take great pride in the work I have accomplished.

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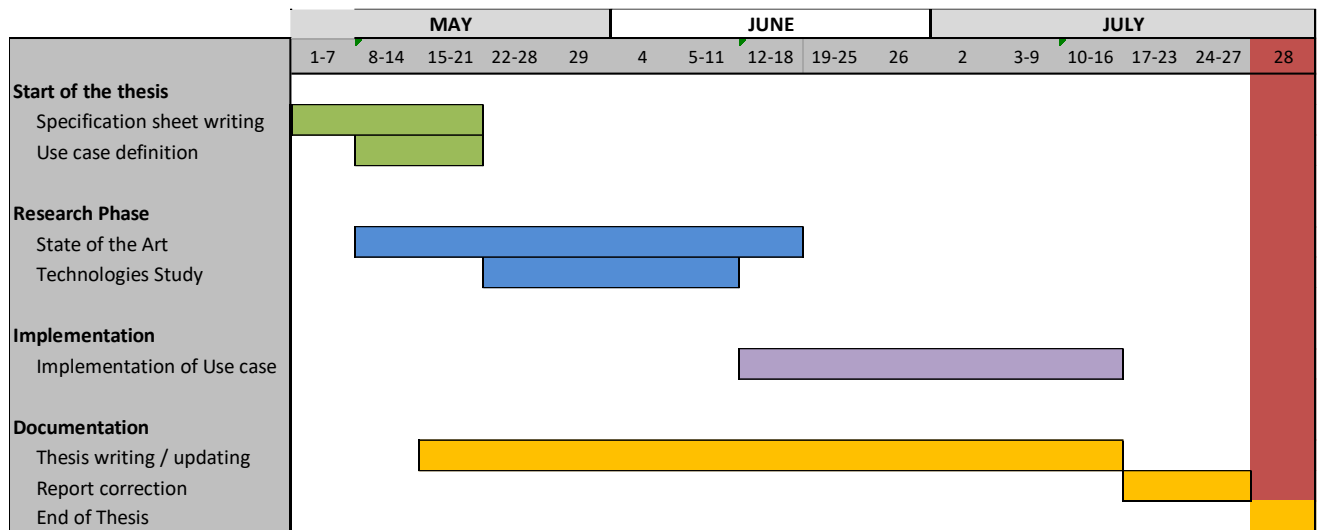
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## Appendix I: Project Planning and Progress



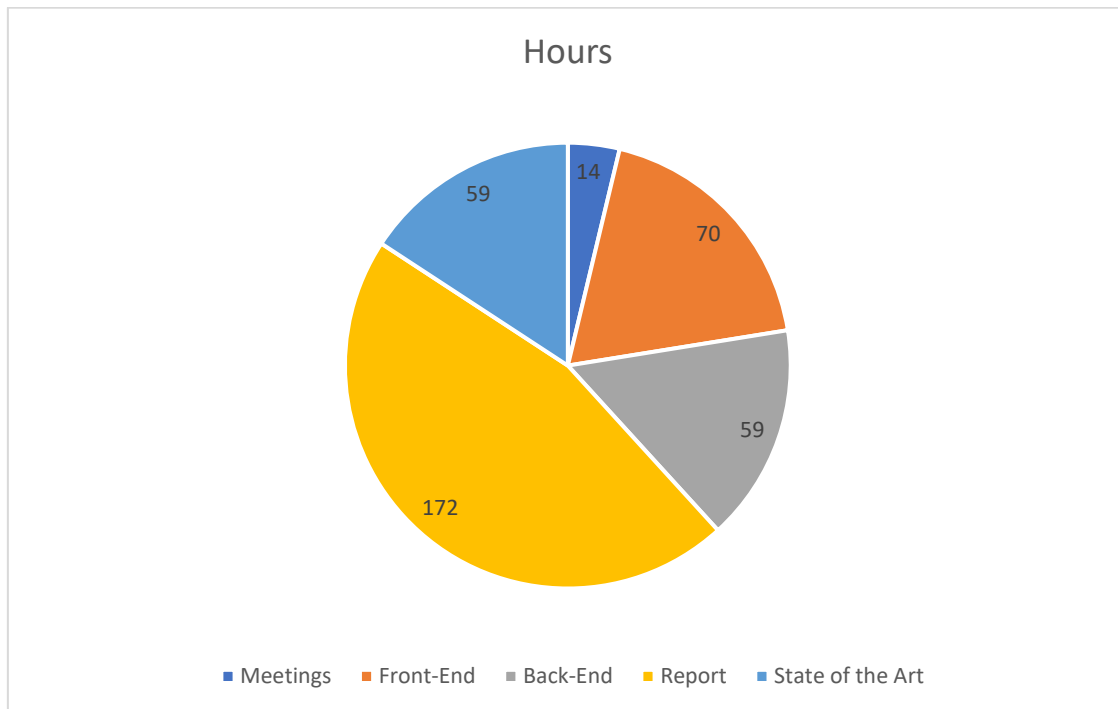
During the initial planning phase, four key axes were established: the Start of the Thesis, Research Phase, Implementation, and Documentation.

- **Start of the Thesis:** This phase involved identifying the use case and defining the overall structure of the thesis.
- **Research:** This intermediate phase encompassed an in-depth exploration of the current state of the art, including an analysis of existing technologies and a comparative study with other relevant approaches.
- **Implementation:** In phase, the use case was programmed and implemented following the Scrum methodology, ensuring an iterative and collaborative approach.
- **Documentation:** This final phase involved completing the thesis report and addressing any necessary corrections to ensure the overall quality and coherence of the work.

By following this comprehensive framework, the project was able to progress through each phase systematically, leading to a successful completion of the bachelor thesis.

## Appendix II: Logbook

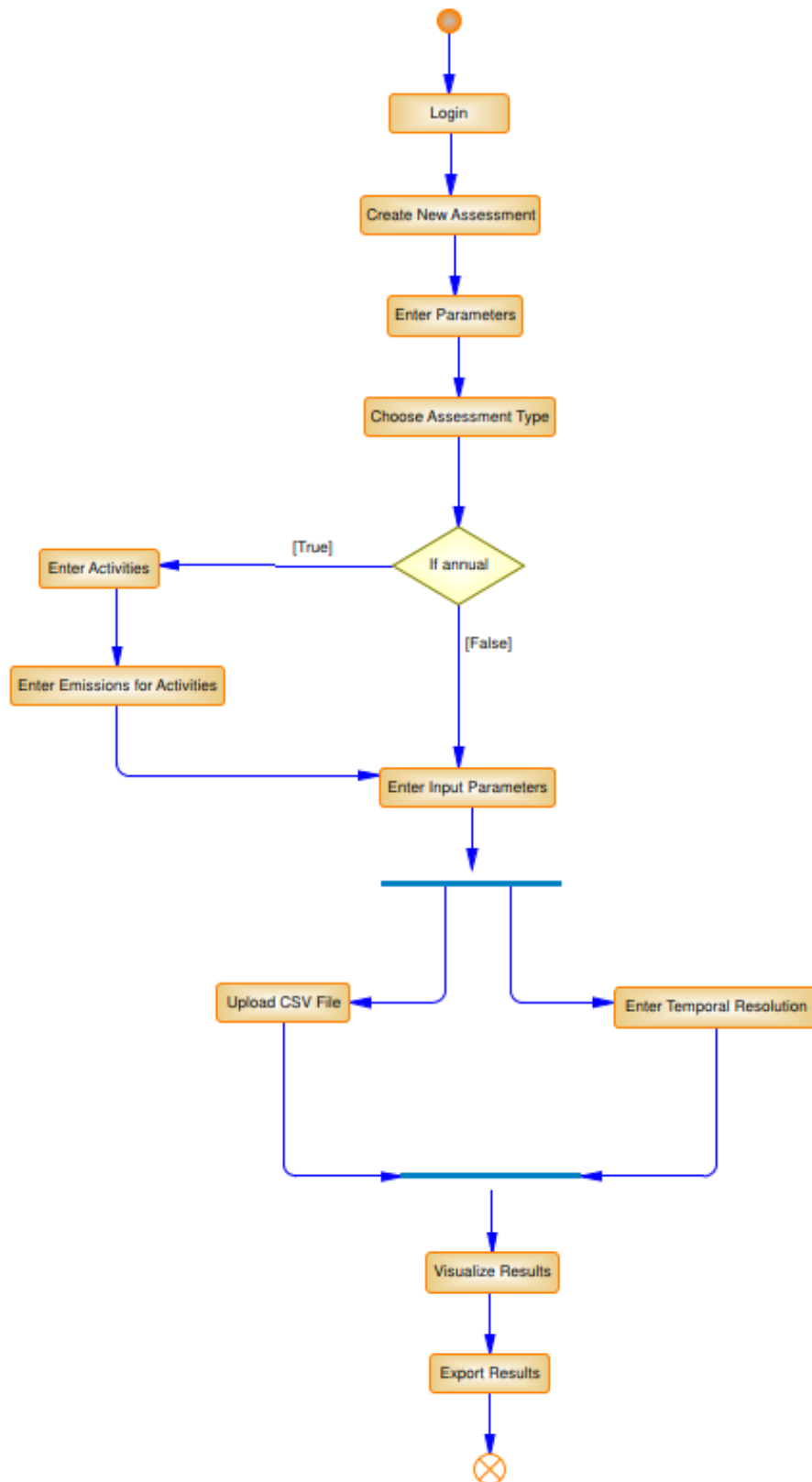
For this project, the initial expectation was to dedicate 360 hours. However, we ended up investing a total of 374 hours to ensure that we could deliver a comprehensive and successful outcome. This extra effort allowed us to address additional aspects and challenges that arose such as understanding the EcoDynElec documentation, as well as the setup and configuration process.



Throughout the course of this project, we encountered various tasks that demanded substantial time and effort. The most time-consuming aspect was undoubtedly the meticulous process of writing the report thesis, which accounted for a total of 172 hours. Next, we dedicated 129 hours to the implementation of the tools and the development of the web application, ensuring that all functionalities were thoroughly integrated and refined. The analysis and research in the state of the art required careful examination, totalling 59 hours of our project timeline.

Additionally, we participated in important meetings such as sprint reviews and follow-up meetings, which added up to 14 hours, ensuring effective communication and progress tracking. By diligently allocating our time and effort to these tasks, we aimed to deliver a comprehensive and well-executed project outcome.

## Appendix III: Full Activity Diagram





## Appendix IV: Personal Product Backlog

US Nr.	Theme	As an/a ...	I want to ...	Priority	Status	Story Points	MoSCoW
1	Preparation	Developer	Prepare Work Environment	1000	DONE	8	MUST
2	Preparation	Developer	Create Architecture	900	DONE	3	MUST
3	Preparation	Developer	Create Product Backlog	800	DONE	5	MUST
9	Frontend	Developer	Get base Dashboard SP5	750	DONE	2	MUST
8	Frontend	Developer	Create Mock ups	740	DONE	5	MUST
4	Backend	Developer	be able to download ENTSO-e data	700	DONE	13	MUST
5	Backend	Developer	be able to make link with EcoDynElect	600	DONE	13	MUST
6	Frontend	Developer	Display simple Data	500	DONE	8	MUST
7	Frontend	Developer	Display Data on a chart	200	DONE	5	MUST
10	Frontend	Developer	Change header to set name	90	DONE	2	MUST
11	Frontend	Developer	Add countries drop down list	88	DONE	2	MUST
12	Frontend	Developer	Set type of assessment	87	DONE	2	MUST
13	Frontend	Developer	Add Pop-up from to end date in Historical assessment	86	DONE	5	MUST
14	Frontend	Developer	Add Years for ANNUAL assessment	85	DONE	3	MUST
15	Frontend	Developer	Freeze Activities Section if FORECASTING	83	DONE	5	MUST
16	Frontend	Developer	Add drop down menu with Time scales if HISTORICAL and Forecast	80	DONE	5	MUST
18	Frontend	User	Export an image of the report	79	DONE	8	MUST
17	Frontend	User	Can Upload a CSV file with data	78	DONE	13	Could
19	Frontend	User	Export as a CSV file	70	DONE	13	Could
20	Backend	Developer	Implement Forecasting assessment	69	REJECTED	13	Could

Above can be found my personal product backlog.

1. **Theme:** In the first column, the "Theme," we categorize user stories based on their focus. They are classified as preparation, frontend, or backend tasks, depending on the area of development they belong to.
2. **User Story:** A user story is a brief, user-centric description of a particular functionality from an end-user perspective. It follows the format "As a [type of user], I want [an action or functionality], so that [benefit or outcome]."
3. **Priority:** The "Priority" column indicates the importance of each user story in relation to others. Priorities are typically assigned as high, medium, or low, reflecting the urgency and significance of implementing the feature.
4. **Status:** The "Status" column tracks the progress of each user story. It is updated to reflect whether the story is "Implemented and Approved" or "Not Implemented" yet.
5. **Story Points:** "Story Points" provide a relative estimation of the effort required to implement each user story. They help the development team understand the complexity and size of the task.
6. **MoSCoW:** MoSCoW stands for Must, Should, Could, and Won't. In this column, user stories are categorized based on their level of importance and priority:

## Appendix V: Product Backlog

Only SP7							
1	<input checked="" type="checkbox"/>	Header	Name	Edit assessment name and site name (data center)	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	DONE
1	<input type="checkbox"/>	Assessment Definition (AD) screen	ENTSO-E countries	Add ENTSO-E only countries	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	DONE
2	<input type="checkbox"/>	Assessment Definition (AD) screen	Type of assessment	Add historical, annual and forecasting	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	DONE
3	<input type="checkbox"/>	Assessment Definition (AD) screen	Date	Add pop-up from to end date if HISTORICAL assessment	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	DONE
4	<input type="checkbox"/>	Assessment Definition (AD) screen	Date	Add slider (0-48h) if Forecasting	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	DONE
5	<input type="checkbox"/>	Assessment Definition (AD) screen	Date	Add years for ANNUAL assessment	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	DONE
6	<input type="checkbox"/>	Assessment Definition (AD) screen	Activities section	Block/Freeze if historical or forecasting assessment	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	DONE
1	<input type="checkbox"/>	Data Input Management (DIM) screen	Temporal Resolution	Add drop down menu with scales ( yearly, hourly, monthly) if HISTORICAL or FORECAST	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	DONE
2	<input type="checkbox"/>	Data Input Management (DIM) screen	Input CSV file	User can upload a CSV file with data	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	DONE
1	<input type="checkbox"/>	Reporting Definition (RD) screen	Export output pdf	add button to generate pdf report	<input checked="" type="checkbox"/>	<input type="checkbox"/>	DONE
2	<input type="checkbox"/>	Reporting Definition (RD) screen	Export output csv	add button to generate CSV report	<input checked="" type="checkbox"/>	<input type="checkbox"/>	DONE
3	<input type="checkbox"/>	Reporting Definition (RD) screen	graph	Show Average based on choice if Forecasting	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	DONE

The product backlog, illustrated above, was made in collaboration with the Product Owner. This is a section of the product backlog for all the WISER dashboards. The product owner has access to it and can make changes or add new features to implement.

It is divided by SP, and above, only the user stories for the SP7 are shown. Each section of the application, including the Header, Assessment Definition Screen, Data Input Screen, and Reporting Definition Screen, has a dedicated column to list the user stories and their corresponding actions. There is a column for the name of the user story as well as its action. The backlog also includes a column to indicate the status of each user story, specifying whether it has been implemented and approved or not. This allows us to track the progress of each feature and prioritize them based on their importance and urgency.

## Appendix VI: mock-ups

**WISER PROJECT**  
 Home  
 Specification  
 Reporting

EN - English  
 Kaja Kristensen  
 Universal Company

Collapse Sidebar

New assessment name | production site name

Shared with: User 1

STEP 1  
 Assessment pathway

STEP 2  
 Input data management

STEP 3  
 Formatting outcome

Save and continue

GENERAL SETTINGS

Country ENTSO-E

Assessment Type

Date

Assessment framework

Environmental data source

Operational Control

LCIA Method

ACTIVITIES

Scope

Category

Search activity type

+ Add new activity

Category	Activity	Scope	Description
----------	----------	-------	-------------

Activities per page: 10 1-10 of 0

**WISER PROJECT**  
 Home  
 Specification  
 Reporting

EN - English  
 Kaja Kristensen  
 Universal Company

Collapse Sidebar

New assessment name | production site name

Shared with: User 1

STEP 1  
 Assessment pathway

STEP 2  
 Input data management

STEP 3  
 Formatting outcome

Save and continue

GENERAL SETTINGS

Country ENTSO-E

Forecasting

FORECAST REACH [MAX. 48 H]  
 24 H

Assessment framework

Environmental data source

LCIA Method

Operational Control

ACTIVITIES

Scope

Category

Search activity type

+ Add new activity

Category	Activity	Scope	Description
----------	----------	-------	-------------

Activities per page: 10 1-10 of 0

Temporal resolution  
**WISER** PROJECT

- Home
- Specification
- Reporting

Kaja Kristensen

Collapse Sidebar

**WISER** PROJECT

- Home
- Specification
- Reporting

Kaja Kristensen

Collapse Sidebar

LCA Production 1 v.1 | Untersiggenthal | 2020

Shared with: User 1

STEP 1  
Assessment pathwaySTEP 2  
Input data managementSTEP 3  
Formatting outcome

Back

Save and continue

CURRENT CARBON FOOTPRINT

7.3125 t  
PRODUCT  
Polyethylene production2.4375 t  
MARKET ACTIVITY  
Market for electricity

Temporal resolution

Input CSV

Rows per page: 10 1-3 of 3

LCA Production 1 v.1 | Untersiggenthal | 2020

Shared with: User 1

STEP 1  
Assessment pathwaySTEP 2  
Input data managementSTEP 3  
Formatting outcome

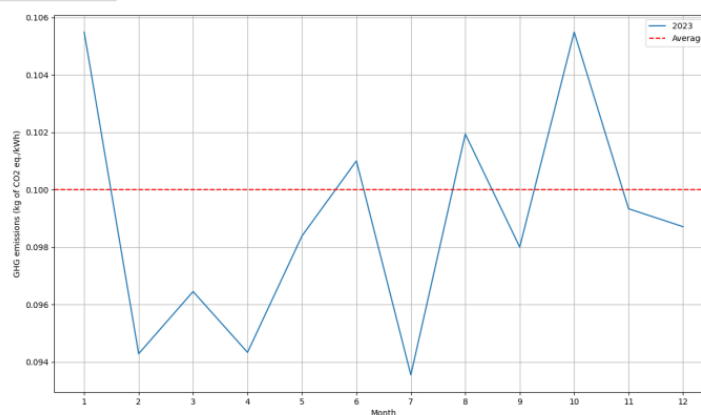
Back

Save

Save report

Download report

REPORT SETTINGS

Forecasting average  
Daily averageExport figura data type  
JPEG

Export

Rows per page: 10 1-5 of 13

## **Declaration of author**

I declare, by means of this document, that I have completed the attached Bachelor's thesis on my own, without any assistance other than that duly indicated in the references, and that I have used only the sources expressly mentioned. I will not provide any copies of this report to a third party without the joint authorization of the program coordinator and the professor in charge of supervising the bachelor's thesis.