Open Data for Circular Economy Monitoring

A Case Study into Electric Vehicles

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By

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Preface

The completion of my master's thesis signifies a major step in my academic journey. I am deeply thankful and appreciative. This work is the outcome of two years of devotion, study, and persistence. Its accomplishment is due to the invaluable support and guidance of many people who have significantly contributed to my academic and personal growth.

I want to start by thanking my amazing supervisors and advisor, Anneke Zuiderwijk - van Eijk, Boriana Rukanova, and Jaco Quist. Your constant commitment to encouraging my intellectual growth, your invaluable insights, and your tireless dedication to the pursuit of knowledge have been the driving force behind this work. I am extremely grateful to each of you for your guidance, patience, and belief in me.

To my friends, your unwavering support has been a constant source of strength throughout this journey. Your encouragement, understanding, and love have provided me with the motivation to overcome the challenges and obstacles that arose along the way. Thank you to my longstanding friends for always being there, and to my new friends, thank you for all the wonderful experiences we've shared.

My family, in particular, deserves special recognition. They have been the bedrock of my life, offering unconditional love, encouragement, and unwavering support. Your sacrifices and unwavering belief in my potential have given me the strength to pursue my dreams. Your wisdom, guidance, and relentless encouragement have been my guiding light. Your support and belief in me have been a constant source of inspiration.

In particular, I would like to extend a special thanks to a dear friend who has been a constant source of inspiration and motivation. Bertha, your unwavering belief in me, your encouragement during moments of doubt, and your willingness to stand by my side through all the tough times, have been -and will be very valuable to me. Your friendship is a treasured gift, and I am profoundly grateful for your presence in my life.

This thesis represents the collective effort and dedication of many individuals, and while it is impossible to acknowledge everyone individually, please know that your contributions, whether large or small, have not gone unnoticed. I am indebted to the academic community, colleagues, and mentors who have enriched my understanding of the subject matter.

As I conclude this preface and embark on the next chapter of my academic and professional life, I carry with me the knowledge that this work would not have been possible without the support and guidance of those mentioned and many others. Your belief in my potential has been a driving force, and I am humbled by your generosity. I hope that this thesis, in its own small way, can contribute to our collective pursuit of knowledge and the betterment of society.

With deepest gratitude,
Y. Emre Torlak
Delft, September 2023

Executive Summary

Introduction: The global shift towards a circular economy aims to optimize resource use, minimize waste, and promote sustainable growth. Monitoring this transition is vital, and open data presents itself as a pivotal tool. This research explores the potential of open data in monitoring circular economy objectives, focusing on electric vehicle batteries.

Research Objective and Methodology: The study's primary goal was to uncover the potential of open datasets for monitoring circular economy goals. A framework was developed, drawing from existing literature and expert insights. This framework was then applied to the context of Electric Vehicle (EV) batteries, utilizing three distinct datasets. Validation interviews further refined the framework and the insights from the EV battery case study.

Conceptual Framework: The research introduced a comprehensive framework designed to evaluate the potential of open datasets in monitoring circular economy objectives. This framework was meticulously crafted by integrating insights from existing literature and expert opinions. Structured around the pivotal dimensions of open data attributes and circular economy principles, the framework delves into aspects such as data accessibility, quality, usability, material flows, resource evaluation, and stakeholder engagement. Serving as a robust tool, the framework offers a systematic approach to assess the compatibility, depth, and versatility of open datasets in the context of the circular economy, ensuring a holistic analysis that bridges the gap between data transparency and sustainable practices.

Case of Electric Vehicle Batteries: The case study on electric vehicle batteries provided a practical lens to test the framework. Three datasets from different sources, namely RDW, Eurostat, and the BatteryPass, were analyzed. The datasets revealed insights into material flows, resource consumption, and environmental impacts associated with the EV battery ecosystem. The RDW dataset, for instance, highlighted the importance of tracking at the vehicle level, while the BatteryPass project showcased potential in monitoring battery lifespans and end-of-life scenarios. The case study illuminated the framework's applicability, revealing usability, opportunities and constraints in the datasets.

Discussion: The research employed mixed methods tailored to each phase. A literature review identified key attributes for analysis, while expert interviews filled gaps overlooked in the literature. The framework was structured around the key dimensions of open data and circular economy principles. The open data division examined data accessibility, quality, and usability. The circular economy division delved into material flows, resource evaluation, product lifespan, end-of-life considerations, and stakeholder engagement.

Conclusion: The research culminated in a comprehensive framework for evaluating open data's potential in circular economy monitoring. The framework's elements spanned both open data attributes and circular economy dimensions. The methodology integrated these elements, refined through expert interviews, and validated using the electric vehicle battery case study. Practical contributions included guidance for governments and policymakers, insights for industries, and a focus on stakeholder engagement. Future research directions include enhancing the framework's comprehensiveness, creating an interactive catalog platform for open datasets, and broadening its scope.

The research journey unveiled the intricate relationship between open data and circular economy monitoring. The developed framework, validated through the electric vehicle battery case study, stands as a testament to the synergy between academic rigor and practical applicability. However, the journey is ongoing, with the identified limitations paving the way for future exploration. The potential of open data, when effectively harnessed, can revolutionize sustainability approaches, driving the world towards a more circular future. This research serves as a foundational step, illuminating the path for future endeavors in open data and circular economy monitoring.

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1. INTRODUCTION

The circular economy is an economic and industrial model that has the objective of maximizing the usage of resources while minimizing waste by promoting the reuse, repair, and recycling of products and materials (Ellen MacArthur Foundation, 2013). In parallel with the emphasis on sustainability in recent years(United Nations, n.d.-b; Vila et al., 2021), the circular economy -as it is a more sustainable system(Geissdoerfer et al., 2017) has gained significant importance.

Open data refers to information that is freely available for anyone to access, use, modify, and share without any restrictions or limitations(Ayre & Craner, 2017; Rouder, 2016; Zuiderwijk, Janssen, et al., 2012). The use of open data offers numerous benefits, including increased transparency, better decision-making, and improved public engagement (Zuiderwijk & Janssen, 2014). Therefore, open data has the potential to improve the monitoring process towards circular economy objectives. Furthermore, it is important to investigate the specific aspects of open data that contribute to its potential benefits in the context of circular economy monitoring. This exploration will enlighten the purposes for which open data can be effectively utilized in monitoring circular economy objectives.

Transparency is a key aspect of open data(O'Hara, 2012), allowing stakeholders to track the flow of resources, materials, and waste throughout their lifecycle. This visibility enhances monitoring and assessment practices related to resource usage, waste generation, and recycling rates. By using data on resource flows, material usage, waste generation, and other relevant factors openly available, governments and policymakers can better understand the patterns and trends of the circular economy. As transparency is a challenging factor in a circular economy(Zhang et al., 2021), using open data could be beneficial to address the challenge. Moreover, this understanding can inform the development of circular economy strategies and initiatives that aim to maximize resource efficiency, reduce waste, and promote the sustainable use of materials.

Data sharing, another important characteristic of open data(Reichman et al., 2011), can enable collaboration among diverse actors involved in the circular economy. It facilitates the exchange of data and information, fostering innovation, informed decision-making, and the development of sustainable practices.

Standardization is prioritized in open data initiatives, ensuring consistency and comparability of data across different sources and sectors. This standardization enables accurate benchmarking, performance evaluation, and identification of best practices across industries and regions.

However, the monitoring of circular economy objectives presents significant challenges, a lack of clarity regarding how open data can be effectively conceptualized, applied, and evaluated in the context of circular economy objectives. Therefore, research that reveals the potential of open data for circular economy monitoring, will be beneficial for literature.

1.1. Research Background and Core Concepts

This subsection provides an exploration of the research background and fundamental concepts underlying the intersection of the main two domains of this research, circular economy, and open data. By presenting the research background and core concepts, this section sets a base for an understanding of between open data and the circular economy.

1.1.1. Circular Economy

The circular economy is an economic paradigm that aims to create a regenerative and sustainable system by minimizing waste and maximizing the use of resources (EMF, 2013). Despite the concept not being novel (Geissdoerfer et al., 2017), there has been a notable increase of research on the circular economy in the last decade, coinciding with the increased emphasis on sustainability by the United Nations (UN), European (EU), and governments.

Geissdoerfer et al. (2017) have comprehensively examined the key components of the circular economy and its potential as a new sustainability paradigm. Moreover, they redefined circular economy as "…a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops" (p. 766). The circular economy involves shifting from the traditional linear model of "take-make-dispose" to a model that focuses on a regenerative system (Geissdoerfer et al., 2017) . Therefore, there is a potential to create and/or new business opportunities, reduce environmental impacts, and promote social and economic development. However, the complete implementation of the circular economy requires a more holistic approach that takes into account the interconnections between economic, social, and environmental factors (Geissdoerfer et al., 2017). The research from Korhonen et al. (2018), emphasized the importance of taking a holistic approach to circular economy as it involves complex interdependencies between economic sectors and environmental systems.

The Ellen MacArthur Foundation introduced a diagram (Figure 1) for the CE concept, also known as the Butterfly diagram, which depicts the functioning of a circular economy, and shows the perpetual movement of materials in two distinct cycles: the technical and the biological(Ellen MacArthur Foundation, n.d.-b). In the technical cycle, products and materials are conserved through strategies such as repairing, reusing, recycling, and remanufacturing. In contrast, the biological cycle focuses on ensuring that nutrients from biodegradable substances are returned to the environment to facilitate nature's regeneration.

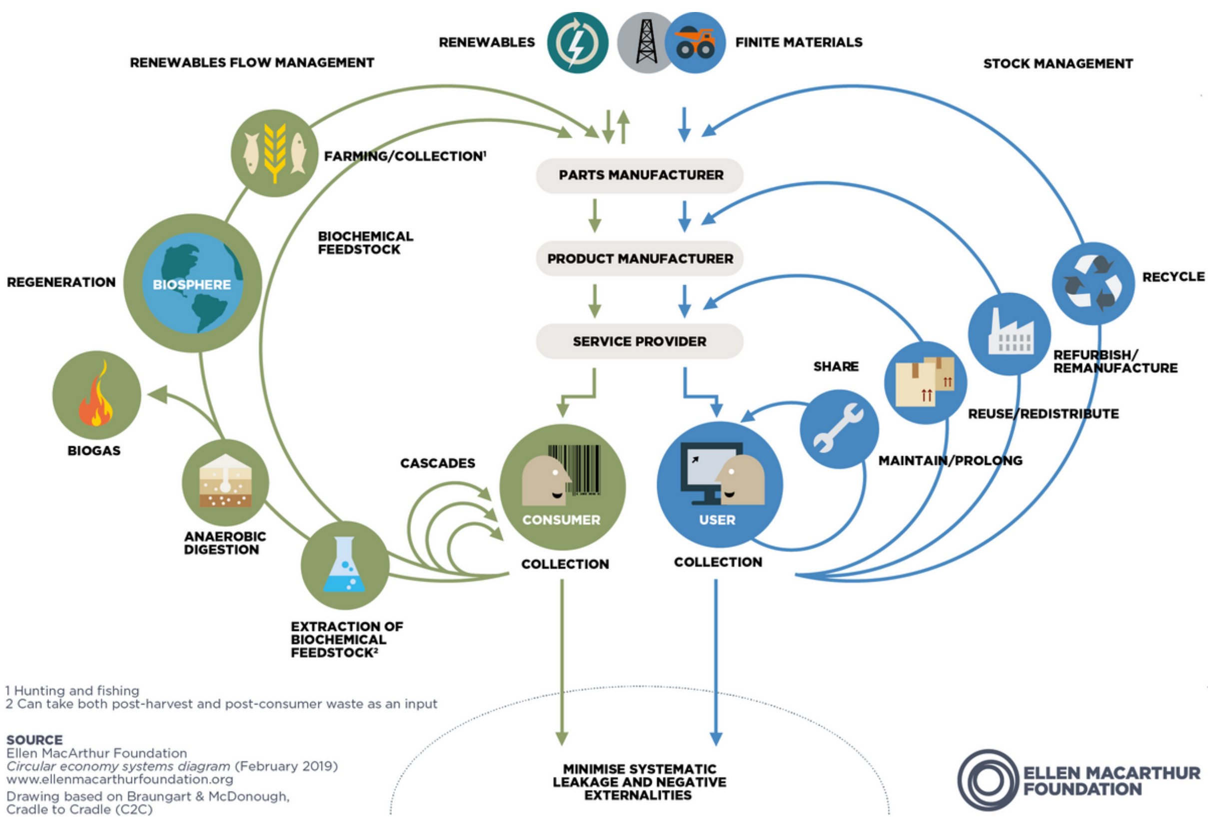


Figure 1: Butterfly Diagram (Ellen MacArthur Foundation, n.d.)

1.1.2. Open Data

Open data is a concept that involves making data accessible to anyone without restrictions on its use, sharing, or distribution. “Open” in data context is defined as “anyone can freely access, use, modify, and share for any purpose”(p.1) by Open Knowledge Foundation (n.d.-b). It has become increasingly important in the digital age as more data is created, collected, and analyzed. Open data can have various forms, including government data, scientific data, educational data, and other data sources.

Open data has several benefits, including promoting innovation, increasing public engagement, and improving decision-making(Zuiderwijk, Janssen, et al., 2012). Moreover, using open data can also lead to cost savings, as it can reduce duplication of efforts and support evidence-based policymaking (Ayre & Craner, 2017; Rouder, 2016). Despite the potential benefits, there are also adoption barriers and myths that may hinder the implementation of open data initiatives. For example, some stakeholders may resist sharing data due to concerns about contradicting results or data misuse (Janssen et al., 2012).

Government can use open data to improve governmental operations and services, such as by tracking performance metrics or analyzing public feedback (Ayre & Craner, 2017). However, using and/or releasing open data can also pose challenges for governments, such as ensuring data quality and addressing privacy and security concerns. To address these challenges, governments can adopt various policies and strategies to promote open data, such as establishing data governance frameworks, creating open data portals, and providing training and support to data users (Ayre & Craner, 2017; Janssen et al., 2012).

1.2. Identification of Literature Gap and Research Objective

As previously stated, the concepts of circular economy and open data have gained significant attention in literature and business practices. While their individual applications are well established, the intersection of these two concepts is an emerging area of research. On the other hand, life cycle assessment (LCA) is a scientific methodology that follows standardized guidelines ISO 14,040–14,044:2006 to evaluate the environmental impacts associated with the entire life cycle of a product or service. It provides valuable insights into the environmental consequences of implementing circular economy (CE) strategies (Peña et al., 2021). Despite its inherent limitations (Ellen MacArthur Foundation, n.d.-a), LCA is extensively utilized in various studies related to the circular economy. In order to ensure comprehensive coverage of relevant literature, LCA and open data relation are included. Detailed search procedure and the table with the articles are presented in Appendix 1.

Pagnon et al. (2020) primarily focus on life cycle assessment (LCA) in the construction industry and highlight the lack of open-access databases for conducting LCA. They emphasize that currently, only experts with access to licensed data are able to perform LCA. Their study underscores the need for open data in LCA and identifies the restricted accessibility of data as a significant gap in the practice. Similarly, Angeles et al. (2019) also concentrate on LCA in the construction industry and mention open data as a prioritized resource. However, unlike Pagnon et al. (2020), they do not provide an in-depth explanation of the context of open data in LCA. Consequently, a comprehensive analysis connecting open data and LCA in the construction industry is required to bridge this gap and provide a clearer understanding of the role and implications of open data in LCA for the construction sector.

Building upon the construction industry focus, Brockmann (2019) examines the role of open data as part of the German international data network called the "Open Data Network for Sustainable Building" for LCA purposes. While this study provides a specific context for open data in LCA, it falls short in providing a broader analysis of open data's potential and impact on LCA in the construction industry.

Shifting the focus to the food industry, Hedin (2018) explores the potential benefits of an open LCA database for food, which is created through crowdsourcing. However, Hedin does not provide an extended analysis of open data itself. Consequently, there is a gap in understanding the specific advantages and challenges of open data in the context of LCA.

Similarly, Ghose et al. (2019) examine the BONSAI Project, which focuses on an open dataset for product footprinting. While this study investigates the use of open data in the context of product footprinting, it does not provide a broader analysis of open data's potential for LCA. Similarly, Jayapal & Kumaraguru (2018) propose an architecture for linked open data to provide regular updates on life cycle inventory data. This study contributes to the understanding of data integration and sharing in LCA. However, similar to the previous studies, it falls short in terms of examining the broader implications and potential of open data for circular economy monitoring. Therefore, future research should aim to conduct a more comprehensive analysis that connects open data, LCA, and circular economy monitoring, in order to address this gap in the literature.

On the circular economy aspect, the research conducted by van der Heide et al. (2017) in the Netherlands examines the use of sensor data to address various urban challenges, including the need for a circular economy. The initiatives explored in their study are part of the "Making Sense for Society" knowledge platform and utilize sensor data to create smart solutions for urban living. In contrast, Garcia et al.'s study (2019) study focuses on the challenges of reverse logistics and waste in the textile and clothing production chain in Brazil, using open data as one of its sources. While this study provides insights into the complex relationships between economic, social, and environmental factors in the industry, it does not directly examine the relationship between open data and the circular economy.

The study from Shennib & Schmitt (2021) provided a systematic review of data-driven technologies and artificial intelligence in the context of waste management systems and circular economy. The study highlights the benefits and challenges of these technologies and offers valuable insights for researchers and practitioners interested in integrating them into sustainable waste management practices. However, in contrast to the work from Garcia et al. (2019), it is limited in scope, focusing mainly on the technical aspects of data-driven technologies, and overlooking broader environmental and societal implications. Moreover, the open data aspect of the research is more focused on generating open data.

On the other hand, Weiher et al. (2022) research explores the potential of the open digital thread in contributing to sustainable value creation in the circular economy context. Unlike the other researchers(Garcia et al., 2019; Shennib & Schmitt, 2021; van der Heide et al., 2017) , Their study lays the foundation for future research on the development of a digitalized, connected, and collaborative circular economy, but it has its limitations as well. The research focuses mainly conducted on business relations and does not cover government.

Lastly, Davila Delgado & Oyedele's (2020) research examines the requirements of Building Information Modeling (BIM) data models for circular economy implementation and asset monitoring. The study provides important insights into the integration of BIM and circular economy principles into asset management practices, but like the previous studies, it has its limitations. The research is the only one that investigates the benefits of open BIM[1] for monitoring, but it is heavily weighted towards the technical aspects of BIM and does not explore the broader social and environmental consequences of circular economy implementation with the inclusion of other open data.

1.3. Literature Gap & Problem Statement

In summary, the current literature gap in the field of open data for LCA and CE is characterized by a lack of comprehensive analyses that connect open data with LCA across different industries, such as construction and food. While some studies mention open data as a prioritized resource, they fail to provide a thorough examination of its implications, benefits, and challenges.

All in all, taking into account the literature gap, there is currently no detailed analysis of the relationship between open data and circular economy (or LCA) in the literature. Moreover, no study has proposed a framework to enable the use of open data by governments in the context of monitoring the circular economy.

Electric vehicle batteries are selected as the context for this study due to their pivotal role in the European Union's pursuit of sustainable and smart mobility. With the demand for EVs on the rise, critical challenges such as resource scarcity and the imperative of adopting circular economy practices emerge within the production and management of these batteries. This focus on the EV battery market allows us to gain insights into the broader sustainability and circularity objectives, revealing the innovative strategies and collaborative efforts necessary to ensure the enduring viability of electric mobility in Europe. As the government a central and pivotal role in formulating policies, regulations, and initiatives that aim to promote and monitor circular economy practices, the government, serves as the problem owner in this research. In the context of the research, the term "government" refers to the role of government as the primary entity responsible for addressing and overseeing circular economy objectives, particularly in relation to electric vehicle batteries.

Including the problem owner and the context, the problem statement for the research is formulated as "*Governments are currently challenged by the effective utilization of open data to monitor circular economy objectives, particularly in the context of electric vehicle batteries, due to the absence of a systematic evaluation for open data quality and usability.*"

Therefore, the main research objective of this study is to evaluate the effectiveness of open data in monitoring circular economy objectives, particularly within the domain of electric vehicle batteries, and provide a systematic approach for achieving this goal.

1.4. Scientific & Academic Relevance and Link to CoSEM Program

The scientific relevance of this research lies in exploring the potential of open data for circular economy monitoring, identifying the challenges associated with its use, and developing a solution to address these challenges. This research can contribute to the development of more effective circular economy monitoring systems and promote sustainable development by analyzing open datasets from various sources.

The societal relevance of this research lies in the potential of open data to promote public engagement in circular economy monitoring, foster transparency and accountability, and contribute to the achievement of sustainable development goals. This research can benefit governments policymakers, and businesses working towards a more sustainable future by providing. The detailed relevancy of this research is illustrated by sections 7.2 and 7.3 at the end of the study, emphasizing its significance and impact.

This research on Circular Economy and open data is a suitable topic for Complex Systems Engineering and Management at TU Delft due to its complex nature and multidisciplinary approach. The research aims to address the challenges and opportunities of using open data to support the transition to a circular economy. Circular Economy is a complex system that involves various technical and social aspects, and the use of open data requires a multi-disciplinary approach to various issues related to data sharing and collaboration among stakeholders. The research also has a management angle as it proposes solutions to overcome the challenges of data sharing and collaboration among stakeholders, contributing to the development of management strategies for circular economy systems. This aligns with the core principles of Complex Systems Engineering and Management, which is concerned with understanding, designing, and managing complex systems with multiple interacting components and stakeholders.

1.5. Thesis Outline

The research document is meticulously structured into distinct chapters, each elucidating a specific facet of the study. This chapter, Introduction, sets the stage, presenting the research context and its significance. The second chapter, Research Approach, outlines the foundational strategies guiding the study. Moreover, the methodologies, research design, data collection, and analysis techniques are detailed. The third chapter, Framework Development, introduces a comprehensive tool designed to evaluate open datasets' potential in monitoring circular economy objectives, drawing from literature and expert insights. The fourth chapter Case Study chapter applies this framework to the realm of electric vehicle batteries, offering a practical exploration of its efficacy. Thereafter, the Discussion chapter reflects on the research findings, analyzing the opportunities, constraints, and implications. Finally, the Conclusion encapsulates the research outcomes, highlighting the study's contributions and suggesting avenues for future exploration.

2. RESEARCH APPROACH & METHODOLOGY

In this chapter, the research approach and methodologies employed to address the core objectives of this study are explained. The chosen research approach, which served as the guiding framework for the investigation, is outlined. Subsequently, the main research question that directed the inquiry is articulated. To ensure a comprehensive and more structured analysis, the sub-questions that played are introduced. A research flow diagram is presented to offer a visual representation of the research journey, providing a roadmap for how each stage of inquiry and analysis contributes to the attainment of meaningful insights. Through the well-crafted integration of the research approach, central questions, sub-questions, and visualization, this section establishes a clear foundation for understanding the methodological integrity of the study.

2.1. Approach

In the introduction, the definition of the literature gap revealed a need in the existing research concerning the absence of a framework to evaluate open data's potential for monitoring circular economy. In response, this study aims to develop a comprehensive framework to assess the potential of open data for monitoring circular economy. This development process of the framework development is aligned with the design science research approach. Thus, the Design Science Research Methodology (DSRM), developed by Peffers et al. (2007), is employed in this study. This approach emphasizes creating solutions to challenges by iteratively designing, developing, and evaluating artifacts. It provides a structured process to craft and refine a framework that addresses needs, ensuring its effectiveness through implementation and iterative improvement.

Peffers et al. (2007) introduced the DSRM, delineating a series of six consecutive steps: problem definition, identification of solution requirements, artifact design (in this research, a framework), demonstration through implementation, evaluation, and communication. With alignment of the research with the DSRM, as presented in Figure 2, in Chapter 1, the problem and research gap are identified, leading to the formulation of the main research question in Section 2.2. Subsequently, Section 2.3 extends from the main research question, introducing sub-research questions corresponding to each step. The communication step in the DSRM pertains to the actual report itself, especially within the discussion and conclusion sections.

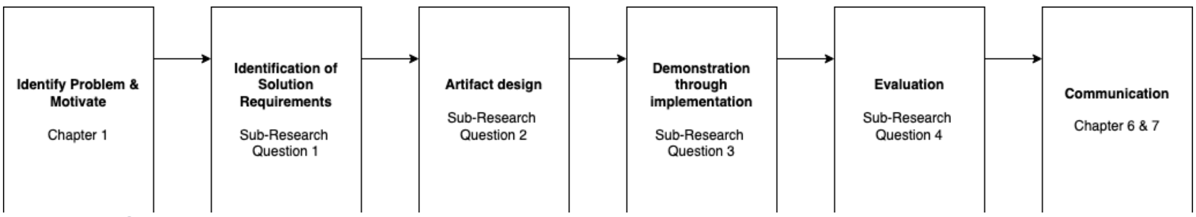


Figure 2: DSRM process model aligned with the research

2.2. Main Research Question

Based on the literature gap and research objective that presented in the previous chapter, the main research question is formulated as follows: "*What is the potential of open data to monitor circular economy objectives for electric vehicle batteries from a government's perspective?"* The primary research question is further examined through the formulation of four sub-questions, each addressing specific aspects of the overarching inquiry. To address the main research question, the research will adopt mixed research methods. Each method is explained relating to each sub-research question.

2.3. Research Methods and Sub-questions

First **sub-research question**, to develop an evaluation framework for the use of open data for circular economy monitoring, it is necessary to identify the important elements that should be included in the framework. This question is the second step of DSRM which is defining the objectives of a solution (Peffers et al., 2007). Therefore, the first sub-question is formulated as: "*What are the important elements that can be used for evaluating open data for circular economy monitoring?"*

To answer the first sub-research question, it is required to collect data existing frameworks for evaluating the use of open data, as well as circular economy monitoring and related concepts. To achieve this, in the research a comprehensive review of relevant literature will be utilized. This will involve collecting data on the types of data that are typically used for circular economy and circular economy monitoring.

Firstly, the literature review will be used in the development of the concept framework, as it provides a comprehensive examination of existing scholarly works and research studies relevant to the research topic(Booth Andrew et al., 2016). By critically analyzing and synthesizing the available literature, the literature review serves to establish the theoretical foundation and conceptual underpinnings of the study(Paul & Criado, 2020). The literature review component of the research will utilize various academic databases such as Web of Science, Scopus, and Google Scholar. Moreover, to ensure the comprehensiveness and rigor of the literature review, also grey literature sources will be used to obtain a broad and diverse perspective. The analysis will be used as input for defining the specifications of the framework. By integrating findings from these and other relevant sources, the literature review contributes to the formulation of a robust and comprehensive concept framework. It ensures that the framework aligns with established theories, incorporates emerging perspectives, and addresses the identified gaps in the existing literature. Moreover, the literature review component of the research will be beneficial for researchers, scholars, and practitioners interested in potential use cases for open data in circular economy, as it provides a general overview of the existing literature.

The second sub-question is the developmental stage constitutes the third step within the DSRM, encompassing the creation of the framework with the findings from the first sub-research question. Therefore, the second sub-research question formulated as: "*How do the identified elements for evaluating open data for circular economy monitoring translate to an evaluation tool?".* Based on the insights gained from the scientific and gray literature, this sub-research question will focus on developing of framework.

To answer the second sub-research question, the outputs of the first sub-question will be used as input data. Additionally, expert interviews will be conducted to gather more insights.

The research method that will be employed for expert interviews is semi-structured interview. Semi-structured interviews are commonly used in qualitative research for collecting rich and detailed data (Kallio et al., 2016). According to Kvale (1994), the semi-structured interview approach allows the researcher to have a general plan for the interview, while also allowing for the flexibility to delve deeper into certain topics based on the interviewee's responses. Furthermore, according to (Seidman, 2006), semi-structured interviews are considered useful for exploring and understanding the subjective experiences and perspectives of individuals in-depth. The flexibility of the semi-structured interview method enables them to adapt their questioning and exploration based on emerging insights and participant responses. This adaptability allows for a deeper exploration of relevant factors and their interrelations within the conceptual framework.

Third sub-question is the fourth step of DSRM, demonstration. Therefore, the question is "*What insights can be derived from the application of the evaluation framework in the context of electric vehicle batteries?"* The aim of this sub-question is to apply it to cases of electric vehicle batteries to gain insights.

In order to address the third sub-research question, the data about the cases will be required. This data will be derived from open sources, and it will entail a comprehensive review of relevant regulations and policies.

The case study method has been deemed appropriate for the research due to its ability to provide in-depth, multifaceted examinations of complex issues in real-world contexts, as presented in the work by Crowe et al. (2011). The aim of this research is to develop a framework for a broad understanding of the relation between circular economy and open data is crucial to developing effective solutions. The case study method is well-recognized method for obtaining an in-depth understanding of the problem and the context in that it occurs(Yin, 2018). This understanding will enable the development of the framework. Furthermore, the value of the case study methodology has been widely recognized in the domains of business, law, and policy (Crowe et al., 2011). Given that this research falls within the field of business and policy, the case study approach was found appropriate.

Lastly, **fourth sub-research question** cooperates with the evaluation step of the DSRM, that assesses the usefulness and effectiveness of the developed framework. Therefore, fourth sub-research question is formulated as: "*From domain experts' perspective, how effective is the created tool for evaluating open data for circular economy monitoring?"* This sub-research question will involve conducting expert interviews. The interviews will help evaluate the framework's practicality and usefulness in monitoring circular economy using open data. Hence, this sub-research question is cooperated with the evaluation step of DSRM.

The fourth sub-research question leads to a validation for the developed framework. To answer this sub-research question, data on the developed framework is needed, in other words output of the third question. In addition, result of fourth sub-question, experts in the field will be required in order to conduct the validation and test the usability through interviews. This could include data on the usability and practicality of the framework, as well as the potential benefits and limitations of the framework.

2.4. Research Flow Diagram

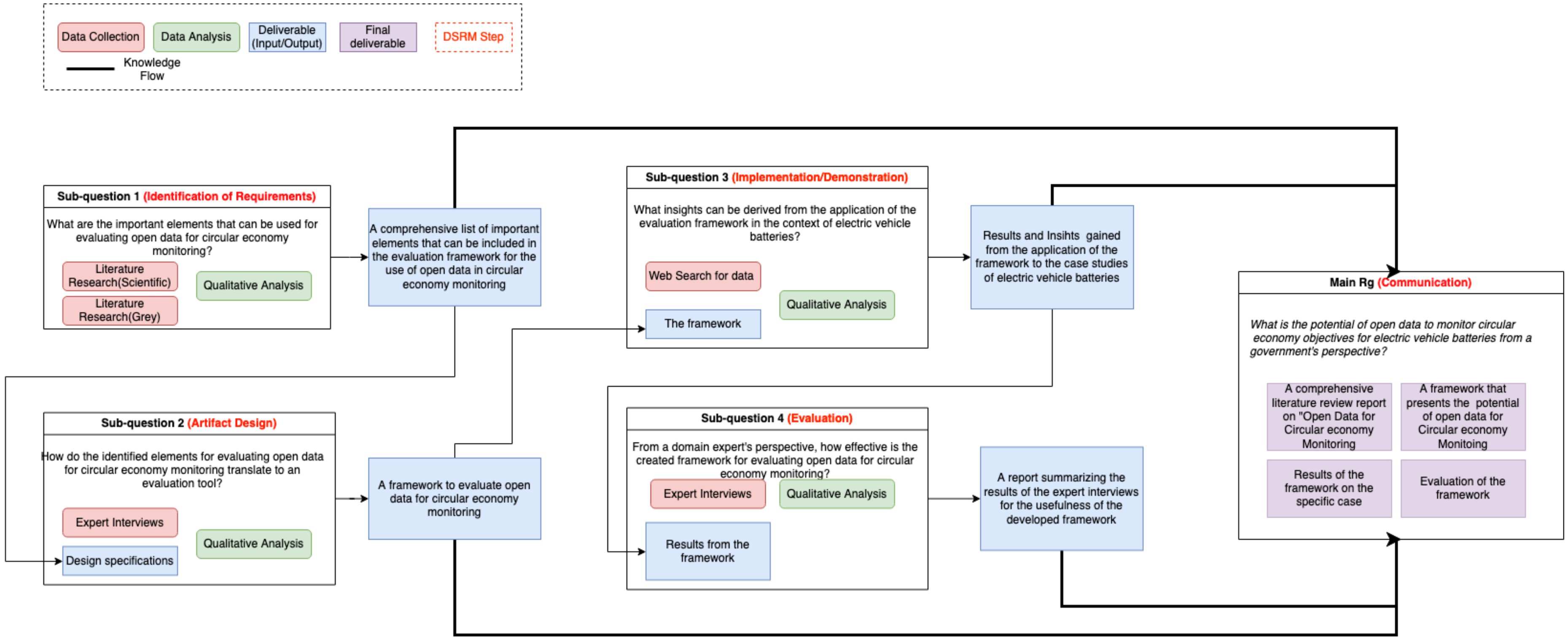


Figure 3: Research Flow Diagram

3. FRAMEWORK

The framework chapter is conducted with two main sections, each follows specific steps in DSRM, **Identification of Solution Requirements** and **Artifact Design (Framework Development).** Therefore, the chapter starts with literature review to identify the requirements and follows with the explorative interviews which will lead design and lastly the chapter will be concluded with the framework.

3.1. Literature Review

To establish an evaluation framework for open data sets used in circular economy monitoring, a comprehensive literature review is undertaken, as outlined in Chapter 2. This review involves a critical analysis of existing research, methodologies, and frameworks, aiming to extract valuable insights and best practices. The findings from this analysis will inform the development of a robust assessment framework that can effectively evaluate the suitability and effectiveness of open data sets in monitoring circular economy processes.

This section starts with outlining the search and selection process, followed by an analysis of the existing literature.

3.1.1. Search and Selection

While this literature review is conducted, a variety of reputable databases and sources have been employed to ensure a comprehensive and up-to-date exploration of the subject matter. Academic search engines such as Google Scholar, Scopus, Web of Science, has been used to gather academic papers. As the search results were similar, Scopus is employed as main search engine. Additionally, government publications and industry-specific platforms have been used to capture practical cases and policy-related developments related to open data and circular economy monitoring. By drawing from a diverse range of scholarly and applied sources, this literature review aims to offer a holistic perspective on the current state and identify the important elements for the framework.

Firstly, the search started with the circular economy side as the main needed data to monitor the circularity. A literature review about index methods used to assess CE strategies has been performed, searching on Web of Science, Science Direct and Google Scholar databases, combining the keywords “circular economy” with “indicators”, “measuring” and “assessment”, among the works published in the last 10 years. In the large amount of articles, only the ones clearly focusing on index-based methodologies or sets of indicators to assess the performance of CE strategies were considered.

3.1.2. Analysis

The concept of Circular Economy (CE) and its goal is to transition from a linear economy to a closed-loop economy, optimizing material flows to maximize the usage and value of materials, products, and components (Ellen MacArthur Foundation, 2013). This understanding of material flows is crucial as it forms the foundation for circularity assessment. However, the literature reveals that research and data availability on circular economy assessment tools are currently lacking (Elia et al., 2017; Rocchi et al., 2021). Existing frameworks often focus on physical parameters and materials circularity but overlook other vital CE aspects like policies, regulations, customer contributions, and technological advancements (Maarten et al., 2017). Consequently, there is a need to develop a comprehensive assessment framework to bridge this gap.

To achieve sustainable development through innovation and disruption, the CE operates at micro (single firm, product), meso (industrial symbiosis, eco-industrial parks) and macro(global, national, regional, city) levels (Saidani et al., 2017). For this research, the primary focus will be on the micro and meso levels, mainly considering the electric vehicle battery product and the electric vehicle battery industry. Monitoring circularity at these levels requires the use of Material Flow Analysis (MFA), which is a crucial tool for quantifying material flows (Millette et al., 2019). MFA helps characterize the physical dimensions of the economy and set sustainable targets for material resource usage (Moriguchi, 2007). By analyzing inputs and outputs, MFA enables the tracking of material movements throughout the economy (Huang et al., 2012). Therefore, acquiring data on material flows becomes essential for effectively tracking circularity.

To assess circularity, Haas et al. (2015) and Van Bruggen et al. (2022) both presented models based on economy-wide material flow accounts. Figure 3 is the framework created by Haas et al. (2015), which is based on Eurostat's conceptual framework and system boundaries, depicts the different flows and processes quantified to assess the circularity of the economy.

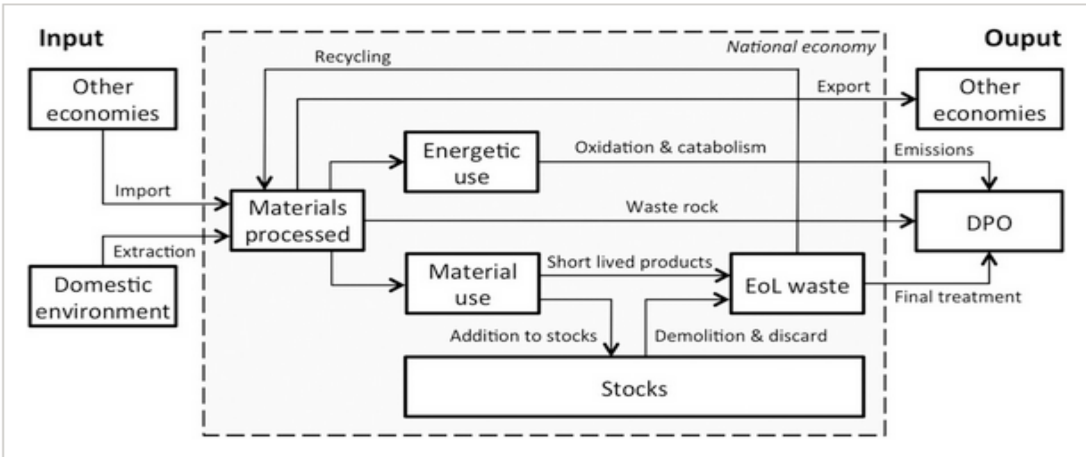


Figure 4: General model of economy-wide material flows (Haas et al., 2015).

van Bruggen et al. (2022) created a similar model (Figure 4) in their study on barriers to CE, particularly in the context of vehicles. Based on the findings from the other two models, these stages have been categorized to emphasize three main dimensions of circularity at the product level: Resource evaluation, Product Lifespan, and End-of-Life. By analyzing datasets for effectiveness and usability within these categories, the assessment framework aims to enhance circularity assessment frameworks by effectively monitoring how resources are efficiently and sustainably utilized throughout a product's lifecycle.

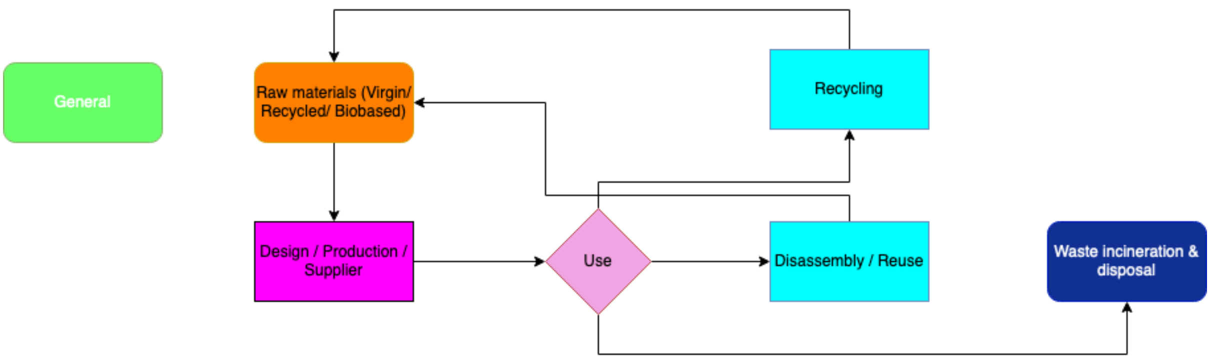


Figure 5: Value chain that is used to present the barriers (van Bruggen et al., 2022)

Resource efficiency is a core principle of the circular economy, aiming to optimize the sustainable use of Earth's limited resources while minimizing their environmental impacts (Ellen MacArthur Foundation, 2015; European Commission, 2022). Circle Economy's Key Elements of the Circular Economy framework also highlight the fundamental importance of prioritizing renewable resources(Circle Economy, 2021). Therefore, incorporating resource efficiency into the circularity assessment framework becomes a critical aspect of evaluating how effectively products and industries utilize sustainable resources.

To effectively assess resource efficiency, the assessment framework identifies two key points for resource evaluation: the utilization of “regenerative resources” and the “secondary usage of recycled materials”. Resources can be broadly categorized into primary and secondary resources. Primary resources refer to natural resources in their original states, while secondary resources encompass recycled waste that can be reused, including industrial waste (e.g., solid waste, wastewater) and waste materials generated in production and social processes (Hu et al., 2018)

However, a significant challenge in measuring the circularity of products and services lies in accurately allocating impacts between their initial cycles and subsequent recycled or recovered cycles (Corona et al., 2020). Baratsas et al. (2022) recognized this challenge and proposed a framework that addresses it by utilizing the proportion of recycled-recovered materials in the product. By integrating this approach into the assessment framework, it becomes possible to enhance the quantification of circularity achieved through the recycling and recovery of materials.

By considering resource efficiency, evaluating regenerative and recycled materials, and implementing innovative impact allocation methods, the assessment framework aims to provide a comprehensive understanding of how effectively circular economy practices optimize resource usage throughout product lifecycles. As a result, it will contribute to a more informed and effective circularity assessment process, facilitating the adoption of sustainable resource management practices and advancing the transition towards a circular economy.

Product lifespan

A product's lifespan is usually defined as the period from product acquisition to its disposal by the final owner (Murakami et al., 2010). Product lifespan is an essential aspect of the circular economy, focusing on evaluating the longevity and durability of products, as one of the key goals is to extend the lifetime of the product (Bakker et al., 2021). This involves employing circular business models that prioritize design for durability, reuse, refurbishment, remanufacture, and other practices to prolong the functional life of products.

An integral aspect of product lifespan assessment in the circular economy is the concept of total usability duration. This term refers to the duration that a product remains functional and useful until it reaches the end of its life. Understanding the total usability duration is essential for evaluating how well circular business models and design practices are employed to extend the functional life of products (Baratsas et al., 2022). Baratsas et al. (2022) categorize product durability under the term "average lifespan," which captures the total usability duration of a product until it reaches the end of its life. By analyzing this duration, the CE assessment frameworks can gauge the overall effectiveness of strategies such as durability-focused designs, refurbishment, and repair in maximizing product utility.

Within the circular economy context, various practices contribute to extending product lifespans. Reuse involves utilizing a product or its components for the same purpose for which they were originally conceived after reaching the end of their first use. Refurbishment, on the other hand, refers to the process of returning a used product to a satisfactory working condition, albeit with warranties that are typically shorter than those for new products (Tecchio et al., 2016)

Another critical element in the circular economy is repair, which plays a significant role in resource efficiency. Repair is recognized as a low-impact activity compared to recycling, which often involves the destruction of products and resource-intensive industrial processes. Instead, repair allows for the preservation of product value and a higher value derivation from products (Benton et al., 2015; Tecchio et al., 2016). The concept of "Repairability," as presented by the U.S. Chamber of Commerce Foundation (2017)), refers to “a specific measure of how many of a product's parts can be accessed, repaired, or replaced" (p. 1), and the availability of replacement parts.

By evaluating the product lifespan aspect within the circularity assessment frameworks can measure the effectiveness and usability of products and the circular business models that promote design for durability, reuse, refurbishment, and repair. Therefore, revealing the possibilities of datasets will provide valuable insights for fostering circular practices and achieving a more resource-efficient and sustainable circular economy.

End-of-Life

The circular economy is gaining increasing attention as a strategy for achieving sustainable resource management. This approach emphasizes the importance of restoring product value at the end of life when products are no longer usable or have become damaged(Vanson et al., 2022). By extending the product life cycle, the circular economy aims to reduce waste and address resource scarcity (Alamerew & Brissaud, 2019).

One key factor in supporting the circular economy and promoting sustainable product design in the EU is disassembly compatibility. This involves designing products to be easily disassembled, which facilitates the recovery of valuable materials and parts from discarded products (Battaïa et al., 2019; Cotton, n.d). Disassembly compatibility is intended to improve the material resource efficiency of products, as well as their durability, reparability, and recyclability (Vanegas et al., 2018). This approach can also help to reduce costs by rationalizing the number and cost of materials, demonstrate regulatory compliance, and facilitate the extraction of value from broken or end-of-life goods (Cotton, n.d.).

When regenerative resources or lifetime extension are not feasible, waste streams should be recovered and processed for use as inputs into production processes (Bocken et al., 2016). Ideally, waste loops can be completely closed by using waste from a product as a resource for the production of the same product (Ellen MacArthur Foundation, 2015). In cases where this is not possible, resources can flow across industries in an open-loop cycle. End-of-life products can be used as an input for a different loop to delay waste, although this may result in a loss of value (Cotton, n.d.; Geissdoerfer et al., 2017).

Overall, the circular economy emphasizes the importance of restoring product value at the end of life to extend product life cycles, reduce waste, and address resource scarcity. Disassembly compatibility, waste recovery, and closed-loop production processes are key strategies for achieving these goals.

Stakeholder Engagement

The circular economy places significant importance on adopting circular business models that rely on effective stakeholder engagement to formulate successful strategies (Hörisch et al., 2014). Stakeholder engagement is a critical aspect of the circular economy, as emphasized in multiple research studies (Ellen MacArthur Foundation, 2013; Geissdoerfer et al., 2017; Walker et al., 2014). It involves collaborating with various industry stakeholders to ensure the effective implementation of circular principles. To achieve this, it is essential to establish structural collaboration among stakeholders to systematically implement core circular economy strategies (Mishra et al., 2019; Ngan et al., 2019).

Collaboration among industry actors is crucial in overcoming common barriers, such as limited capital, knowledge, and tools for efficient circular operations (Ngan et al., 2019). The successful implementation of circular economy practices requires stakeholders to cultivate a culture that prioritizes responsible consumption, and environmental preservation by reducing the impact of activities, promoting product and service reuse, recycling, and refurbishment while minimizing waste generation. Furthermore, embracing long-term value creation principles based on sustainability and adopting inclusive stakeholder engagement approaches are essential (Salvioni & Almici, 2020). By working together, organizations can pool resources, expertise, and develop innovative business models to create value from waste streams.

Assessing the level of cooperation and information exchange between organizations is crucial to drive systemic change and improve overall circular economy performance. Such assessments help identify areas for improvement, facilitate the sharing of best practices and lessons learned, and foster collaborative solutions. Additionally, establishing networks and platforms for collaboration allows stakeholders to collectively address challenges and collaboratively develop solutions. Hence, information about stakeholder engagement plays a pivotal role in advancing circular economy practices and achieving sustainable outcomes.

In the introduction, the benefits and background of open data were discussed, laying the foundation for the subsequent sections of this literature review. Building upon this groundwork, the following section aims to identify essential elements for the conceptual framework in the successful implementation of data-driven approaches for circular economy monitoring. Public sector information has emerged as a valuable resource with substantial potential for various stakeholders, including governmental agencies, businesses, non-profit organizations, and citizens (Batini et al., 2009). Therefore, the utilization of open data can create significant benefits for these stakeholders.

The conceptual framework will encompass key dimensions such as Data Accessibility, Data Quality, and Data Usability, all of which play critical roles in unlocking the potential of open data for fostering a more sustainable and resource-efficient circular economy RESOURCE.

Data Accessibility

Data accessibility serves as a pillar in data-driven circular economy monitoring. It pertains to the ability of users to access data based on their cultural context, physical abilities, and available technologies, which is especially critical in cooperative and network-based information systems (Batini et al., 2009). Open Knowledge Foundation (n.d.-a) emphasizes the importance of making data easily obtainable for analysis and monitoring purposes. This involves evaluating Data Availability, encompassing aspects such as whether the dataset is accessible online in various forms, such as raw data, reports, or APIs. Hjalmarsson et al. (2015) classified access types into four categories: a) No access (data limited to the organization); b) Anonymous access (data accessible without registration); c) Online registration (data available to registered users); and d) Offline registration (data accessible after signing a contract).

Another aspect that is included is free access. As “Open” in defined in data context defined as “anyone can freely access, use, modify, and share for any purpose”(Open Knowledge Foundation, n.d.-b, p. 766) data should be accessible freely without any cost. Moreover, free Access is essential to promote inclusivity and equity in data access. Sunlight Foundation (2010) urges for evaluating whether the dataset is available free of charge, without any cost or subscription requirement.

While free access is one that does not mean necessarily freely licensed. Therefore, as mentioned by several studies(Attard et al., 2016; Kubler et al., 2016; OpenGovData.org, 2007; Overheid, n.d.; Sunlight Foundation, 2010) ensuring Open Licensing is in place is crucial to enable users to freely use, share, and build upon the data legally for circular economy monitoring purposes.

Data Quality

The reliability and accuracy of data are critical for deriving meaningful insights from circular economy monitoring. Data Quality encompasses several dimensions that contribute to data integrity. Ensuring Completeness is paramount, as highlighted by (Cai & Zhu, 2015) and Sunlight Foundation (2010). Evaluating whether all the necessary data fields and records are present helps avoid missing or incomplete data points that could skew analysis and interpretation.

Regular Update Frequency, as emphasized by (Open Knowledge Foundation, n.d.-a), ensures that the dataset is kept current, maintaining its accuracy and reliability over time. In rapidly changing environments, data quickly becomes outdated, rendering it less valuable and potentially misleading. Besides, regular updates enable to track latest trends, and events, enhancing its accuracy and applicability. Outdated data may lead to incorrect conclusions, hinder accurate predictions, and compromise the effectiveness of data-driven initiatives. Therefore, assessing the update frequency is beneficial.

Furthermore, the availability of comprehensive Metadata & Documentation, advocated by European Commission (2014)) and (Zuiderwijk, Jeffery, et al., 2012), aids in understanding and utilizing the data effectively. Also, Kubler et al. (2016) used metadata as a quality dimension in their framework that assesses the open data portals. Although their work focuses on the portals, as the portal assessment dis irectly related with the data that is included, this specification is also important for open data.

Data Usability

Efficient data processing and analysis are essential for effective circular economy monitoring. Data Usability encompasses factors that facilitate seamless data utilization. The format of the data is an essential aspect(Attard et al., 2016). Two of the eight Open Government Data Principles, in fact, regard the format in which data is made available to the public(OpenGovData.org, 2007; Overheid, n.d.). They state that such data should be available in a machine-processable format which is nonproprietary. Such data would enable easier and unrestricted use of the data for value creation. Machine-Readability, as highlighted by Open Knowledge Foundation (n.d.-a), plays a pivotal role in promoting data interoperability and reusability. Evaluating whether the dataset is provided in machine-readable and reusable formats, such as CSV, JSON, or XML, enables data-driven insights.

Data identifiers play a crucial role in data management and analysis, contributing significantly to the overall data quality and usability. By assigning unique identifiers to key elements within the dataset, such as resources or materials, data identifiers ensure that each piece of information can be accurately distinguished and tracked throughout its lifecycle. This uniqueness and consistency enable efficient data integration from various sources, facilitating seamless data aggregation and consolidation. As a result, data identifiers enhance data interoperability, allowing different systems and applications to effectively communicate and share information. Furthermore, data identifiers streamline data analysis processes, as they enable quick and precise referencing, reducing the likelihood of errors and duplications. The implementation of standardized data identifiers also fosters collaboration and data sharing among different stakeholders, as it establishes a common language for identifying and accessing specific data points. Overall, the emphasis on data identifiers by the Open Knowledge Foundation reinforces the importance of this practice in ensuring data integrity, reliability, and coherence, ultimately empowering organizations to harness the full potential of their data for informed decision-making and sustainable circular economy monitoring.

Combining open data assessment with circular economy assessment offers significant advantages in advancing circular economy monitoring and management efforts. By evaluating the relevance of available open data in relation to circular economy indicators, such as material flows, regenerative resources, product lifespan, end-of-life, and industry orchestration, we can determine the extent to which open data can effectively support circular economy initiatives. Furthermore, by using the framework the feasibility of utilizing open data within the context of the circular economy ecosystem is enabled. Extracting valuable insights from the integrated data will facilitate informed decision-making and contribute to effective circular economy management.

In conclusion, combining open data assessment with circular economy assessment offers an insightful and comprehensive approach to enhance circular economy monitoring efforts. By addressing data relevance, gaps, and limitations, evaluating data integration and analysis feasibility, and promoting stakeholder engagement, we can develop valuable recommendations and best practices that will drive progress and innovation in the circular economy ecosystem. This integrated approach will ultimately contribute to a more sustainable and resource-efficient future.

3.2. Explorative Interviews

3.2.1. Introduction

To delve deeper into the contextual nuances, the experts chosen for this interview are primarily distinguished by their expertise in two key areas: circular economy and lifecycle assessment, as well as open data proficiency. The interviewees come from diverse backgrounds.

Table 1: Explorative Interview Participants

Participant Number	Participant Background	Role of Participant
1	Circular Economy	LCA Expert
2	Circular Economy	LCA Expert
3	Sustainable Innovation, Transitions Governance	Researcher
4	Open Data	Researcher
5	Open data	Researcher

Kicking off the interview, participants are prompted to describe their involvement with circular economy monitoring, life cycle assessment (LCA), and open data. This initial inquiry serves as a preliminary exploration, aimed at grasping the interviewees' foundational knowledge and skill sets within these domains. Following this, to gauge their familiarity with open data, a question delves into the interviewees' current practices, encompassing how they make use of open data in their work, including specific datasets and types they engage with. The main goal of these questions is to unearth the range of information available and its potential applications in the sphere of circular economy monitoring and LCA.

Before unveiling the initial version of the conceptual framework, a query is posed to unearth key specifications and criteria, without any influence from the ongoing research. By identifying the essential prerequisites, we can then augment the framework with elements that might not have been initially presented. Drawing on the interviewees' diverse experiences with various types of data, the inquiry seeks to grasp their perspectives on optimal methodologies or approaches for devising a successful assessment framework tailored to the usability of open data. Furthermore, experts are prompted to provide instances or case studies where open data has been employed in this context, elucidating the pivotal components or features that have contributed to its effectiveness.

Subsequently, after garnering insights into the specifications, a preliminary conceptual framework is presented to the experts. The interviewees are encouraged to share their expert evaluations regarding the effectiveness of the presented specifications in evaluating the usability of open data within the circular economy realm. This question is designed to shed light on their viewpoints about the suitability of the proposed criteria in assessing the quality, relevance, and reliability of open data for circular economy monitoring. Furthermore, the conversation explores potential limitations or challenges associated with implementing the assessment framework for open data usability in the context of circular economy monitoring and LCA.

The importance of involving stakeholders from diverse fields, including circular economy practitioners, data scientists, policymakers, and other pertinent experts, in the development of the assessment framework is thoroughly examined. The interviewees are asked to provide insights into strategies or methodologies for gathering their input and feedback.

In conclusion, the participants, being acknowledged authorities in their respective fields, are invited to offer comprehensive recommendations and guidance for the development of an effective assessment framework tailored to the usability of open data within the scope of circular economy monitoring and LCA. By structuring the interview in this manner, the research aims for an in-depth exploration of the usability of open data in the context of circular economy monitoring and LCA. At the same time, it amalgamates the expertise and experiences of the interviewees to enhance the depth and breadth of the inquiry.

3.2.2. Findings

This section presents the analysis of the findings derived from explorative interviews conducted with five experts representing diverse backgrounds including academia, research, development, and consultancies. The objective of these interviews was to gain comprehensive insights into the establishment of a framework for open data aimed at monitoring the objectives of the circular economy. Additionally, summaries of the interviews are in Appendix D.

Participants shared different data repositories such as Eurostat, CBS, FOA stat, general literature resources, EPD library, and EcoInvent. EcoInvent, in particular, was widely acknowledged as a prominent data source due to its extensive coverage of environmental impact data. However, interviewees also raised concerns regarding certain limitations within the database. Notably, the absence of comprehensive material flow information for specific entities like automobiles and scooters hindered a complete understanding of circularity within these sectors. Additionally, outdated material flow data in EcoInvent was recognized as a challenge, necessitating the integration of more up-to-date data to ensure accuracy in circular economy assessments.

The experts expressed their consensus that the proposed framework, based on the existing literature, is robust and holds substantial potential for practical application. They emphasized its comprehensive approach and integration of key elements relevant to both open data utilization and circular economy monitoring. With its emphasis on transparency, data accessibility, and intelligent data analysis, the framework was deemed highly useful in guiding evidence-based decision-making within the circular economy domain.

Furthermore, Interviewees emphasized the need for data granularity, highlighting the significance of capturing data at a detailed level to obtain valuable insights into the overall flow of materials and resources within the circular economy. This level of detail is essential for comprehensive monitoring of material flows, identifying inefficiencies, and making informed decisions regarding circular economy interventions. Therefore, a detail level could be added to the framework.

Additionally, interviewees stressed the need for robust documentation and data identifiers to ensure data reliability and comprehensibility. A clear understanding of the data's context and characteristics is essential for its effective utilization in circular economy assessments and decision-making processes. However, while acknowledging the potential of open data in circular economy applications, interviewees also voiced the challenge of ensuring stakeholder alignment and engagement. A common concern was the diverse interests of different parties involved in circular economy initiatives, necessitating a mediator role within the framework to address conflicting interests and facilitate effective decision-making.

Several challenges were identified during the interviews, signifying the complexities associated with integrating open data into circular economy endeavors. Participants highlighted licensing costs as a major obstacle, particularly for accessing certain valuable data sources. This financial constraint may impede the accessibility of critical data for circular economy monitoring and research. Moreover, the paucity of granular data was recognized as a challenge, with some interviewees expressing the need for more specific and detailed information to support corporate-level transitions toward circularity effectively. In addition, the issue of data formatting inconsistencies over time was raised, underscoring the necessity for standardized and updated data formats to ensure data consistency and comparability.

Safeguarding sensitive information and addressing privacy concerns were also critical challenges highlighted by the interviewees. The potential disclosure of confidential data or the misuse of sensitive information could hinder the willingness of stakeholders to share data openly. Furthermore, garnering public acceptance for open data initiatives emerged as a significant concern, as there may be apprehensions regarding data sharing and transparency.

The interviews culminated in valuable suggestions to enhance the efficacy of the proposed framework. They proposed strengthening the linkage between open data and circular economy components to create a more pragmatic and user-friendly framework. This integration would render the framework more solid grounded and enable foundational recommendations for the stakeholders.

In conclusion, the explorative interviews provided profound insights into the dynamic and intricate interplay between open data applications and the circular economy. The findings showed that the framework design based on literature could be used with some extension in both CE and open data division. Furthermore, by addressing the identified challenges and incorporating valuable suggestions from experts, the proposed framework can be refined to create a powerful tool for facilitating informed and evidence-based decision-making within the circular economy domain.

3.3. Conceptual Framework

Based on the literature review, and explorative expert interviews conceptual framework is designed. To enhance the practicality of the framework, it has been transformed into a tabular format (Appendix A). This table provides a concise analysis and overview of the datasets utilized within the framework.

For improved clarity, a color grading system is introduced. Green signifies full alignment with the framework's criteria, while yellow indicates a need for additional work or analysis, such as supplementary data. Conversely, red denotes a lack of information about a particular aspect or an inconsistency with the framework's criteria.

3.3.1. Open Data Division

1. ***Data Accessibility***
   a) **Data Availability:** This assesses the data's obtainability for analysis and monitoring, including online availability in forms like raw data, reports, or APIs.
   b) **Free Access:** This evaluates whether the data is openly accessible to all users, being free of charge without subscriptions.
   c) **Open Licensing:** This assesses whether the data is legally and openly licensed for free use and sharing in circular economy monitoring.

2. ***Data Quality***
   a) **Completeness**: This evaluates if all necessary data fields and records are present to ensure accurate analysis and interpretation.
   b) **Detail level**: Assesses the granularity and comprehensiveness of information provided in the dataset.
   c) **Update Frequency**: This assesses how often the dataset is updated for ongoing accuracy and reliability.
   d) **Metadata & Documentation**: This checks for clear metadata and documentation to maintain data accuracy.

3. ***Data Usability***
    a) Machine-Readability: This assesses whether the data can be easily processed and analyzed using software tools, promoting interoperability through formats like CSV, JSON, or XML.
    b) **Data Identifiers**: This assesses whether the data is well-structured and identified with key elements.

3.3.2. Circular Economy Division

1. ***Material Flows***
    a) **Total Inflow:** This refers to the total amount of materials entering the economy, including raw materials, recycled materials, and recovered waste.
    b) **Total Outflow**: This refers to the total amount of materials leaving the circular economy system, such as waste, emissions, and exported materials.

2. ***Resource Evaluation***
    a) **Regenerative Resources**: This evaluates the availability of data on utilization and integration of regenerative resources, to promote a regenerative approach to resource management.
    b) **Quality of the Material**: This measures the availability of data on quality of materials used in the circular economy, ensuring that they maintain their value and functionality throughout their lifecycle. (Interview - 1)
    c) **Re-usage of secondary materials**: This evaluates the availability of data to the extent to which secondary materials, such as recycled or recovered materials, are reused in the production of new products.

3. ***Product Lifespan***
    a) **Total usability duration**: This evaluates the availability of data on the total amount of time a product remains functional and useful before it reaches the end of its life.
    b) **Reusability/refurbishment**: This evaluates the availability of data of the ease with which a product can be reused, either in its entirety or through the repurposing of its components.
    c) **Repairability**: This evaluates the availability of data on the ease with which a product can be repaired, prolonging its lifespan and reducing waste.

4. ***End-of-life***
    a) **Disassembly compatibility:** This evaluates the availability of data on how easily a product can be disassembled at the end of its life, allowing for the recovery and reuse of its components.
    b) **Waste stream recovery:** This evaluates the availability of data on the effectiveness of waste management systems in recovering valuable materials from waste streams, minimizing waste, and promoting recycling.

5. ***Stakeholder Engagement***
    a) **Knowledge Sharing:** This assesses the extent to which organizations within the circular economy share information, best practices, and innovations to improve overall system performance.
    b) **Circularity Collaboration levels:** This evaluates the degree of cooperation and collaboration between different stakeholders in the circular economy, such as businesses, governments, and NGOs, to achieve common goals and drive systemic change.

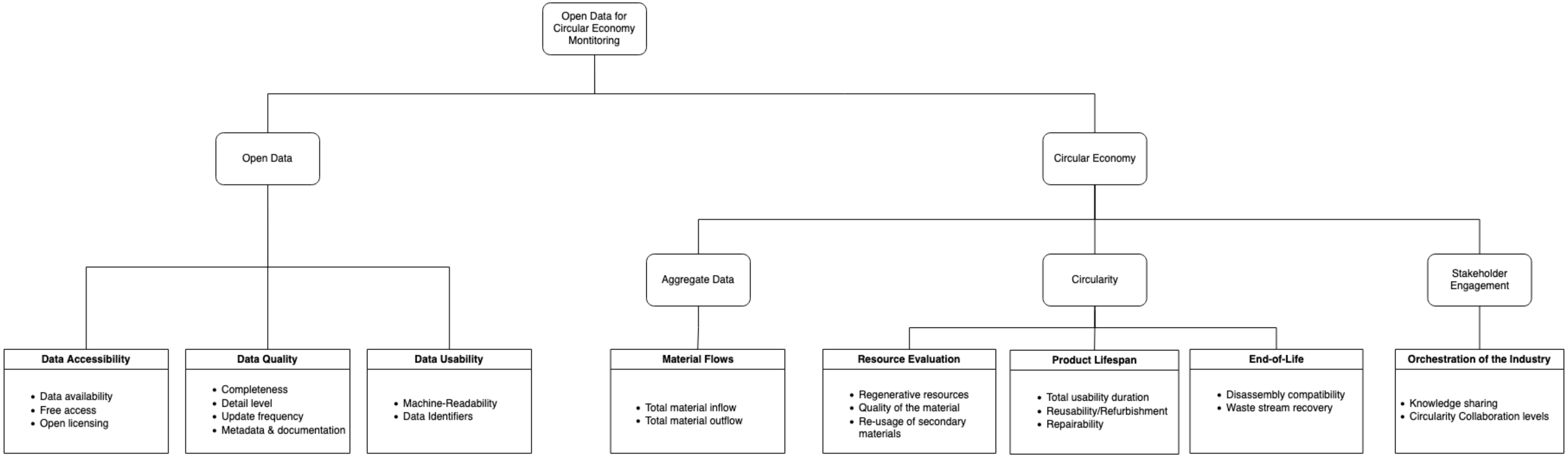


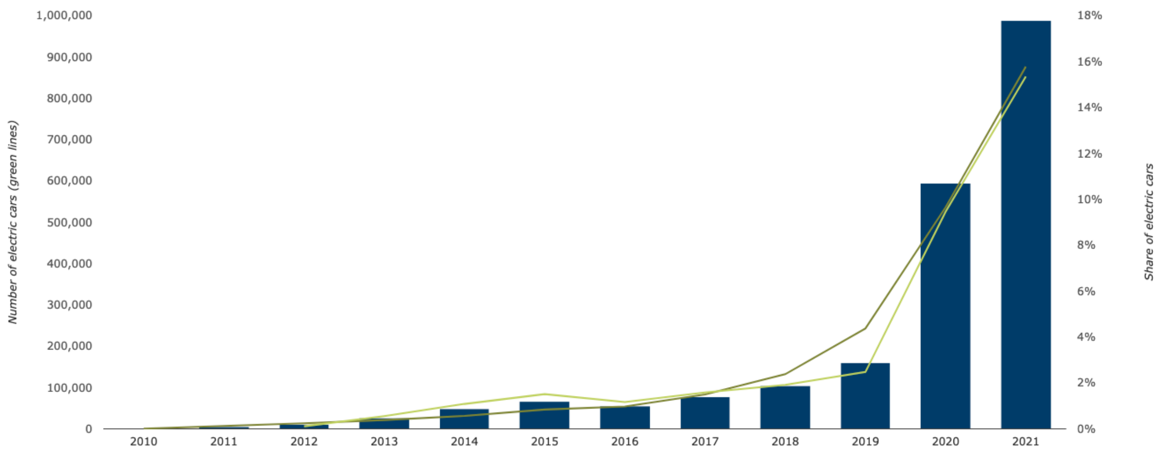
Figure 6: Visual presentation of the conceptual framework

4. CASE STUDY

Chapter 4 of this research work is dedicated to the exploration of the nuances of **Demonstration** phase through a case. Here, the process of transforming the artifact – the framework – from concept to an implication. The detailed motivation of the case, data search & collection, and the implementation of the framework, and the analysis are presented in the following subsections.

4.1. Case Study Introduction

The European Union's "Sustainable and Smart Mobility Strategy" sets forth ambitious targets for the incorporation of electric mobility, aiming to achieve the integration of 30 million electric passenger cars and vans into the transportation landscape by the year 2030, with a long-term perspective wherein a substantial majority of automobiles, encompassing cars, vans, and buses, will have transitioned to electric vehicles by the year 2050 (European Commission, 2021). This strategic orientation has led to a significant penetration of electric cars, including both battery electric vehicles and plug-in hybrid electric vehicles, into the European market. This transformation is evident through a consistent increase in new electric car registrations on an annual basis, a trend illustrated in Figure 6. The trajectory shows an increase from a mere 600 registrations in the year 2010 to a notable rise of approximately 1,061,000 units in the year 2020, constituting 11% of the new registrations. In 2021, occurred a substantial surge in electric car registrations, marking an impressive share of nearly 18% of new passenger car registrations(European Environment Agency, 2022)



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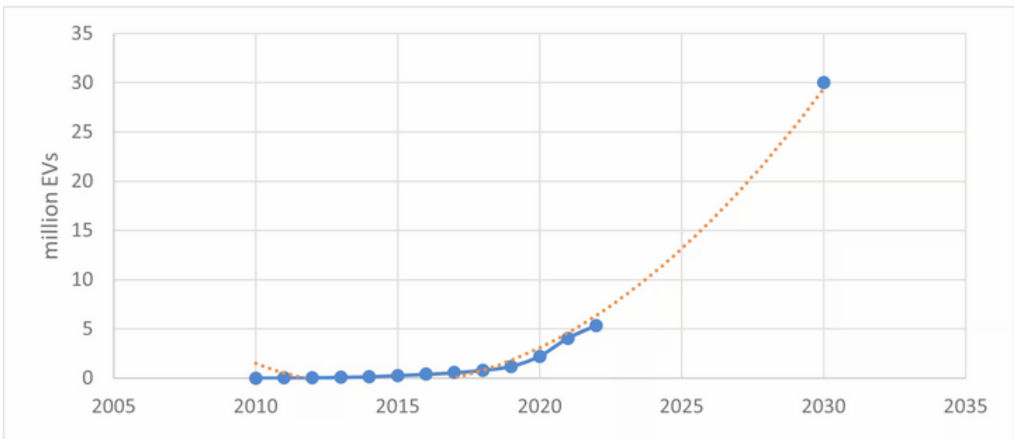

Figure 8: EV market development trend & required path to reach EU 2030 Target (Ruiz, 2023)

Accompanying with the increased demand and production of electric vehicles, the market for EV batteries has encountered a substantial growth rate across recent years. The demand for Automotive lithium-ion (Li-ion) batteries, increased by approximately 65%, scaling to 550 gigawatt-hours (GWh) in 2022 from around 330 GWh in 2021. This demand increase is mainly the result of a 55% increase in sales and registrations of electric passenger vehicles between 2021-2022 (International Energy Agency, 2023).

In the production of electric vehicle batteries, one of key concerns is the limited availability of critical materials like lithium, cobalt, and nickel. These resources will be depleted with the current linear economic practices of the take-produce-consume-dispose approach. Therefore, recovering these resources is essential to meet future demand, given their limited availability (Sopha et al., 2022). To address this and ensure sustainable practices, integrating a life-cycle perspective into end-of-life management becomes crucial. This emphasizes the importance of transitioning to a circular economy approach.

In response to this situation, the European Battery Alliance, formed in 2017 by European Commission, to create a collaboration with EU national authorities, regional bodies, industry research institutions, and other stakeholders in the battery value chain. The alliance aims to create a circular economic model for the battery value chain(European Commission, n.d.). Since one of the most important steps to achieve this goal is to monitor the circularity of the batteries, the case of the electric vehicle battery has been chosen.

4.2. Case Study Data Search & Collection

This section outlines the procedure for finding and collecting data for the case study. The process began by focusing on sources referenced by interviewees during exploratory interviews. These sources include CBS, Eurostat, FOA stat, common literature resources, EPD library, and EcoInvent. Following this, by using online search engines, a comprehensive search was performed using various search terms. Initially, the sources that were intentionally excluded from the search will be introduced. Subsequently, some data sources will be introduced although not selected for the case study. Finally, the chosen data sources and datasets, along with the reasons behind their selection will be presented.

EcoInvent is a widely recognized and comprehensive life cycle inventory database for assessing the environmental impacts of various products and processes. It's used primarily for life cycle assessment (LCA), which is a technique to evaluate the potential environmental impacts of a product, process, or activity throughout its entire life cycle. However, due to its subscription requirement, it has been excluded from the search.

EPD Library is a database that contains Environmental Product Declarations which can be defined as a standardized document that provides transparent and comparable information about the environmental performance of a product. However, due to its subscription requirement, it has been excluded from the search.

FAOSTAT is an extensive database maintained by the Food and Agriculture Organization of the United Nations (FAO) that provides a wide range of statistics related to food, agriculture, fisheries, forestry, and rural development. Since FAOSTAT serves as a repository for agricultural and food-related data, it has been excluded from the search.

CBS, which stands for Centraal Bureau voor de Statistiek, serves as the national statistical agency of the Netherlands. This agency generates reports, publications, and statistical databases that provide valuable insights into the economic, social, and demographic developments within the country. Additionally, CBS offers various statistics and datasets concerning the transportation sector. During the search process, it came to light that transport-related data was sourced from RDW, the Dutch vehicle authority. Consequently, the search conducted on CBS directed the search to the primary data source, **RDW**. A detailed introduction to RDW will be presented in section 4.2.1.

Eurostat is the statistical office of the European Union, responsible for collecting and providing high-quality statistical information about Europe. It covers a wide range of topics, including economy, population, trade, and more. Further details about Eurostat will be provided in section 4.2.2.

Following data sources, and datasets, have been found by using **general literature resources** and **online search engines;**

IEA (The International Energy Agency) is an intergovernmental organization that operates within the framework of the Organization for Economic Co-operation and Development (OECD). Through data collection, analysis, and technology collaboration, the IEA contributes to fostering sustainable energy systems and addressing energy-related challenges. The data compilation encompasses the "Global EV Outlook," an annual publication that identifies and deliberates on recent advancements in global electric mobility. This publication also encompasses the dissemination of worldwide electric vehicle data, providing insights into the number of electric vehicles in various countries and their respective types. Given the data's resemblance to Eurostat, using Eurostat would cover the aspects of IEA data.

Geotab is a commercial company that in the IoT (Internet of Things) and connected transportation technology sector. It specializes in providing advanced telematics solutions for fleet management, vehicle tracking, and data analytics. Although the company does not share the original datasets that contain “the battery health of 6,300 fleet and consumer EVs, representing 1.8 million days of data” (Argue, 2020, p. 1), they share a tool that presents average EV battery health based on make, model and year. However, the data tool has limitations such as formatting, usability. Moreover, there is no information presented about licensing.

IEEE DataPort is a platform provided by the Institute of Electrical and Electronics Engineers (IEEE) that enables researchers to share, store, and access datasets across various scientific disciplines. The SiCWell Dataset contains data of battery electric vehicle lithium-ion batteries for modeling and diagnosis purposes. One dataset available on IEEE DataPort is the SiCWell Dataset, which encompasses data from lithium-ion batteries used in battery electric vehicles. This dataset is particularly useful for modeling and diagnostic applications, contributing to advancements in electric vehicle technology. However, it’s important to note that while the SiCWell Dataset holds value for overall average tracking, its full utility is best realized when combined with other datasets. On its own, the dataset might lack comprehensive insights, underscoring the potential benefits of integrating it with complementary data sources.

Besides the data sources and sets that are above mentioned, it has been seen that availability of EV data on the statistical set is high. However, a comprehensive dataset encompassing all facets of EV batteries is currently absent. Nonetheless, there is a relevant project called BatteryPass, in alignment with EU Battery legislation, aiming to create a digital product passport for batteries. While the actual data is not presently available, it's included due to its anticipated realization. Further elaboration on this will be provided in section 4.2.3.

4.2.1. RDW

The "Rijksdienst voor het Wegverkeer" (RDW), which translates to the Netherlands Vehicle Authority, embodies the principles of safety, sustainability, and legal certainty in the realm of mobility. With a keen focus on international advancements, including vehicle data, RDW aligns its actions with the objectives set forth by the European Commission(RDW, 2023). Their website serves as a platform for presenting comprehensive data, encompassing the entirety of registered information.

Serving as the official registration database for vehicles in the Netherlands, it serves as the ***primary source*** for data collection in the national context. The website hosts various datasets, originating from both RDW itself and the community. However, the principal dataset, encompassing comprehensive information, is the *Open Data RDW: Gekentekende_voertuigen (signed_vehicles)*. Other datasets available on the website are derived from this primary dataset, utilizing its foundational data as a basis.

As of the latest access date on 10 June 2023, the dataset comprises an extensive collection of approximately 16.1 million rows, with each row representing a distinct vehicle, and a comprehensive set of 96 columns serving as attributes for each vehicle. The unique identifier assigned to each vehicle is its license plate (kenteken). Detailed analysis of these attributes will be conducted during the implementation phase, elucidating their significance in the context of the research.

To accommodate the continuous influx of new vehicle registrations, the database undergoes regular updates, ensuring its timeliness and constant enrichment with the latest information. This practice enables the researchers to work with the most ***up-to-date*** and ***comprehensive*** dataset, further enhancing the accuracy and relevance of the findings.

4.2.2. Eurostat

Eurostat is the statistical office of the European Union, responsible for providing high-quality statistical information to enable comparisons between countries and to support evidence-based decision-making at the EU level. Eurostat gathers data from national statistical authorities of EU member states, ensuring ***reliable*** statistics and *data* across the region. The agency covers a wide range of topics, including the economy, population, society, and the environment.

When it comes to transport data, Eurostat plays a crucial role in collecting, processing, and disseminating various datasets related to the transportation sector. These datasets offer valuable insights into the state of transportation infrastructure, mobility patterns, and the movement of goods and people within the European Union.

One of the fundamental datasets Eurostat provides is related to the total vehicle amounts in the EU member states. The data includes the number of registered passenger cars, trucks, buses, motorcycles, and other types of vehicles. As the focus of the study is EVs mainly two datasets is analyzed, namely new passenger cars by type of motor energy [road_eqr_carpda] and passenger cars by type of motor energy [road_eqs_carpda].

4.2.3. BatteryPass

In the search for open data, as have faced certain limitations of data availability. But despite this limitation, a new project is being developed: Battery Pass. Battery Pass aims to meet the compliance requirements set by the EU Battery Regulation while **accompanying sustainability and circular practices**. The project is led by a consortium of diverse expertise spanning sectors, academia, and beyond. The overall aim of the project is to develop cross-industry content and technical standards for a digital battery passport, a transformative innovation that will revolutionize battery tracking and management.

Set to comply with the EU Battery Regulation, which is due to take effect in 2026, the battery passport will be the first digital product passport (DPP) implemented in the EU, which are seen as a key tool to advance the European Twin Transition(Battery Pass Consortium, 2023). Digital product passports (DPPs) are a concept that involves creating a digital record of a product's environmental and social impact throughout its lifecycle. They are seen as a key tool for advancing the European Twin Transition by promoting a more sustainable, circular and digital economy. The European Twin Transition is a policy framework that aims to simultaneously address two major challenges: the green transition to a sustainable and low-carbon economy and the digital transformation of society.

4.3. Implementation of the Conceptual Framework

4.3.1. RDW Data

Name Of Dataset		Open Data RDW: Gekentekende_voertuigen	
Case		Electric Vehicle Batteries	
Open Data	Data Accessibility	Data availability	Available via RDWs open data website
		Free access	Free without any limitation (account is not necessary)
		Open licensing	Creative Commons (CC0)
	Data Quality	Completeness	Most complete (Missing data points on older records), assured by RDW
		Detail level	Each unit (Per vehicle)
		Update frequency	Daily
		Metadata & documentation	Detailed presence of documentation and metadata
	Data Usability	Machine-readability	CSV, RDF, RSS, TSV, and XML; Also API available
		Data identifiers	As explained in the documentation
Aggregate Data	Material Flows	Total Material Inflow	Could be obtained after processing data (Electric vehicle filter & and brand/models).
		Total Material Outflow	Could be obtained after processing data (Electric vehicle filter & brand/models).
Circularity	Product Lifespan	Total Usability Duration	Potential derivation based on historical records
		Reusability	No information
		Repairability	No information
		Refurbishment	No information
	Resource Evaluation	Regenerative Resources	No information
		Quality of the Material	No information
		Re-usage of Secondary Materials	No information
	End-of-life	Disassembly compatibility	No information
		Waste stream recovery	No information
Stakeholder Engagement	Orchestration of the Industry	Knowledge sharing	No information
		Circularity collaboration levels	No information

Open Data

Data Accessibility

The dataset is conveniently accessible through RDW's website(RDW, 2015), providing free and unrestricted access without requiring any account registration. This commitment to open data principles allows every user to **freely** obtain and utilize the information, contributing to transparency and inclusivity. The dataset can be accessed freely through RDW's dedicated portal for open mobility data, http://opendata.rdw.nl.

The dataset is **openly licensed** under Creative Commons 0 (CC0), a licensing framework that empowers creators and copyright owners to waive their interests in the works, placing them effectively in the public domain(Creative Commons, n.d.-a). Scientists, educators, and artists can enhance, and reuse the data for diverse purposes without encountering any copyright or database law restrictions.

Data Quality

The dataset exhibits a predominantly high level of **completeness** as the data collected by RDW itself. However, there is the presence of some incompleteness, particularly evident among older registrations. The dataset offers a vehicle-centric **detail level**, featuring 96 columns per individual vehicle entry.

An aspect that further enhances the dataset's quality is its **update frequency**, with near-daily refreshes ensuring the inclusion of the most recent information. Such regular updates substantiate the dataset's reliability and relevance for real-time analysis and decision-making in the realm of circular economy monitoring.

RDW website presents intricately detailed **documentation** data and **metadata**. This documentation elaborates on each column, outlining key attributes and presenting connections to pertinent datasets.

Data Usability

The dataset presents a diverse range of export formats, namely CSV (Comma-Separated Values), RDF (Resource Description Framework), RSS (Really Simple Syndication), TSV (Tab-Separated Values), and XML (eXtensible Markup Language). Additionally, the dataset showcases connection through the Socrata Open Data API (SODA), extending programmatic access to its wealth of information. Through the SODA API, programmatic access to this dataset including the ability to filter, query, and aggregate data is provided. Consequently, the dataset offers various options in terms of **machine readability**, allowing for efficient and seamless data processing across a wide range of computational environments.

Key columns and essential identifiers are well-structured and comprehensively explained in the accompanying documentation. As a result, **data identifiers** are readily available and accessible, facilitating effective data integration, cross-referencing, and data linkage for robust circular economy monitoring endeavors.

Circular Economy

Upon completing the analysis of the open data component within the framework, the subsequent phase involves analyzing the circular economy aspect.

Aggregate data

The dataset encompasses information about every registered vehicle within the system, providing an overall count of vehicles. By applying appropriate filters, such as electric vehicles, specific counts for different types of cars could be obtained. The dataset also contains essential details about each vehicle, including the brand, model, and build year, which are valuable in determining the specific battery model used in the car. This comprehensive approach enables the calculation of the **total material inflow and outflow.**

Product Lifespan

While the dataset lacks detailed information about re-usability, refurbishment, and repairability, it remains a valuable resource for deriving insights into the total usability duration of electric vehicle (EV) batteries. The dataset encompasses two crucial components: periodic technical inspection records and registered kilometers, both of which are pivotal in assessing the overall lifespan of EV batteries.

Periodic technical inspections provide invaluable glimpses into the condition and health of EV batteries over time. By monitoring the battery's compliance with safety and performance standards, these inspections offer an indication of its well-being and efficiency. A consistent and well-documented history of passing inspections could provide insights into the **total usability duration** of the EV battery.

Simultaneously, the dataset's provision of registered kilometers presents an essential metric for assessing the intensity of vehicle usage. By quantifying the distance traveled by each vehicle, we gain insights into the potential wear and tear experienced by various components. Higher registered kilometers might indicate increased usage and consequently impact the vehicle's overall durability and usable lifespan.

Resource Evaluation

The dataset lacks directly related information on resource evaluation, including regenerative sources, material quality assessment, and re-usage of secondary materials in the circular economy.

End-of-Life

Similar to resource evaluation, the dataset also lacks directly related information on the end-of-life component of the framework. This critical aspect encompasses disassembly compatibility and waste stream recovery.

Stakeholder Engagement

The dataset is also lacking information on stakeholder engagement, encompassing knowledge sharing and circularity collaboration.

4.3.2. Eurostat

Name Of Dataset			New passenger cars by type of motor energy/ Passenger cars, by type of motor energy
Case			**Electric Vehicle Batteries**
Open Data	Data Accessibility	**Data availability**	Available via the Eurostat Website
		Free access	Free access without any limitation (account is not necessary)
		Open licensing	Attribution 4.0 International (CC BY 4.0)
	Data Quality	**Completeness**	Assured with European Statistical System
		Detail level	Country-based yearly EV stocks (aggregate)
		Update frequency	Yearly
		Metadata & documentation	Detailed presence of documentation and metadata
	Data Usability	**Machine-readability**	TSV, CSV, SDMX 2.1, TXT, JSON; also API Available
		Data identifiers	Not specifically presented
Aggregate Data	Material Flows	**Total Material Inflow**	Total EV inflow provided; average battery amount could be derived.
		Total Material Outflow	By using Total EV inflow and stock amount could be derived.
Circularity	Product Lifespan	**Total Usability Duration**	No information
		Reusability/ Refurbishment	No information
		Repairability	No information
	Resource Evaluation	**Regenerative Resources**	No information
		Quality of the Material	No information
		Re-usage of Secondary Materials	No information
	End-of-life	**Disassembly compatibility**	No information
		Waste stream recovery	No information
Stakeholder Engagement	Orchestration of the Industry	**Knowledge sharing**	No information
		Circularity collaboration levels	No information

Open Data

Data Accessibility

The dataset is conveniently accessible through Eurostat’s website, providing unrestricted access without requiring any account registration.

Eurostat encourages the free re-use of its data for both non-commercial and commercial purposes. Users can freely utilize statistical data, metadata, web page content, official publications, and other documents from Eurostat's website, except certain materials that may have specific re-use restrictions(Eurostat, 1995). The dataset is **openly licensed** under Creative Commons the Attribution 4.0 International [CC BY 4.0](European Union, 1995), a licensing framework that allows users to freely share, adapt, and use a work for any purpose, even commercially, provided they give appropriate credit to the original creator. This license grants significant freedoms to the user while ensuring proper attribution, promoting open sharing and collaboration of creative content(Creative Commons, n.d.-b).

Data Quality

Eurostat collaborates with National Statistical Institutes and other national authorities within the European Union Member States as part of the European Statistical System (ESS) to produce European statistics. The completeness of the dataset relies primarily on the reporting competence of the national authorities, owing to the voluntary nature of data collection. Regular follow-ups on completeness are conducted by Eurostat in cooperation with the reporting countries. Consequently, the data is generally considered to be complete; however, there may be instances of incompleteness within historical records that exceed 12 years.

The dataset encompasses the total number of vehicles per country, categorized by fuel type and recorded on a national level. While this high-level data proves valuable for tracking overall average inflow and outflow, it may present challenges when seeking to achieve granular tracking.

To support data interpretation and analysis, the dataset provides comprehensive metadata in a documentation format. This includes relevant information such as the unit of measure, reference period, and the frequency of data updates, which is yearly as outlined in the documentation.

Data Usability

The dataset provides a variety of export formats, including TSV (Tab-Separated Values), CSV (Comma-Separated Values), SDMX 2.1, TXT (Plain Text), and JSON (JavaScript Object Notation). Moreover, it supports a Rest API, with detailed explanation of the user manual(Eurostat, n.d.). This diversity in data formats and the availability of a Rest API offer flexible and seamless data processing capabilities across a wide range of computational environments.

The dataset's documentation does not delve into detailed explanations of data identifiers, but the dataset itself is relatively straightforward, obviating the necessity for extensive explanation.

Circular Economy

Upon completing the analysis of the open data component within the framework, the subsequent phase involves analyzing the circular economy aspect.

Aggregate data

The dataset contains information about new Electric Vehicles (EVs) in the table. However, it lacks specific details regarding the brands and models of these vehicles. Consequently, tracking precise data about individual EV batteries becomes impractical. Nevertheless, it is feasible to monitor the data on an aggregate level to observe general trends and patterns.

Furthermore, the dataset does not directly record outflow data. Nonetheless, by employing calculations that take into account the total stock of EVs and new registrations, one can derive the outflow information. This approach allows us to infer the number of EVs leaving the market during a given period, even in the absence of explicit outflow records.

Product Lifespan

The dataset lacks directly related information on product lifespan, including Total Usability duration, reusability/refurbishment, and repairability in the circular economy.

Resource Evaluation

The dataset lacks directly related information on resource evaluation, including regenerative sources, material quality assessment, and re-usage of secondary materials in the circular economy.

End-of-Life

Similar to resource evaluation, the dataset also lacks directly related information on the end-of-life component of the framework. This critical aspect encompasses disassembly compatibility and waste stream recovery.

Stakeholder Engagement

The dataset is also lacking information on stakeholder engagement, encompassing knowledge sharing and circularity collaboration.

4.3.3. Battery Pass

Name Of Dataset		**Battery Passports**	
Case		**Electric Vehicle Batteries**	
Open Data	Data Accessibility	**Data availability**	Will be available online, however, there will be limitations based on the group of the accessor
		Free access	Will be free
		Open licensing	Creative Commons Attribution-Noncommercial 4.0 International (CC BY-NC 4.0)
	Data Quality	**Completeness**	Collected by economic operators, reviewed by the battery commission
		Detail level	Each unit (Per Battery)
		Update frequency	Static Points (Will not have regular changes), Dynamic Points (Frequency will be defined based on)
		Metadata & documentation	Detailed presence of documentation and metadata
	Data Usability	**Machine-readability**	PDF, Reporting Portal
		Data identifiers	Explained in the documentation (attribute list)
Aggregate Data	Material Flows	**Total Material Inflow**	Could be obtained by total count with filters of electric vehicle
		Total Material Outflow	Could be obtained by total count with filters of electric vehicle
Circularity	Product Lifespan	**Total Usability Duration**	Charge-discharge cycles, state of charge, and remaining capacity are present
		Reusability/ Refurbishment	Contact details are shared for spare parts; Manuals for disassembly are present
		Repairability	Contact details are shared for spare parts; Manuals for disassembly are present
	Resource Evaluation	**Regenerative Resources**	Renewable content share is present
		Quality of the Material	Data on critical raw materials, battery chemistry, anode cathode materials present
		Re-usage of Secondary Materials	Pre and post-consumer recycled elements (nickel, cobalt, lithium, lead) share present
	End-of-life	**Disassembly compatibility**	Manuals for disassembly is present
		Waste stream recovery	Post-consumer recycled elements (nickel, cobalt, lithium, lead) share present
Stakeholder Engagement	Orchestration of the Industry	**Knowledge sharing**	The project will be realized within all stakeholder levels
		Circularity collaboration levels	The project will be realized within all stakeholder levels

Open Data

Data Accessibility

Currently, the dataset remains unavailable; however, upon the project's implementation, it will be an integral component of the EU Battery Regulation. According to the Battery Regulation, the battery passport is envisioned as part of a decentralized data system, overseen by economic operators responsible for its establishment and maintenance(Battery Pass Consortium, 2023; European Commission, 2022).

As mandated by the Battery Regulation, actors within the battery ecosystem shall be granted free access to the battery passport, in line with their respective access rights. This access is divided into three distinct groups: “the general public”, “Notified bodies, market surveillance authorities, and the Commission”, or “any natural or legal person with a legitimate interest”(Battery Pass Consortium, 2023).

The access levels for these groups are carefully differentiated. The "general public" shall have access to a comprehensive list of battery model information, providing them with valuable insights into batteries placed on the market and their associated sustainability requirements. Conversely, "Notified bodies, market surveillance authorities, and the Commission" will have access to compliance test report results at the battery model level. Furthermore, battery model information will only be accessible to interested parties and the Commission, encompassing detailed compositions, part numbers, dismantling information, and safety measures.

Despite the dataset's current unavailability, the project is licensed under the Attribution-Noncommercial 4.0 International (CC BY-NC 4.0) license. Under this Creative Commons license, content creators can share their work under specific conditions, requiring proper attribution to the original creator (BY) and restricting usage to non-commercial purposes only (NC). Users are allowed to copy, redistribute, remix, transform, and build upon the work, provided they adhere to these conditions(Creative Commons, n.d.-c). Importantly, the CC BY-NC 4.0 license is applicable worldwide and imposes no additional restrictions on the work beyond those explicitly specified in the license.

Data Quality

Regarding Completeness, the Battery Regulation does not currently specify means for economic operators to collect and process the necessary information for the battery passport. However, the Commission will undertake a comprehensive review, evaluating data collection, sources, and methodologies. This evaluation will encompass the assessment of **data completeness**, timeliness, and consistency, ultimately providing valuable recommendations for improvement.

As the battery passport aims to create a comprehensive record for each battery, the **Detail level** will be tailored to the characteristics of each unit. The consortium presented an attribute list and classified data points into two main categories: static, which does not change often or regularly, and dynamic, which undergoes frequent changes. The **update frequency** or variance thresholds for dynamic data attributes will be defined based on specific use cases, considering connectivity and potential time series provision within the battery passport.

To enhance traceability and auditing capabilities, each data point of an attribute will be linked to appropriate **Metadata**, such as a time stamp or data provider. This linkage enables seamless tracking and verification of additional information, bolstering the reliability of the battery passport data. Detailed **documentation** and guidelines have been provided by the battery consortium.

Data Usability

The registry will store all unique **data identifiers**, including unique battery identifiers, which exemplify a meticulous approach toward traceability and data retrieval. Moreover, aligning the

Battery Regulation(European Commission, 2022), the emphasis on "machine-readable, structured, and searchable" information enhances data usability.

Currently, due diligence reports are usually presented in PDF format. Therefore, the battery passports would be provided a link to the PDF uploaded on the company website. Additionally, the establishment of an electronic reporting system by Member States further enhances the usability of the battery passport project. Leveraging the connectivity of data services, this system fosters efficient data exchange and promotes standardized reporting practices across the battery ecosystem.

Circular Economy

Upon completing the analysis of the open data component within the framework, the subsequent phase involves analyzing the circular economy aspect.

Aggregate data

Although each battery passport does not provide any direct information about material flows, as each battery would have a unique passport deriving the total count of battery would be possible, by implementing filters such as battery type (EV Battery).

Product Lifespan

The dataset includes essential spare part contact details, which may indirectly enhance the potential for repairability and reusability of batteries. By providing stakeholders with access to spare part information, the dataset becomes a valuable resource for extending battery lifespan through repair and refurbishment.

Moreover, the dataset comprises critical data points necessary for evaluating the total usability duration of batteries. Information such as the battery's initial service date, expected lifetime measured by charge-discharge cycles, state of charge, and remaining capacity, plays a crucial role in determining the overall durability and longevity of batteries.

The date of putting the battery into service allows for calculating the battery's service life, serving as a foundational metric for assessing its usability duration. Similarly, the expected lifetime, based on the number of charge-discharge cycles, provides insights into the battery's potential lifespan before reaching its functional capacity end.

Additionally, data points such as state of charge and remaining capacity aid in evaluating the battery's current health and performance levels. This information helps in assessing the feasibility of continued usage or the need for potential refurbishment, further contributing to circular economy goals by extending the battery's useful life.

Resource Evaluation

In the implementation of the "resource evaluation" component within the framework, the focus is on essential data points that provide valuable insights into the quality and sustainability aspects of battery materials. Therefore, data on critical raw materials, battery chemistry, and specific data related to cathode, anode, and electrolyte materials. Additionally, pre-consumer and post-consumer recycled resource shares, as well as the renewable content share, all of which contribute to the re-usage of secondary materials and regenerative resources.

The quality assessment of the critical raw materials as well as battery chemistry, allows an understanding of their performance, durability, and potential environmental impacts. The sustainability and sourcing practices of these materials provide insights into their regenerative properties.

Specific data about cathode, anode, and electrolyte materials are also used resource evaluation process. The analysis of the quality of these individual components and the evaluation of regenerative resources within these materials indicates their potential for secondary use, reducing the dependency on virgin resources and contributing to the circularity of the system.

Furthermore, the assessment of pre-consumer and post-consumer recycled resource shares, including nickel, cobalt, lithium, and lead, could provide information on re-usage of secondary materials in battery production. The utilization of recycled materials decreases the demand for primary raw materials, conserving natural resources and minimizing environmental impacts. Lastly, the examination of the renewable content share highlights the role of regenerative resources in battery production.

End-of-Life

Post-consumer recycled resource shares provide valuable insights not only about resource evaluation but also about waste stream recovery. By analyzing the proportion of recycled resources from post-consumer batteries, information about the effectiveness of recycling processes and the extent to which valuable materials are recovered from discarded batteries could be gained. A higher percentage of post-consumer recycled resource shares indicates efficient recycling practices and successful waste stream recovery, contributing to the reduction of electronic waste and resource depletion.

On the contrary, manuals for the removal of the battery from the appliance and disassembly of the battery pack provide information on disassembly compatibility. The presence of clear and comprehensive instructions in these manuals ensures that batteries can be disassembled and dismantled efficiently and safely. Disassembly compatibility is essential for facilitating proper end-of-life treatment, as it allows for the effective separation of valuable components and materials for recycling or refurbishment.

Stakeholder Engagement

While specific data points may not directly capture stakeholder engagement within the framework, the Battery Pass project serves as a prime example of collaboration around circularity. By providing a platform for information sharing and involving diverse stakeholders in the development of a digital battery passport, the project exemplifies a collaborative approach to sustainable battery management.

4.4. Case Study Analysis

The framework has been applied to three distinct cases. These implementations have shed light on various aspects of open datasets for circular economy monitoring within the context of EV batteries. While the cases share commonalities, they also exhibit unique characteristics that contribute to the overall understanding of open datasets for EV batteries.

In these implementations, it is evident that different data resources behave differently based on their scope and objectives. The Eurostat case primarily focuses on the aggregate level, providing yearly data about new passenger cars categorized by type of motor energy. While this provides valuable insights into the overall trends in EV adoption, the data in its aggregate form might not be directly usable for in-depth circular economy analysis. On the other hand, the RDW Data case not only offers a more comprehensive dataset at the individual vehicle level, allowing for potential insights into specific EV batteries' lifecycle aspects, but also by using filters and processing methods, it is possible to derive material inflow and outflow insights, contributing to a better understanding of material flows.

However, it's notable that current datasets, even when granular, may not be directly usable by themselves to derive comprehensive insights. To obtain a more detailed understanding of circularity in EV batteries, there is potential for cooperation and integration with different datasets. By leveraging the strengths of various datasets and combining them, a more holistic picture of EV battery usage, lifespan, and material flows can emerge. An example of this case could be RDW Data could be cooperated with EV battery life data such as provided with the tool from Geotab. This combination could provide estimations of product lifespan.

Even after cooperation with the other datasets, having full aspects of the circularity assessment is not currently feasible. However, The BatteryPass case introduces a future concept – battery passports – that can leverage circular economy monitoring. Although some aspects need to be process with field experts, it captures the all circularity aspects.

Another noteworthy aspect that has been brought to attention by implementing the case is the recognition that while stakeholder engagement cannot be directly derived and monitored from the dataset, the existence of the dataset imparts information about stakeholder collaboration and information sharing. This assessment leans towards the qualitative dimension. This observation could potentially offer insights into the future, accompanied by pertinent recommendations.

The case study findings demonstrate the potential and challenges of open data in monitoring circular economy aspects of EV batteries. These analyses have collectively demonstrated the framework's adaptability and potential in comprehensively revealing the ability of open datasets to monitor circular economy dimensions within the context of EV batteries. By recognizing the strengths and limitations of individual datasets and fostering collaboration among other datasets, the circularity of EV battery systems can be more comprehensively monitored. These findings advocate for the continued refinement and expansion of the framework to accommodate the intricacies of real-world data dynamics, allowing for more accurate estimations of material flows, lifecycle assessments, and resource efficiency. Thus, the case study findings serve as a catalyst for the further development and improvement of the framework, steering it towards a more robust and effective tool for unraveling the complexities of circular economy practices within the realm of electric mobility.

5. EVALUATION & VALIDATION

In Chapter 5 of this research work, the **Evaluation** phase is delved into. Evaluation of the findings is realized through conducted interviews with the experts. In this chapter, the valuable perspectives on the application of the framework provided by experts in the field of circular economy and open data are delved. Their insights are important for understanding the validity, strengths, and potential limitations of the assessment framework developed. The chapter commences with an overview of the interview procedure design that was employed. Subsequently, the results of these interviews are presented. A comprehensive analysis of the experts' viewpoints sheds light on various facets of the framework's applicability and effectiveness. This analysis is structured around themes emerging from the experts' responses, offering a coherent and insightful narrative.

5.1. Evaluation & Validation Interview Protocol

For the diversification of the stakeholders, experts who have different backgrounds have been select. The interviews are conducted as semi-structured interviews. All questions are asked are open questions to gather expert opinions on the developed assessment framework's merits, its alignment with circular economy goals, and its applicability within the EV sector. Each question serves as a unique lens through which we explore the framework's potential to shape sustainable practices in this domain.

Table 2: Validation Interviewees

Participant Number	Participant Background	Role of Participant
1	Circular Economy, Open data	Researcher
2	Circular Economy, Open data	Researcher
3	Circular Economy, Recycling Companies	Executive Member (Business)

To start the interview, the participant’s background and expertise within the circular economy and electric vehicle battery sectors. This information grounds their perspectives, helping to understand the depth of their insights and the relevance of their opinions. Their expertise enriches the discourse, fostering credibility and trust in the validation of the framework. Subsequently, to explore participants' familiarity with open data and its potential applications in the circular economy. Similar to the first question, understanding participants' knowledge of open data and circular economy practices is essential for interpreting their viewpoints on the assessment framework.

Subsequently, an explanation is provided for the introduced framework and its approach to implementation. Followingly, the data sources the original databases, and the implemented case analysis are presented. Followingly, based on the analysis, the question examines the participants' perspectives framework's design and alignment with real-world challenges. Expert feedback on the framework's alignment with open data principles and circular economy objectives highlights its relevance and potential impact. Moreover, these insights form the foundation for the following discussions on strengths and areas for improvement. As identifying the framework's strengths from expert perspectives validates its effectiveness and real-world applicability. Therefore, another question that delves into the perceived strengths of the assessment framework is asked. Additionally, to gather areas for improvement, a question about further improvement is asked. By inquiring about aspects of the framework that require enhancement or further development, and identifying potential weaknesses or limitations that may hinder its efficacy.

Another important aspect to identify is the participants' evaluation of the two datasets used for monitoring circular economy objectives related to EV batteries. As identified through the case study analysis, some datasets, are not enough to track a level of circular economy objectives. Therefore, a question is asked to gather expert opinions on this insufficiency.

Although, key specifications for the framework are asked in the explorative interviews, as there are different experts present, a question about any additional specification to evaluate open data for circular economy monitoring is added.

Lastly, to understand barriers and challenges that might show up when realigning the assessment framework into real-world action, a question about limitations and barriers is asked. While their experience helps to identify potential limitations, also they can provide some suggestions to address these limitations.

In conclusion, the validation interviews on the case implementation of the framework are used to reveal its various aspects, including the framework's alignment with open data principles and circular economy goals, its practical usability, and potential challenges in real-world implementation.

5.2. Evaluation & Validation Results

In this section, the results of the analysis of interviews are presented. The section is commencing with the validity and reliability of the framework based on the expert opinions. Secondly, barriers to the use of the framework that may be raised are addressed. Lastly, the section is concluded with considerations for further development recommendations on validation. Additionally, summaries of the interviews are in Appendix G.

5.2.1. Validity and Reliability of the Framework

The framework's capacity to effectively interpret datasets was emphasized, even though it might not directly encompass the entire circular economy process. The significance of the framework was underscored not only for specific products like batteries but also for all products within the circular economy domain. It was noted that well-defined and easily accessible aspects facilitate a better understanding and knowledge acquisition, which plays a crucial role in advancing circular economy initiatives.

The framework's comprehensiveness was also highlighted. Its ability to address multiple facets of circular economy monitoring ensures a holistic approach, providing a deeper understanding of the sustainability performance of products and processes.

Additionally, positive comments were made about the resource evaluation component, highlighting its effectiveness in assessing available resources for circular economy monitoring.

Particular attention was given to the "Stakeholder engagement" aspect of the framework. By establishing a reporting mechanism for the open datasets, the framework was seen to facilitate enhanced circularity and transparent reporting practices. This is considered crucial as it encourages active participation from stakeholders, empowering them to improve their circular economy efforts.

Furthermore, the framework was regarded as a source of valuable insights for companies, assisting them in meeting legal obligations and adhering to regulatory requirements in the example of the European Battery Regulation. By offering a structured approach to circular economy monitoring, companies are aided in aligning with regulations and showcasing their commitment to sustainable practices.

Regarding the framework's open data aspect, its significance and user-friendly interpretability were commended. The overview of the dataset with the open data aspects increases the efficiency. By looking at the table, the dataset’s openness aspects could be easily understandable. This ease of understandability increases the informed decision-making about the dataset.

Finally, the value of the framework in providing an overarching perspective, especially for legislators, was emphasized. Gaining such a comprehensive view of circular economy data allows policymakers to make well-informed decisions and guide initiatives in the appropriate direction.

5.2.2. Challenges

The novelty of the sector and the emerging nature of circular economy practices are acknowledged as challenges. With a limited reservoir of existing expertise, it was pointed out that experts in the field are in a state of continuous evolution and adaptation, driven by the development of the sector. In support of this, not many experts, especially from commercial sources, could be found for this research.

One challenge that was identified in the interview is the difficulty encountered in providing measurable metrics for certain elements within the framework, such as disassembly compatibility. These elements may exhibit subjectivity to some extent, rendering the definition of precise and quantifiable metrics a challenging endeavor.

Another significant challenge that was brought to light by the interviewees pertained to resource evaluation and end-of-life tracking. The precise location of end-of-life processes and accurate assessments of resource utilization were noted as intricate tasks, owing to the ongoing developments and fluctuations within the industry.

The acknowledgment of the potential issue of dataset completeness was also made. Ensuring thorough attention to this aspect during the planning stages was underscored as crucial. As a valuable approach, the interviewees suggested the implementation of cross-checking and verification mechanisms for datasets to elevate their reliability.

Another primary challenge that faced concerning the reluctance of organizations to disclose their datasets. Especially commercial companies do not want to share their data as a result of various concerns they have. Moreover, the challenges linked to data updates were also highlighted by the interviewees, particularly from the perspective of the customer journey. In the context of the battery case, the prospect of updates presented complexities. Therefore, the necessity for a comprehensive analysis of the update component was emphasized, factoring in aspects such as update timing, responsible entities, and update processes. Although barriers directly affect the framework used to assess the open dataset in first place, this obstacle could lead to some future problems for monitoring.

5.2.3. Considerations Further Development and Recommendations on Validation

Valuable suggestions for further development of the framework were provided by the interviewees. Notably, a recommendation was made to include a column for the dataset's API to enhance data accessibility and usability. As this aspect is covered within both, data availability and machine readability; this improvement is already covered.

To augment the framework's comprehensiveness and tangibility, the proposition of incorporating more quantifiable values, particularly for aspects like repairability and reusability, was put forward. It was suggested that a rubric or scoring system could be introduced to facilitate a clearer understanding of these qualitative elements. The suggestion of implementing measurable metrics within the framework was put forward to enhance its interpretability. This adjustment would not only render the framework clearer but also alleviate subjectivity, thereby supporting its reliability and applicability across diverse contexts.

The need for an external verification mechanism to counter misleading claims, such as "greenwashing," was emphasized. Drawing inspiration from an example project within the building industry, this approach was seen to enhance the credibility of the data. Although direct validation is not possible through the framework; the presence of a mechanism to check the accuracy of the data can also be analyzed within the framework.

In terms of broader impact, it was proposed that an explanation of the framework's contribution to the United Nations Sustainable Development Goals (SDGs) be offered. This connection provides a clear direction for achieving specific SDGs, fostering global collaboration, attracting resources, and enabling measurable impact assessment. Moreover, as this alignment ultimately presents the connection with a obally recognized and accepted standards, it enhances visibility, advocacy, and overall validity.

The interviewees advised the definition of the specific stakeholders who would derive the greatest benefit from the framework's implementation. While government influence may be prominent in certain sectors like the battery industry, understanding the framework's value for other stakeholders was deemed crucial to encourage broader participation and collaboration.

6. DISCUSSION

This chapter engages in a comprehensive discussion of the findings derived from the conducted research. The primary objective of this study was to discover the potential of open datasets for the purpose of monitoring circular economy goals. To fulfill this objective, a framework was formulated, drawing ideas from existing literature and insights provided by numerous domain experts.

Subsequently, this created framework was applied to the context of EV batteries, utilizing three distinct datasets to facilitate the investigation. The validation phase involved conducting insightful validation interviews, which served to thoroughly probe the efficacy of both the framework and the outcomes observed within the EV battery case study. Throughout these stages, a multitude of opportunities and constraints were identified, illuminating the path for future exploration.

The outcomes of this process resulted in an in-depth understanding of the issue at hand. Consequently, this chapter embarks on a reflective journey, reflecting on the research process, the applicability of the framework, and the insights gained from the EV battery case study. In a nutshell, this chapter serves as a platform to reflect on the comprehensive endeavor undertaken and its implications, shedding light on the complex interactions of outcomes, opportunities, and limitations that emerged along the way.

This chapter is made up of various parts. First of all, there is a reflection on the research methodologies used in this research. This is followed by a discussion about the framework through case application. Thereafter, through alignment with Sustainable Development Goals, benefits of the research are discussed. Lastly, with scrutiny of the limitations the chapter is concluded. The outcomes and elements of this chapter help to put this research into perspective to make the results usable and possibly support future research.

6.1. Methodologies Through Research Journey

The research uses a combination of mixed methods suited to the specific needs of each phase. Initially, it was identified that there is a lack of existing approaches that integrate open data evaluation with circular economy assessment. As a result, a comprehensive **literature review** was conducted, focusing on both open data assessment and circular economy assessment. This review aimed to identify the key attributes that should be analyzed. Through this process, the degree of openness associated with a dataset was determined and the relevant informational facets necessary for circular economy assessment were delineated.

However, given the relatively nascent nature of research on the intersection of open data and the circular economy, relying solely on the literature may inadvertently overlook insights derived from real-world implementations. To address this potential shortcoming, and to increase the robustness of the framework, insights from experts in the field were required.

To address this need, **semi-structured interviews** were conducted with a set of 5 experts with diverse backgrounds. These interviews were instrumental in revealing aspects of the framework that had not gained significant attention in the existing literature, thereby enhancing conceptual understanding and refining the framework itself. In particular, one point made by these experts highlighted the importance of including different degrees of detail within the framework in order to facilitate a comprehensive assessment. From these insightful interviews, key concepts and an enriched approach were extracted and subsequently incorporated into the overarching framework.

Insights from both the literature review and the interviews conducted led to the development of the framework, followed by its application to a practical case. The use of this framework in a **case study** facilitated the identification of specific dataset opportunities. Given the current emphasis on alignment with the circular economy goals outlined by the European Union, the case study focused on electric vehicle batteries, a domain relevant to these goals. In particular, three different sources, namely RDW, Eurostat, and the BatteryPass project, were chosen carefully to provide datasets. This selection was motivated by their comprehensiveness, timeliness, reliability, and alignment with sustainability and circularity principles. A comprehensive analysis was then conducted using the above framework. This analysis not only examined the effectiveness of the datasets for circular economy monitoring but also tested the functionality of the framework itself.

The final step in this research was to validate both the framework and the case study results through expert engagement. Similar to the exploratory interviews conducted earlier, **semi-structured interviews** were used as the method of choice. These interviews involved three experts, each with a unique background and varying levels of experience. The underlying goal of this validation process was to assess the practicality and usefulness of the framework in the context of monitoring the circular economy through open data. During these interviews, the datasets, framework, and analysis were presented, followed by discussions facilitated by open-ended questions. Through this iterative process, the utility of the framework was established and opportunities for subsequent improvements and further validation were identified.

6.2. Framework Through Case

The developed framework for evaluating open data for circular economy monitoring is structured around several key dimensions, each of which focuses on specific aspects of both, open data and, circular economy's success. The framework's versatility and depth are underscored by its various components, enabling a comprehensive analysis of the open datasets for circular economy principles.

6.2.1. Open Data

The open data division of the framework was developed by reviewing several existing frameworks, principles, and research on open data. This particular part of the framework is dedicated to examining the structural attributes of datasets. The aspect of **data accessibility**, which is constructed from the components of data availability, free access, and open licensing, is at the inception of the analysis.

DATA AVILABILITY aspect is a prerequisite for the framework's usefulness. Without access to data, it is impossible to comprehend its content and conduct meaningful analysis. Notably, all of the data sets used for the case study were readily accessible, with the exception of BatteryPass, which will be available after the realization of the project.

The flexibility of data accessibility is evident in the area of licensing and free access. The variability in licensing is considerable; while data should be freely licensed, there are distinctions between different types of free licenses. For example, the RDW dataset uses the CC0 license, which essentially places the work in the public domain, while the BatteryPass dataset uses the CC-BY-NC 4.0 license, which allows use with attribution but restricts commercial uses. This creates a contrast where the RDW dataset can be used for commercial purposes, while the same can't be done with BatteryPass. However, given that this research adopts a government perspective, this distinction doesn't have a direct binding influence.

Furthermore, the flexibility of free access can be extended based on the context of the case. Although the cases used in this study were freely accessible, certain cases may require the employment of different approaches to free access depending on specific requirements or cases. For example, during the data search phase, the tool "GeoTab" was identified as providing access to specific data, on a limited level. Consequently, this dataset could be classified as semi-open due to the requirement to pay a fee for full access. As a result, the degree of flexibility regarding this aspect could vary depending on the specific context.

In essence, the framework's division of open data is not only based on established principles but also adapts to the nuances and dynamics present in different datasets and contexts. This approach ensures that the framework remains adaptable and relevant across a spectrum of open data scenarios.

DATA QUALITY aspect of is more formed from the completeness, detail level, update frequency, and metadata & and documentation. The framework examines the completeness of the dataset, by analyzing the assurer of the dataset and/or the missing points on the data itself. Although there could be counter cases, if the completeness is controlled by an organization; this would increase the likelihood of the completeness. For instance, in the case of RDW and Eurostat, organizations have a control mechanism. Therefore, the data completeness would be acceptable.

The level of detail emerges as another key element examined within the data quality dimension. The appropriate level of detail depends on the specific tracking requirements. While comprehensive data can provide a general understanding of the overall system, a finer level of granularity is essential for precise monitoring. For example, the RDW case highlights the importance of tracking at the vehicle level, which facilitates more accurate monitoring by enabling links between vehicles and EV batteries. Conversely, Eurostat, with its broader and averaged data, provides insights into broader trends, but may not capture the detail.

The dimension of update frequency is also an important feature as certain aspects of circular economy assessment may not require frequent updates, others, such as material flows and product lifespan, require dynamic tracking. For example, the BatteryPass project exemplifies an approach where certain data points were identified as dynamic and the update frequency was determined based on the nature of the asset being tracked.

The presence of data identifiers, metadata, and documentation are important as they provide essential context, structure, and attributes that enable proper understanding, interpretation, and effective utilization of the dataset. This information ensures that the data's origins, definitions, and limitations are transparent, enhancing its reliability and applicability. This aspect was covered in all datasets within the case study.

DATA USABILITY aspect is formed by the machine readability and data identifiers. Machine readability ensures that data can be efficiently processed by software tools, enabling automated analysis and interoperability. If the data format is not directly machine-readable, there could be additional efforts required, as in the example of BatteryPass.

6.2.2. Circular Economy

The circular economy division of the framework was developed by reviewing several circular economy assessment frameworks. As the research focused on a specific case, the focus was more on the micro and meso levels. This particular part of the framework is dedicated to examining the content of the open datasets. The main content types were categorized under three main headings, aggregate data(material flows), circularity, and stakeholder engagement.

MATERIAL FLOWS dimension within the framework captures the holistic view of material movement within the circular economy. By evaluating both total inflow and outflow, the framework addresses the core concept of resource circulation. Within the implementation of the datasets, the information on material flows is not presented directly as in and outflow. For example for the RDW dataset, while the inflow is as soon as the vehicle signed in the system counted, the outflow could be derived by the last used date. Also, in the context of electric vehicles, if the battery is removed from the vehicle and the vehicle is still in the system, there will be a flaw in monitoring. Another problem that could occur is the outflow of material. Although the outflow from the system is monitored in the vehicle context, the information about where the battery ended missing. BatteryPass project has the potential to address this possible challenge as it focuses on the batteries itself. Therefore, monitoring would be more precise in terms of in-out flows.

RESOURCE EVALUATION is part that focuses on material composition within the circularity aspect of the framework. Therefore, the presence of information about sub-dimensions, regenerative resources, quality of materials, and re-usage of secondary materials, is checked. Through case application, it came out that, there is a lack of organized sources for the resource evaluation data. In the case of the RDW dataset, there is no information about any materials. However, as in the example of BatteryPass, there are upcoming sources that would present this data in an organized manner. With the right experts in the specific context of the cases, a comprehensive assessment would be possible.

PRODUCT LIFESPAN focuses on the product through its time within the system including, total usability duration, reusability/refurbishment, and repairability. While information about total usability duration would provide insights about how long the material stayed in circulation, reusability/refurbishment and repairability will provide about the extension of the life product. Similar to the resource assessment, the available datasets do not directly cover the total availability time. However, some derivations can be made in collaboration with some databases. To illustrate with a more concrete example, the inspection results and recorded KMs contained in the RDW dataset, when mapped together with the data containing the average battery life per vehicle, will provide information on this. With BatteryPass data, this issue is also addressed, as it will be containing specific information such as charge-discharge cycles, state of charge, and remaining capacity.

The other aspects that should considered are reusability/refurbishment, and repairability. While the framework is only focused on the presence of any information that could be related to this aspect, to make more tangible assessments, specific experts on the area are required.

END-OF-LIFE dimension examines the circularity of products' disposal stages. With parameters such as disassembly compatibility and waste stream recovery, the framework investigates the information on waste stream recovery as in the share of the new product. An example could be post-consumer recycled element share within the battery, as in BatteryPass. On the other hand, one way to investigate disassembly compatibility information is presence of the manuals for disassembly as in BatteryPass project. However, there is a need for further elaboration for required information on disassembly compatibility.

STAKEHOLDER ENGAGEMENT is a important dimension that acknowledges the collaborative nature of the circular economy. Although tracking through a specific dataset could provide information directly about it, the presence of collaboration in the industry could provide insights abouts this aspect. As in BatteryPass, the project connects the stakeholders within the EV battery environment. However, there is still room for further improvement regarding this dimension.

ALL IN ALL The available datasets, although limited in number, are notable for their adherence to open data principles. This adherence underscores the datasets' reliability and suitability for use within the framework. These datasets predominantly offer insights into material flows within the circular economy, a fundamental aspect that aligns with the essence of resource circulation and the circular economy's core principles. However, to delve deeper into the intricacies of circularity, it becomes evident that combining knowledge from various datasets is essential. By cross-referencing and integrating data from multiple sources, a more comprehensive understanding of circular economy dynamics can be achieved, enhancing the framework's analytical capabilities.

Looking ahead, the prospect of upcoming projects aligning closely with the framework's criteria is promising. These anticipated projects hold the potential to contribute datasets that adhere to the framework's established dimensions. This alignment signifies the framework's practical relevance and adaptability to real-world situations. Despite the current constraints posed by limited datasets, the framework's ability to resonate with forthcoming projects showcases its capacity to evolve, accommodate new data sources, and remain pertinent in the ever-changing landscape of circular economy monitoring. In this way, the framework stands as a practical tool for current and future circular economy assessments, even amidst dataset limitations.

6.3. Alignment with Sustainable Development Goals

As mentioned by the experts, a discussion of the alignment of the research with Sustainable Development Goals will benefit the research. The Sustainable Development Goals, or SDGs, are a set of 17 global goals established by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development. These goals were adopted by all UN member states to address a wide range of social, economic, and environmental challenges facing the world. The primary aim of the SDGs is to promote sustainable development – “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”(United Nations, 2015; World Commission on Environment and Development, 1987, p. 54).

Aligned with the objectives of the Sustainable Development Goals (SDGs), the circular economy (CE) emerges as a pivotal strategy that bolsters the pursuit of Sustainable Development Goal 12 (SDG 12) - "Ensure sustainable consumption and production patterns"(United Nations, n.d.-a, 2015). Circular economy, by promoting resource efficiency, waste reduction, and the regeneration of materials, offers a holistic approach that is uniquely aligned with the goals of SDG 12. The circular economy, by promoting resource efficiency, waste reduction, and the regeneration of materials, offers a holistic approach that aligned with the goals of SDG 12.

Monitoring the circular economy (CE) is immensely beneficial for achieving the objectives of various aspects of Goal 12, particularly Goals 12.4, 12.5, 12.6, and 12.7. Goal 12.4, which emphasizes environmentally sound management of chemicals and waste throughout their lifecycle, CE monitoring becomes pivotal. Tracking the circulation and proper handling of chemicals and materials in a circular manner not only aligns with the sustainable consumption and production patterns sought by Goal 12.4 but also ensures that the potential risks and adverse impacts associated with the management of these substances are minimized.

CE monitoring plays a pivotal role in advancing Goal 12.5's aim to substantially reduce waste generation. By systematically tracking the implementation of circular economy strategies, such as prevention, reduction, recycling, and reuse, monitoring provides valuable insights into the efficacy of waste management practices. This allows for a data-driven assessment of progress and the identification of areas that require adjustment. By promoting continuous improvement in waste reduction efforts, CE monitoring contributes directly to the accomplishment of Goal 12.5's targets.

The integration of sustainable practices into corporate operations, as emphasized in Goal 12.6, is further empowered by CE monitoring. Through systematic tracking of circular economy initiatives within businesses, monitoring enables the evaluation of sustainability measures adopted by companies, especially concerning resource utilization, waste management, and ethical sourcing. This monitoring-driven approach ensures that the integration of sustainability principles becomes a dynamic part of a company's reporting cycle, fostering transparency and accountability in line with the objectives of Goal 12.6.

Furthermore, Goal 12.7 seeks to promote public procurement practices that are sustainable in nature. CE monitoring provides a means to assess how procurement processes are integrating circular principles, such as considering the lifespan and end-of-life scenarios of products, as well as the utilization of recycled materials. Effective monitoring can facilitate the identification of areas where circular procurement practices can be enhanced to better align with the objectives of Goal 12.7

All in all, while not a direct monitoring of the circular economy, the research and created framework significantly enhances the monitoring of circular economy objectives through the use of open data sets. By establishing a framework to evaluate the compatibility of open datasets with circular economy targets, the project bridges a gap in transparent information sharing. This, in turn, contributes to the larger goal of transitioning to a circular economy by enabling informed decision-making, evidence-based policies, and resource allocation. The project's focus on leveraging open data for monitoring aligns seamlessly with the principles of transparency, accountability, and sustainable resource management inherent in the circular economy concept. Through its indirect yet impactful contribution, the research plays a pivotal role in propelling sustainable development forward.

6.4. Limitations

As mentioned above, open data has the potential for monitoring the circular economy. However, this approach is not without its limitations. To begin with, the **overall availability of data** is a significant constraint. The effectiveness of circular economy monitoring depends on access to comprehensive data that outlines resource consumption, waste generation, and material flows across industries. Inadequate data availability hinders the ability to accurately measure the impact of circular practices, which hinders the development of effective strategies and policies.

Moreover, even when data is available to assess the circular economy, it is **not always fully open.** Open data fosters transparency, collaboration, and innovation, but when data is not fully open, it limits the ability of researchers, policymakers, and businesses to effectively analyze and integrate information. This can inhibit cross-sector collaboration and holistic assessments of circular economy progress.

The specific absence of comprehensive data on the circular economy can be attributed to several interrelated factors. Firstly, the circular economy concept is relatively **new** and **rapidly evolving**, making it challenging to establish standardized metrics and data collection methodologies. Unlike traditional linear economic models, the circular economy focuses on minimizing waste, reusing materials, and promoting sustainable practices, which require novel approaches to data gathering and measurement.

Secondly, the circular economy is a **complex**, **multi-dimensional** concept that encompasses various industries and sectors. Data collection in this context involves tracing product lifecycles, monitoring resource flows, and assessing environmental and economic impacts at multiple stages. This complexity leads to fragmented data sources and a **lack of standardized data formats**, hindering efforts to create a unified dataset.

Another limitation faced during the research is that the open data available is mostly at a **high and statistical level**. While high-level data can provide a broad overview, it falls short when it comes to monitoring circular economy practices. Making precise monitoring from total numbers is not possible.

Moreover, the **lack of specific information** regarding the circular economy such as repairability, refurbishment, and stakeholder engagement further complicates matters. These are key elements of circular assessments, but without accurate data, it's difficult to accurately measure their impact and formulate targeted strategies to improve circularity. This limitation is not only for the high-level data but also more detailed data such as RDW data.

In addition to these limitations, **companies are reluctant to share data**. Concerns about intellectual property, competition, and privacy often prevent companies from openly sharing operational data. However, data on supply chains, and product lifecycles, are critical to assessing circular economy performance. Building trust through data anonymization and demonstrating the mutual benefits of data sharing are essential to overcoming this challenge.

Also related to the last limitation, the process of **collecting and updating data** throughout a product's lifecycle is complex and involves multiple stakeholders and industries. Inconsistent reporting practices, delays, and gaps in data collection can lead to incomplete or outdated insights. Standardizing data collection methods and promoting timely reporting are critical to maintaining accurate and up-to-date circular economy monitoring. Another issue directly related to this situation is the **validation of data** for accuracy and reliability.

In addition, the novelty of the sector and the emerging nature of circular economy practices is also a limitation. With **limited existing expertise**, experts in the field are continuously evolving and being shaped through the development of the sector. Effective circular economy monitoring requires expertise in diverse fields such as environmental science, economics, and data analysis. The lack of such experts can hinder the proper analysis of available data, the interpretation of trends, and the formulation of evidence-based recommendations.

All in all, while open data holds great promise for monitoring progress on the circular economy journey, these limitations Collaboration across sectors, standardized reporting practices, incentives for data sharing, and efforts to build expertise are essential to overcoming these limitations. Through these concerted efforts, the potential of open data through monitoring can guide the transition to a more circular and sustainable economy.

7. CONCLUSION

7.1. Answering the Research Questions

7.1.1. First Sub-Research Question: Elements of the Framework

"*What are the important elements that can be used for evaluating open data for circular economy monitoring?"*

Developing a robust framework for evaluating the dynamics of the circular economy through open data necessitates the identification of key elements that hold significant importance. Drawing insights from various sources, these elements can be categorized into two main components: open data and the circular economy itself.

About open data, the focus revolves around three primary aspects: **accessibility, quality, and usability**. Accessibility entails factors such as **data availability**, **free access**, and the utilization of open licenses. Data quality encompasses considerations such as **data completeness, update frequency**, and the **availability** of comprehensive documentation. Usability delves into the ease with which **machine readability** and **data identifiers**.

For the circular economy, elements have been categorized into five core categories. These categories serve to enhance our comprehension of the circular economy's intricacies. Initially, attention is directed towards the **material flows** – both inflows and outflows, encompassing the resources entering the cycle and the end products exiting it. Subsequently, **resource assessment** focuses on **regenerative resources**, along with the **reusage of secondary materials**. The third facet pertains to the **product lifespan**, encompassing total **usability duration** and potential for refurbishment or reuse. The fourth category scrutinizes the products at the **end of life**, assessing factors such as **disassembly compatibility** and **waste stream recovery**. Lastly, **stakeholder engagement** is explored, focusing on **knowledge sharing** and **circularity collaboration efforts** among stakeholders in the industry.

As these elements converge, a more comprehensive understanding of the interplay between open data and the circular economy begins to emerge. These foundational components, sourced from diverse references, offer the potential to construct a framework that effectively navigates the intricate interconnections between open data and circular economy principles.

7.1.2. Second Sub-Research Question: Design

"*How do the identified elements for evaluating open data for circular economy monitoring translate to an evaluation tool?".*

The integration of identified elements into a framework for open data evaluation in circular economy monitoring requires a systematic approach. The framework is further developed through expert interviews. The framework has led to a **qualitative analysis** of the data set. Moreover, additional elements namely, **material quality, and detail level** have been discovered and integrated into the framework. This process has led to a robust framework that addresses the multidimensional aspects of circular economy monitoring.

7.1.3. Third Sub-Research Question: Case Study

"*What insights can be derived from the application of the evaluation framework in the context of electric vehicle batteries?"*

The application of the framework to electric vehicle batteries case provided valuable insight for refinement. By analyzing the datasets through specific cases, the framework has been further tested, and improved. Moreover, the insights gained from the case study can shed light on nuances and challenges in electric vehicle battery context. These insights will enable adjustments to be made to the framework, enhancing its adaptability and effectiveness in addressing diverse circular economy monitoring scenarios.

7.1.4. Fourth Sub-Research Question: Validation

"*From domain experts' perspective, how effective is the created tool for evaluating open data for circular economy monitoring?"*

By conducting expert interviews, the usefulness and effectiveness of the developed framework has been validated. Engaging with subject matter experts in circular economy, and open data provided valuable feedback. These interviews explored the framework's practicality, ease of implementation, relevance to monitoring circular economy objectives, and its alignment with real-world challenges. Expert opinions have provide a qualitative assessment of the framework's potential impact and highlight areas for further refinement, ensuring its applicability in practical scenarios.

7.1.5. Main Research Question

"What is the potential of open data to monitor circular economy objectives for electric vehicle batteries from a government's perspective?"

The analysis conducted throughout this study highlights that open data holds immense potential to serve as a potent tool for governments in monitoring and steering circular economy objectives in the realm of electric vehicle. Although the insight from the current datasets is not enough, through upcoming projects with open data, the abilities of the data for circular economy monitoring will be beneficial. Moreover, by integrating different open datasets with each other, it is already possible to gain insights, although not as much as future projects. This information empowers policymakers to make informed decisions, streamline resource allocation, and tailor regulations to align with circular economy principles.

From a government's perspective, open data facilitates evidence-based policy formulation by providing a comprehensive understanding of material flows, resource consumption, and environmental impacts associated with the electric vehicle battery ecosystem. Such insights enable the calibration of policies aimed at extending product lifespans, promoting repairability, encouraging secondary material utilization, and facilitating effective end-of-life strategies.

Moreover, the potential of open data to enhance stakeholder engagement cannot be underestimated. Governments can utilize open data to foster collaboration with industries, research institutions, and communities, collectively driving circular economy initiatives forward. This collaborative approach not only ensures a broader pool of expertise but also garners public support by enabling transparency in policy implementation.

In conclusion, this exploration of the potential of open data to monitor circular economy objectives for electric vehicles batteries from a government's perspective highlights the transformative capacity of data-driven insights. Open data offers a pathway for governments to proactively steer the transition towards a circular economy through monitoring.

7.2. Scientific Contributions of the Study

As afore mentioned in the literature gap section, the intersection of the open data and circular economy were missing. Although, several studies discussed (Angeles et al., 2019; Brockmann, 2019; Pagnon et al., 2020) the open data for LCA, the context is limited to construction sector. Moreover, there is no systematic analysis approach to combine both context, circular economy and open data. Therefore, this study makes a significant scientific contribution by pioneering new field through the creation of a comprehensive evaluation framework. This framework is a testament to the merging of detailed research and robust analysis, encompassing the complicated realm of open data in the pursuit of monitoring circular economy goals. The foundation of this framework lies in systematic analysis, where the study analyzes a variety of critical elements gathered from the academic literature. This compilation of components is not static, but rather a dynamic product, continuously refined through iterative processes that refine it into a robust tool ready to navigate the complex landscape of circular economy monitoring.

Insights into the amalgamation of methodologies and approaches for the integration of open data within the context of the circular economy are offered by this study. Such insights cater to the needs of researchers and practitioners seeking structured pathways to construct effective monitoring mechanisms.

Moreover, the study extends its reach beyond theoretical realms, manifesting its contributions through practical applications. By applying the framework within specific case study, namely electric vehicle batteries, it enhances our understanding. This exploration, while expanding scientific knowledge, also delves into the specifics of different industries, highlighting how the framework can be adapted to various contexts.

In summation, the study's contributions encompass the creation of a framework, the illumination of methodological integrations, and the application within practical scenarios. This amalgamation not only enriches academic discourse but also empowers a practical understanding of the synergy between open data and circular economy monitoring.

7.3. Practical Contributions of the Study

The study offers insights into the potential of open data for, particularly within the context of electric vehicle batteries. By analyzing three different open datasets with framework, study emphasizes the nuanced behavior of diverse data resources and their implications for circular economy analysis, a facet of utmost relevance for government policymakers. These insights become pivotal for informed decision-making, ultimately enhancing the government's ability to steer the transition towards more circular and environmentally responsible practices in the electric vehicle battery sector.

Although the study focused on the particular sector of electric vehicle battery sector, the framework is not necessarily limited to the sector. At the heart of the study lies a spotlight on framework adaptability and scalability. This approach ensures that the framework is applicable to a wide range of sectors and contexts, such as industrial batteries, whole vehicles, metals, and so on. This flexibility enables organizations and governments to customize the framework according to their specific requirements, fostering coherence in circular economy monitoring based on context.

The framework becomes a practical tool for governments and policymakers, offering them a clear overview of open datasets for monitoring circular economy objectives, particularly within the electric vehicle battery sector. This guidance draws strength from insights driven by data, empowering more informed decision-making processes. These decision-making processes may vary according to different stakeholders in the government's perspective. Stahel’s (2016) work emphasizes the necessity of adapting policies to foster circular economy practices. Therefore, from the policy makers' perspective monitoring would be beneficial to gain insights to be used in decision-making. By assessing open data in a more structured way for circular economy monitoring, policymakers could make decisions on policies such as the need for more data sharing for monitoring. In addition, by identifying the open data sets that are valuable for the circular economy, they could gain insights into the status of circular economy goals in the context of electric vehicle batteries. On the other hand, since the primary responsibility of customs is to monitor border crossings(Customs Administration of the Netherlands, n.d.), the framework can be used to identify data sets that can add value at the material flow level.

An essential facet that the study accentuates is stakeholder engagement. Through the revelation of the missing connection between open datasets for monitoring the circular economy objectives, the study underscores the importance of collaboration among governments and industries, especially for data sharing. Moreover, this collaboration is not only limited to cooperating for open datasets but also, as the circular economy requires collaboration between each stakeholder (Stahel, 2016), the importance of stakeholder engagement becomes clearer. This collaborative ethos nurtures a comprehensive approach to circular economy monitoring, wherein all actors contribute to sustainable progress.

As the study forges connections between open data and circular economy by showcasing the open datasets, such as Battery Passport will be useful to monitor the circularity, it Is beneficial to bridge the gap between sustainability and industries. This bridge provides monitoring of circular economy objectives into various industrial sectors. For instance, through the monitoring of the material flows from open data, recycling companies could gather insights on the expected share of materials available for recycling, that ultimately serves for waste stream recovery. Consequently, the study plays a role in steering practices towards more sustainable trajectories, contributing harmoniously to global environmental aspirations.

7.4. Directions for Further Research

Moving ahead, a range of captivating research avenues emerges from the present work focused on discovering the potential of open data through created framework for assessing open dataset usability within circular economy monitoring.

One direction involves enhancing comprehensiveness and clarity by considering quantitative aspects. The framework was focused on the qualitative assessment. By including a quantitative approach both, interpretability, and tangibility. This could encompass the development of indices assigning numerical values to different facets of dataset usability. These indices could provide a standardized means to compare diverse datasets, enabling more effective data utilization.

Another intriguing path for future exploration entails the potential creation of an interactive platform. This platform could take the form of a catalog, utilizing the framework's overview page to systematically organize and showcase various open datasets pertinent to circular economy monitoring. Such a user-friendly platform could serve as a nexus for researchers, policymakers, and industries, facilitating streamlined access to curated datasets.

Broadening the framework's scope stands as yet another avenue. By formulating a more generalized version on the macro, broader perspectives could be incorporated into the evaluation process. For instance, this extended framework could encompass considerations of energy flows within the circular economy system and delve into the intricacies of production processes driving resource circulation. This expansion would render the framework even more adaptable across diverse industries and contexts.

By embracing these research directions, the trajectory of framework evolution is set to make significant contributions to the domains of circular economy monitoring and open data utilization. This journey continues to foster more effective decision-making, elevate sustainability practices, and deepen the comprehension of the dynamic world.

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9. APPENDIX

A. Literature Gap Search Terms and Articles

A systematic search in the Scopus database with the search term "TITLE-ABS-KEY (["circular economy" AND "open data"]))" resulted in a total of 12 relevant studies. When the studies are limited at the keyword level (KEY (["Open Data" AND "Circular Economy"])), the number of relevant studies resulted with 5.

In order to ensure comprehensive coverage of relevant literature, the search term (KEY (["life cycle assessment" AND "open data"]) is also employed to discover additional sources. The search resulted in 12 articles. Then, articles were selected based on their potential to contribute to the understanding of the integration of LCA and open data. Relevance to the research topic, scientific rigor, novelty, and the presence of theoretical insights were key criteria for inclusion. Articles that did not align with the research focus were excluded.

Table: Articles that are used in literature gap definition.

No	Title	Authors	Year	Key Concepts
1	The Circular Economy – A new sustainability paradigm?	Geissdoerfer et al.	2017	Circular Economy
2	Circular economy as an essentially contested concept	Korhonen et al.	2018	Circular Economy
3	Socio-technical Impediments of Open Data	Zuiderwijk et al.	2012	Open Data
4	Open Data: What It Is and Why You Should Care	Ayre & Craner	2017	Open Data
5	The what, why, and how of born-open data	Rouder	2016	Open Data
6	Benefits, Adoption Barriers and Myths of Open Data and Open Government	Janssen et al.	2012	Open Data
7	Making sense for society	van der Heide et al.	2017	Open Data, Circular Economy
8	Reverse Logistics and Waste in the Textile and Clothing Production Chain in Brazil	Garcia et al.	2019	Open Data, Circular Economy
9	Data-driven technologies and artificial intelligence in circular economy and waste management systems: A review	Shennib & Schmitt	2021	Open Data, Circular Economy
10	Towards an open digital thread for electric mobility	Weiher et al.	2022	Open Data, Circular Economy
11	BIM data model requirements for asset monitoring and the circular economy	Davila Delgado & Oyedele	2020	Open Data, Circular Economy, Monitoring
12	A review of online sources of open-access life cycle assessment data for the construction sector	Pagnon et al.	2020	Open Data, LCA
13	Advancing resilient and sustainable buildings through a new normative workflow for integrated life-cycle assessments	Angeles et al.	2019	Open Data, LCA
14	Digitalization of building LCA and international activities - In the context of German assessment system for sustainable building	Brockman	2019	Open Data, LCA
15	Lcafdb-a crowdsourced life cycle assessment database for food	Hedin	2018	Open Data, LCA
16	An Open Source Dataset and Ontology for Product Footprinting	Ghose et al.	2019	Open Data, LCA
17	Real-time linked open data for life cycle inventory	Jayapal & Kumaraguru	2018	Open Data, LCA

B. Framework Overview Table

Name Of Dataset			
Case			
Open Data	Data Accessibility	**Data availability**	
		Free access	
		Open licensing	
	Data Quality	**Completeness**	
		Detail level	
		Update frequency	
		Metadata & documentation	
	Data Usability	**Machine-readability**	
		Data identifiers	
Aggregate Data	Material Flows	**Total Material Inflow**	
		Total Material Outflow	
Circularity	Product Lifespan	**Total Usability Duration**	
		Reusability/ Refurbishment	
		Repairability	
	Resource Evaluation	**Regenerative Resources**	
		Quality of the Material	
		Re-usage of Secondary Materials	
	End-of-life	**Disassembly compatibility**	
		Waste stream recovery	
Stakeholder Engagement	Orchestration of the Industry	**Knowledge sharing**	
		Circularity collaboration levels	

C. Full List of Interview Participants

Participant Number	Participant Role: Background	Type of interview
1	LCA Expert: Circular Economy	Explorative Interview
2	LCA Expert: Circular Economy	Explorative Interview
3	Researcher: Sustainable Innovation, Transitions Governance	Explorative Interview
4	Researcher: Open Data	Explorative Interview
5	Researcher: Open data	Explorative Interview
6	Researcher: Circular economy, open data	Validatory Interview
7	Researcher: Circular economy, open data	Validatory Interview
8	Executive: Circular economy	Validatory Interview

D. Consent Form

INFORMED CONSENT FORM
Study information:

We would like to invite you to take part in a research study titled **'Open Data for Circular Economy Monitoring: A Case Study into Electric Vehicles'** This study is being conducted by Yunus Emre Torlak, an MSc student at TU Delft, as a component of his master's thesis project.

This research aims to assess the potential of open data for monitoring circular economy objectives in the electric vehicle sector from a government perspective and trough a created assessment framework. The interview will take you approximately 60 minutes to complete. The data collected during the interview will be utilized in the creation of framework and analysis of the case study. The findings will be included in the master thesis report, which will be published in the TU Delft repository. We will ask you to discuss the specifications of the framework and/or case results based on the framework implementation.

There is always a possibility of a breach with any online activity. However, we are committed to safeguarding the privacy of your responses in this study to the best of our abilities. To minimize risks, we will securely store all data containing personal information, including the interview recording, the transcribed interview script, the consent form, and any data you provide us, in a secure TU Delft storage. Access to this information will be restricted solely to the project members, which includes the researcher (Yunus Emre Torlak) and supervisors mentioned below. After conducting the interview, a summary will be generated. Once it is ready, it will be shared with you for your approval before being published as part of the project.

Your participation in this study is entirely voluntary, and you are free to withdraw at any time. You have the option to skip any questions. If you would like to withdraw from the study, data obtained during the interview, including the recording or data sent by you later, will be deleted within one week of your request.

This study is supervised by:
Dr. A.M.G. Zuiderwijk- van Eijk
Dr.ir. J.N. Quist
Dr.ir. J.N. Quist

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information above or it has been read to me. I have been able to ask questions about the study, and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to participate in this study and understand that I can refuse to answer questions and withdraw from the study at any time without having to give a reason.	☐	☐
3. I understand that participating in the study involves: interview video recording. I also understand that the interview will be summarized as text during the study. The recording and the signed consent form will be deleted no later than one year after the end of this project (August 2024).	☐	☐

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
4. I understand that the study (the master thesis project) will end by the end of August 2023	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
5. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) [such as names, email address, signature, title, years of experience and current organisation] and associated personally identifiable research data (PIRD) [such as the interview recording and the transcript] with the potential risk of my identity being revealed the case of a security breach to the secure project data storage environment; or in case of anonymisation was incomplete on the interview data that will be part of the thesis report.	☐	☐
6. I understand that the following steps will be taken to minimise the threat of a data breach and protect my identity in the event of such a breach all personally identifiable information (PII) and associated personally identifiable research data (PIRD) will be stored in a secured environment with restricted access to the research team (Yunus Emre Torlak, Anneke Zuiderwijk, Jaco Quist, and Boriana Rukanova); the recording and any collected information from the participants will be destroyed one year after the end of this project (by September 2024). The data collected from the interview will be anonymised entirely before being included in the master thesis report.	☐	☐
7. I understand that personal information collected about me that can identify me, such as my name, signature, current organisation and email address, will not be shared beyond the study team.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
8. I acknowledge that once the summary is created, it will be shared with me, and only with my explicit consent, it will be incorporated into the project.	☐	☐
9. I agree that my responses, views, or other input can be quoted anonymously in research outputs	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
11. I understand that after the research study, the summary will be included for the master thesis report and presentation and will be made publicly available.	☐	☐

Signatures

____________________	____________________	________
Name of the participant [printed]	Signature	Date

Study contact details for further information:
Yunus Emre Torlak

Dr. A.M.G. Zuiderwijk- van Eijk

E. Explorative Interview Protocol

This interview is a part of my master's thesis project which aims to assess the potential of open data for monitoring circular economy objectives in the electric vehicle sector from a government perspective and through a created assessment framework. To collect the data, I will conduct semi-structured interviews with the employees of several non-profit organizations that re-use open data in their projects. I will ask you approximately 10 questions about the circular economy and open data.

This interview is going to take approximately 1 hour. I will record and summarize the interview and send you the summary for approval. If you have had an opportunity to read and sign the informed consent form and do not have any questions about it, we will proceed with the interview. During the interview, you can ask clarifying questions if needed. After the interview, a copy of the summary and, later, the findings report will be sent to you via email used in previous communications.

1. Can you share your experience with the circular economy (CE) monitoring, life cycle assessment (LCA), and open data?
2. Do you use open data within your work? (Open data in this context is data that is openly accessible to the public, free of restrictions allowing for its unrestricted use, reuse, and distribution.)
3. What kind of data sets/types and sources are you using?
4. What do you believe are the key specifications or criteria that should be considered for open data usability in the context of circular economy monitoring?
5. In your experience, what could be best practices or approaches for designing an assessment framework for open data (You can reflect it from normal data)? Are there any specific considerations or challenges that should be taken into account?
6. Can you provide examples or case studies where the usability open data is evaluated in the context of CE/LCA?
    1. What were the key components or features of these examples that contributed to their effectiveness?

FRAMEWORK PRESENTATION

7. Based on the presented specifications assessing open data usability in the context of circular economy monitoring, what is your expert opinion on its effectiveness in evaluating the quality, relevance, and reliability of open data for circular economy monitoring purposes?
8. Are there any potential limitations or challenges that you foresee in implementing or using the assessment framework for open data usability in the context of CE monitoring (or LCA)?
    1. How do you suggest addressing these challenges to ensure the effectiveness and practicality of the framework?
9. What are some potential next steps or considerations that should be taken into account in the development and implementation of the assessment framework for open data usability in the context of circular economy monitoring especially for electric vehicle case?
10. How important do you think it is to involve stakeholders from different domains, such as circular economy practitioners, data scientists, policymakers, and other relevant experts, in the development of the assessment framework?
    1. What strategies or methods would you recommend for obtaining their input and feedback?
11. Finally, as an expert, what overall recommendations or advice do you have for developing an effective assessment framework for open data usability in the context

of circular economy monitoring? Are there any additional insights or suggestions you want to share based on your expertise?

Thank you. As aforementioned, after summarizing the interview, I will be sharing the summary for your approval. After finishing the study, I will also share the report with you. Thank you for your participation.

F. Explorative Interview Summaries

Interview- 1

Background

The interviewee studied Industrial Design Engineering and focused on both product design and process design. They have been working for almost two years as an LCA expert in the manufacturing industry, where they explore the implementation of smart industry technologies to improve production processes. They are also involved in a project -aims to assist relevant government entities in improving their responsibilities in the context of circular economy by delivering a problem analysis report, piloting blueprint, and recommendations-, where they analyze environmental impact data and work on material flow analysis. Their primary focus is on finding circular economy solutions and optimizing sustainability alongside environmental impact assessments. The interviewee's personal information has been anonymized for confidentiality purposes.

The interviewee (and the organization) uses both open data and data that is not entirely open. The data, which is not entirely open, is widely used within the industry and can be considered almost as accessible as open data.

Data Sources and Types

The interviewee mentions that they primarily use Eurostat and CBS data, which are mostly used to describe material flows or types of materials. They also occasionally use FOA stat, a database related to agricultural data, and consult general literature resources. Additionally, the interviewee describes the EPD library, which contains environmental product declarations for specific products.

And they mention that the most used data source is EcoInvent, which is a semi-public open data sources a large database of industry average dataset on environmental impact. This database is a kind of an extensive bill of material for products that offers a detailed breakdown of all inputs and outputs, encompassing aspects such as energy and waste. For instance, the database offers information regarding emissions during the process of aluminum production. However, the database is focuses more on the environmental impacts rather than material flows. Consequently, limitations may arise concerning the comprehensive representation of material flows, such as the unavailability of direct material flow information for automobiles, scooters, and other related entities or outdated material flow data. The EcoInvent database is mainly global in scope, but can also have geo-specific data such as the Netherlands, Germany, Europe etc.

Framework Specifications

The interviewee stated that in order to retrieve information from a circular economy data set, it is important to be specific about the type of information needed, particularly regarding material flows and where materials are in use. Additionally, the quality of materials is also important for monitoring purposes. For instance, while some steel can be reused in building and infrastructure, high-quality steel is needed for cars. The interviewee noted that describing the quality of materials is difficult, and there is no standard for what constitutes quality in this context. Another aspect that needs to be considered when retrieving information from a circular economy dataset is the specific characteristics of materials. For instance, different characteristics are important for plastics than for concrete. However, the challenge is that some individuals may place more value on one characteristic over another, making it difficult to establish a specific way of describing material characteristics.

Design Approach

The interviewee discussed approaches to monitoring circularity depends on the aspect of monitoring, such as from a product or material perspective, or total usage of the raw materials within the economy etc. One possible approach would be evaluating the key factors that require monitoring and suggesting recommendations based on the identified criteria. However, interviewee highlight that they cannot prescribe what is needed for monitoring; it could be achieved through a cooperative establishment of what information is needed.

Comments on The Specifications

Specification headlines: Regenerative Resources, Life-Time Expansion, Waste Stream Recovery, Collaboration Levels, Knowledge Sharing

The interviewee initially expresses that the monitoring areas presented can be discerned by their ability to depict material flows. Additionally, the interviewee highlights that another aspect involves orchestrating elements to proficiently implement principles and practices. Therefore, it's essential to distinguish between these two areas of focus when working towards a circular economy. It would be helpful to explore potential overlaps between companies that share data and their level of circularity, as this could aid in monitoring the progress towards a circular economy. Currently, some companies are not sharing enough information, which can impede the flow of materials and hinder the transition to a circular economy. Moreover, also collaboration between parties does not mean always the system is circular.

Challenges

The process of energy transition requires a predominantly localized optimization wherein the alteration lies in the substitution of energy sources. Conversely, the transition towards a Circular Economy demands a broader global optimization, entailing a comprehensive transformation of the entire value chain. Given the significant differences in the orchestration of value chains, the likelihood of a global solution for all chains appears as a challenge. Hence, a uniform approach seems unlikely in this regard.

Moreover, again the problem could be it is not possible to directly interfere with every product with same approach. For instance, while repair or maintenance could be an option for IT interventions, it will not be suitable for others. Sometimes recycle could be better and easier for a circular intervention.

As the circular economy is a broad concept, it provides numerous opportunities for intervention, but it also presents challenges. Long-lasting products require different monitoring compared to short-lived products, as technological advancements can significantly impact their environmental impact within a year. Narrowing the scope to regenerative resources can ease intervention efforts. However, legislative requirements for declaring a product's environmental effects within 15 years of its end-of-life pose challenges for certain products with unclear futures.

Additionally, data quality poses challenges, as different databases exhibit varying levels of quality and detail. If data quality distribution is highly uneven, it may be more beneficial not to use open data. Therefore, it may not be feasible to use open data if it is offered at different levels of depth and quality.

The interviewee mentions that there are two different approaches to obtain data sets in the circular economy: the bottom-up approach and the top-down approach. The former involves looking at the element level and moving towards the top level, while the latter involves starting with the product and moving downwards. There can be significant differences between the two approaches due to the assumptions made in the calculations and what is included or not. The interviewee also notes that guidelines for these assessments have a significant impact. However, there are not strict guidelines.

Last Suggestions

The interviewee suggests that if open data is used, it is important to clarify what kind of data and guidelines are being used. It is important to clearly define the methods and assumptions made when using open data. This approach can make open data useful as it allows for identification of potential disadvantages. They suggest that it's best to first identify what everyone wants and then determine what can be done with the available information to fulfill their goals. They emphasize the importance of focusing on the feasible goals. Last suggestion is to trace back more detailed information about materials used in the circular economy, such as where they come from and how they are produced. This would help to better understand the environmental impacts of material flows in the economy. Currently, assumptions are made about how materials are produced and their associated environmental impacts. Having more detailed knowledge about the origin and production methods of materials would be beneficial.

Interview – 2

Background

The interviewee graduated from Civil engineering. The domain is the study material science and transport modelling and economic impact of it. They mention that the composition is quite important as its relationship with circular economy is quite good with circular economy (critical raw material research). Therefore, the interviewee has an extensive background in the field. Currently, they are working at an organization that acts as a bridge between academia, businesses, and governments. They express deep interest and passion for the circular economy, having dedicated 13 years to working on this topic. Their experience and expertise make them a valuable contributor to the field.

The interviewee (and the organization) uses both open data and data that is not entirely open. The data, which is not entirely open, sometimes requires a small license fee. Therefore, it can be embraced as grey zone.

Data Sources and Types

The interviewee highlights the significance of EUROSTAT and the availability of national-level databases maintained by Member States. They also mention several key sources of open data, including the United Nations, academic research from projects like Horizon Europe, and studies conducted by individuals. In addition, they refer to the World Bank and OECD as valuable providers of open data. These diverse sources offer a rich collection of open data that is utilized for their work. Lastly, another example is for data sources is EcoInvent, which could be assumed as semi-open data.

The interviewee expresses a personal preference for trade data on imports and exports, specifically in the harmonized system (HS) or combined nomenclature (CN). They appreciate the harmonization at the global level, covering over 5,000 product groups. Despite the aggregation, this harmonized data is considered significant. The interviewee generally prioritizes sectors, products, raw materials, and environmental impacts when analyzing input data and emphasizes the importance of linking them using classifications and correspondence tables. They also highlight the importance of detail level on the data, it is important to get the most detailed level on the data.

Framework Specifications

The interviewee suggests starting with the open data side. Thereafter, the process would be followed by semi-licensed or even licensed property data. They acknowledge the significance of data with emphasizing that its intrinsic meaning alone is not substantial. From an open data perspective, reliability is vital, and the data should be regularly updated. It is also important for the data to originate from authoritative institutions that adopt transparent methodologies.

The interviewee points out that the intrinsic value of the circular economy may not be immediately evident. Instead, the focus is on how the circular economy enables companies to generate profits while considering environmental impacts and striving to avoid negative consequences. The assessment of value is based on these factors. They emphasize the importance of authoritative sources and mention the usefulness of shadow prices in research, particularly when assigning a monetary value to intangible elements like biodiversity.

The interviewee explains an example project, which aims to model the material flow of vehicles. The project examines various stages such as imports, manufacturing, usage, and end-of-life in a centralized manner. Data harmonization and balancing are crucial to ensure accuracy. Additionally, similar approaches are applied to domains like household appliances and specific metal products, with a focus on sectors or branch organizations of interest.

The interviewee emphasizes the importance of considering the lifetime of cars and the potential for component reuse. Specifically, with the rise of electric vehicles, ensuring proper recycling processes for batteries is crucial for environmental and human safety. The ability to reuse batteries in less demanding applications, such as household energy storage, can significantly extend their lifespan. By leveraging open data on vehicle flows, the interviewee aims to investigate factors like component lifespan, reusability, high-value parts, and support legal enforcement to prevent environmental contamination.

Design Approach

With the design, they rely on trusted sources like the Bureau of Statistics, appreciating the rigorous verification and behind-the-scenes work conducted by these organizations. They highlight the importance of double-checking data and ensuring harmonization, exemplified by confirming import-export balances between countries. As a researcher, they place significant reliance on these authoritative institutions, valuing their protocols and procedures.

Moreover, about the approach the interviewee highlights the disparity between macro-level and micro-level data. While macro-level data is typically reliable, the same cannot be said for micro-level information concerning individual companies or their interconnections. In the context of open data, this kind of data is often missing or unavailable. Therefore, attempting to assess its quality becomes irrelevant since it is lacking by nature.

Comments on the Specifications

The interviewee acknowledges the relevance of the requirements for open data presented in the meeting (see the end). They express agreement with all the listed requirements and further suggest the consideration of data quality and completeness as additional important factors. Namely, adding the detail level or aggregation is important.

Challenges

The interviewee acknowledges the value of utilizing some data (which could be considered as semi-open) that comes with sometimes high licensing costs. Moreover, sharing the data in its original form is restricted due to licensing limitations. Therefore, data for the public study, it needs to be open. However, semi-licensed data also could be used with a detailed description of with which conditions are followed to access data.

They point another point as a challenge is that open data is valuable for consulting governments or conducting academic research. However, they point out that when it comes to supporting the circular transition at a corporate level, relying solely on open data may not be enough. To implement specific initiatives, such as showcasing investments in electric vehicles and adopting new business models, more detailed and specific data is necessary. Obtaining such granular data within an open data environment may not be readily feasible or accessible. Moreover, some data in this context will not be available as open data, mostly it will be companies' confidential data.

The interviewee presents the importance of protecting intellectual property and privacy in both corporate and personal contexts. However, they highlight that the main challenge, not specific to the circular economy transition, revolves around the presence or absence of a viable business case. The question of whether the generated data holds value and can generate profits or demonstrate other forms of worth is crucial. It may require governmental intervention if the market alone cannot address the issue. The presence or absence of a business or government model becomes a significant determining factor, and the answer to this challenge varies in different situations. To address this challenge although there is not a direct advice for the solution, there is a underlying opportunity within the autonomous Information Communication Technology (ICT) developments.

Last Suggestions

The interviewee emphasizes the significance of regulatory drivers, particularly in the context of electric vehicles and battery regulations. They highlight the need for consistency between these drivers and the data and information required for effective implementation and enforcement. The interviewee advises aligning open data practices with regulatory requirements, considering aspects like battery passports. They encourage researchers and public servants to be aware of these drivers and assess how open data can be improved or aligned to meet regulatory needs.

About involving some other stakeholders, the interviewee proposes as another domain from Public Health and Safety, as they also work on improve open data on raw materials. Although, they are not directly CBS, they mentioned that they could be relevant for the study.

Interview – 3

Background

The interviewee describes themselves as a transdisciplinary scholar with a background in molecular sciences. They have experience working outside of academia in sustainable (technology) foresight and later returned and worked on collaborative processes, particularly backcasting. Their current work revolves around sustainable innovation, transitions, and governance within the context of circular economy. Their knowledge of open data is limited and primarily obtained from colleagues in the ICT section of their organization.

The interviewee acknowledges that their personal use of open data is limited, often relying on search engines like Google for information. They have worked with a PhD researcher on a renewable energy project that involved using openly accessible data sources and GIST data. However, their experience with open data in the context of circular economy applications is not extensive, but they express interest in exploring it further. They also emphasize that increasingly realized that there is a need for open data for the circular economy.

Data Sources and Types

They have used geospatial data, such as GIS data, for location-related information but haven't extensively worked with quantitative data for circular economy applications.

Framework Specifications

The interviewee highlights transparency, accessibility as key specifications for the framework. Moreover, they emphasize the importance of uncovering data in an intelligent manner for effective decision-making in the circular economy. They acknowledge the presence of uncertainties in data but suggest that aiming for estimates that are approximately 80 to 90% accurate can still be valuable. This data particularly could be valuable for strategic decision-making regarding the use, reuse, and recycling of materials.

Design Approach

The interviewee states that there are no significant additional aspects to consider regarding approach beyond what has already been discussed. They acknowledge the existing framework being worked on as a strong example that encompasses the necessary elements for data analysis and decision-making in the circular economy.

Comments on the Specifications

The interviewee highlights the discussion around the distinction between recovery and recycling. They explain that recycling focuses on the final material, while recovery involves extracting valuable components before disposing of the remaining waste. They suggest considering whether it is necessary or meaningful to include this distinction in the framework, given its level of detail.

They suggest distinguishing between collaborations that specifically focus on circularity and those that involve governance aspects, such as industry orchestration and policy regulation. This highlights the broader context in which circular collaborations take place.

The interviewee suggest that the framework may not be limited on circularity but also consider other strategies that can contribute to sustainability, such as material substitution and reduction.

Challenges

Even within the life-cycle-assessment, assessment is as good as the data on the database that had been used. Therefore, they highlight the importance of distinguishing between foreground and background processes and the need for transparent data combinations. They also acknowledge data uncertainties and advocate for continual improvement in data quality. The interviewee recognizes the challenges related to data availability online.

They highlight the trade-off between transparency and protecting sensitive information. The importance of collaboration along the value chain is also acknowledged, as not all actors may be willing to share information due to competitiveness.

The interviewee acknowledges that one potential limitation and challenge of implementing a new framework is the initial unfamiliarity and the need for individuals to develop the capacity to use it effectively. However, they do not mention any other significant limitations or challenges associated with the framework.

The interviewee suggests that improving public acceptance can involve leveraging civil society's data availability and ensuring traceability of data at the individual or household level. They mention ongoing initiatives to analyze material flows and consumer data, but acknowledge that privacy concerns arise when tracking extensive data.

Last Suggestions

The interviewee suggests that exploring other frameworks, like responsible office technology assessment, can provide valuable analogies for the development of the new framework. While specific details are not provided, the interviewee believes that leveraging analogies from other frameworks could be advantageous.

Interview – 4

Background

Interviewee introduces themselves as a PhD researcher focusing on open data intermediaries. Their research revolves around studying third-party actors that enhance the use and accessibility of open data. While they don't have specific experience in the circular economy and open data, they have encountered research that explores the use of open data for circular economy applications. The interviewee's research on "open data" was prompted by their work on an analysis of agricultural policy.

Data Sources and Types

The interviewee discussed a project called GeoFluxus, initiated by students in the Master of Geomatics program at the Faculty of Architecture. GeoFluxus focuses on utilizing data obtained from municipalities to track and identify unused materials that are still in good condition. Although the data utilized in the project was not open data, with the analysis and efforts, they were able to advocate for certain data to be made open.

They are currently working a lot with geospatial sector and fields. Therefore, they are using Geospatial data. The main source for the data is INSPIRE geoportal which is a EU Directive that provides standards and allows data sharing among the EU Countries. INSPIRE was kind of an beginning for the open data movement in the geospatial field because with the standardised data then data sharing is easier among European countries.

Framework Specifications

The interviewee emphasizes the importance of standardizing the data format for effective circular economy monitoring. They also highlight the challenge of formatting changes over time, which can affect data consistency and comparability.

Design Approach

According to the interviewee, the design of the framework should primarily consider the stakeholders who are direct users of the data. They suggest the inclusion of a mediator role to address the diverse interests of different stakeholders effectively.

Comments on the Specifications

The interviewee stresses the significance of data granularity, suggesting that capturing data at a detailed level would provide valuable insights into the overall flow of materials and resources within the circular economy.

While machine readability is important, the interviewee highlights that it may not be sufficient on its own, as formatting issues could arise. Therefore, data identifiers and comprehensive documentation are crucial, especially when multiple datasets are used, to ensure a clear understanding of the data model.

Stakeholder engagement is deemed essential, not only for knowledge sharing but also for aligning the interests of different parties involved in circular economy monitoring.

Overall, the interviewee expresses positive feedback on the framework, indicating that it appears to meet their expectations and requirements.

Challenges

The interviewee mentions that finding open data is particularly challenging in their country of origin due to the absence of a legal framework that encourages or enforces open data practices. Addressing this issue would be crucial to promote data availability and accessibility.

Although open data is generally freely accessible, the interviewee highlights the hidden cost of sustaining open data, as it requires assigning workforce and resources. Some organizations may lack the necessary resources, so the framework should address this aspect to ensure long-term sustainability.

Another challenge cited by the interviewee is findability, where data exists but stakeholders struggle to locate it, especially if they are unaware of the responsible data provider. Addressing findability issues can significantly enhance the usability of the framework.

Last Suggestions

The interviewee suggests conducting a stakeholder analysis to define the users of open data, enabling a better understanding of their specific needs and requirements.

To improve findability, the interviewee proposes the creation of a single portal that centralizes open data resources. This portal should allow data users to be guided to the appropriate data provider, ensuring a more efficient and user-friendly experience.

Interview – 5

Background

The interviewee's background in political science, with a specific focus on public sector innovation and governance, makes them a valuable resource for understanding the governmental perspective in the context of open data and circular economy monitoring. Their current research topic on open data ecosystems brings valuable insights to the exploratory phase of the study, particularly in understanding the challenges and opportunities related to open data applications.

As part of a project, the interviewee is working on training the next generation of open data researchers to foster user-driven, circular, and inclusive open data ecosystems. They have developed a game with civil servants to discuss the benefits and risks of opening specific governmental datasets. Recently, they are exploring ways to use open data to describe societal issues.

Data Sources and Types

The interviewee primarily focuses on national or municipal open data portals, considering them essential data sources. However, they find EuroStat data insufficient and not directly relevant for their needs.

Framework Specifications

The interviewee's emphasis on key characteristics of open data, such as ease of access, recentness, completeness, contextual information, documentation, and open formats, underscores the importance of data quality and usability. These factors are crucial for ensuring that the data used for circular economy monitoring is reliable and accessible to a broader audience.

Design Approach

Their consideration of data overview as a critical aspect speaks to the practical needs of developers and users, highlighting the significance of providing a clear and concise understanding of the data's relevance and applicability.

Comments on the Specifications

The interviewee acknowledges their limited knowledge of the circular economy but provides feedback on the open data side. They believe the framework adequately captures the open data part but suggests considering circular economy expert opinions to ensure a more tailored solution.

Challenges

The interviewee points out that the open data side of the framework is somewhat generic, which may lead to missing points related to circular economy aspects. They suggest addressing this challenge by seeking input from circular economy experts to create a more customized solution.

Last Suggestions

The interviewee proposes incorporating a concise survey within the research to gain a better understanding of the needs and importance of elements in the framework.

Additionally, they suggest strengthening the connection between the open data and circular economy components to make the framework less abstract and more practical.

G. Validation Interview Protocol

Welcome to this validation interview, which is a crucial part of my master's thesis project. The aim of this study is to assess the potential of open data in monitoring circular economy objectives in the electric vehicle sector from a government perspective, using an assessment framework I have developed. The focus of this interview is to gather insights and validate the framework. Your organization's expertise in utilizing open data in circular economy projects makes your participation highly valuable.

This interview will last approximately 1 hour. The conversation will be recorded for accuracy, and I will also summarize the key points for your approval. You have already signed the informed consent forms, so if you have no questions regarding those, we can proceed with the interview. During our discussion, feel free to seek clarifications on any aspects if needed.

Questions:

1. Can you briefly introduce yourself and your expertise in the field of circular economy and/or electric vehicle batteries?
2. Are you familiar with the concept of open data and its potential applications in the circular economy? If yes, please share your thoughts on this matter.

(Presentation of the framework and case application)

3. Considering your familiarity with the concept of open data and its potential applications in promoting the circular economy, please share your thoughts on the framework I have developed.
4. In your expert opinion, what do you see as the strengths of the framework, and how do you think it can effectively contribute to advancing circular economy objectives in the electric vehicle sector?
5. What aspects of the framework do you think need improvement or further development?
6. The framework employs two datasets for monitoring circular economy objectives related to electric vehicle batteries. From your expertise, do you think these datasets are appropriate and sufficient for the purpose, or are there additional datasets you recommend?
7. Are there any specific specifications or functionalities you believe should be added to enhance the usability and effectiveness of the framework?
8. From your perspective, what potential barriers do you foresee when implementing the framework in real-world scenarios, and how do you suggest addressing these challenges?

Thank you for your valuable participation in this interview. As mentioned earlier, I will summarize the discussion and share the summary with you for your approval. Additionally, upon completing the entire study, I will share the findings report with you via email, using the same communication channel we have been using. Once again, I sincerely appreciate your contribution to this research.

H. Validation Interview Summaries

Interview – 1-2

This interview conducted with two participants.

Background

One of the interviewees is relatively new to the research area but possesses valuable industry experience. Their familiarity with open data within the industry is limited. The second interviewee is an experienced researcher which worked in several institutions in different countries. Presently, they are conducting a project focusing on the robotization of recycling. In this context, the utilization of open data becomes crucial as the project requires data for training purposes.

The second interviewee is a experienced researcher which worked in several institutions. Currently works currently works as the senior researcher at the project.

They have managed to identify some relevant data for the project. However, the found data is not directly suitable for the country in which the project will be implemented. Additionally, while there are some government-provided datasets available, they are not comprehensive enough to meet the project's needs.

They emphasize the significance of open data since it is indispensable for numerous projects. However, the process of locating and processing suitable data demands substantial effort, resulting in inefficiencies. They suggest that if the availability of data can be collectively addressed by the community, the focus could then shift to more critical aspects, such as analyzing and interpreting the data, ultimately enhancing the effectiveness of circular economy monitoring initiatives.

Comments on the Framework

They highlighted that while the framework may not encompass the entire circular economy process directly, it still offers the possibility to interpret datasets. They stressed the importance of such a framework not only for specific products like batteries but for every product within the circular economy domain. Furthermore, they stressed the importance of having comprehensive aspects covered in the framework. They noted that when aspects are well-defined and easily accessible, people gain better knowledge and understanding, which is a crucial factor in advancing circular economy initiatives.

Regarding the open data aspect of the framework, they praised its significance and, easy interpretability. Additionally, they commented on the resource evaluation component, indicating its effectiveness in evaluating available resources for circular economy monitoring.

They pointed out that implementing the framework for the products they are currently focused on would greatly benefit their initiatives, providing valuable insights and forward-thinking perspectives.

One notable aspect of the framework mentioned by them was its ability to inform and make recommendations for datasets, using the example of the battery pass project. They highlighted how this functionality could facilitate data accessibility and utilization.

Lastly, they emphasized the value of the overview perspective provided by the framework, particularly for legislators. Having such a comprehensive view of circular economy data would enable policymakers to make more informed decisions and steer initiatives in the right direction.

Challenges

According to the interviewees, one of the primary challenges they faced was the reluctance of organizations to publish their datasets. To address this issue, they are planning to implement a citizen science project as a potential solution to encourage data sharing and collaboration.

Another significant challenge identified by the interviewees was related to resource evaluation and end-of-life tracking. Understanding the exact location of end-of-life processes and accurately assessing resource usage proved to be complex, given the ongoing developments and changes within the industry.

They also acknowledged that dataset completeness could become an issue. Ensuring thorough attention to this aspect during planning stages is crucial. As a valuable approach, the interviewees suggested implementing cross-checking and verification mechanisms for datasets to enhance reliability.

The interviewees also highlighted the challenges related to data updates, particularly from a customer journey perspective. In the context of the battery case, updates may present difficulties. Therefore, they emphasized the need for an in-depth analysis of the update component, considering factors such as the timing of updates, responsible parties, and update processes.

To address these challenges, the interviewees proposed considering various potential solutions, including legislative measures to enforce data sharing and the exploration of co-financing initiatives to incentivize organizations to contribute data. Taking proactive measures to tackle these challenges will be essential to ensure the successful implementation and continuous improvement of the circular economy monitoring framework.

Further development

The interviewees provided valuable suggestions for further developing the framework. One important recommendation was to include a more specific column for the dataset's API, enhancing data accessibility and usability.

To make the framework more comprehensive and tangible, they proposed incorporating more quantifiable values, particularly for aspects like repairability and reusability. A rubric or scoring system could be introduced to facilitate a clearer understanding of these qualitative aspects.

They also emphasized the importance of adding an external verification mechanism against to misleading claims such as “greenwashing". Implementing such a mechanism, as conducted in an example project related to the building industry, would improve the credibility of the data.

Regarding the Data Quality component, they suggested providing more detailed explanations since direct assessment of data quality can be challenging. Introducing an interpretable value, like a score, would enhance the framework's interpretability and usefulness.

In terms of broader impact, the they proposed explaining the framework's contribution to the United Nations Sustainable Development Goals (SDGs). They specifically highlighted Goal 12 (Responsible Consumption and Production) and the following subgoals as strong contributions:

- 12.4: Responsible management of chemicals and waste
- 12.6: Encourage companies to adopt sustainable practices and sustainability reporting
- 12.7: Promote sustainable public procurement practices

Additionally, the interviewees recognized the framework's weak contribution to subgoal 12.8, which is “Remove market distortions that encourage wasteful consumption”.

While the framework offers a good overview of circular economy aspects, the interviewees noted that it currently lacks an overall interpretable value. They suggested exploring ways to at least enable informed decision-making using the framework's outputs, which would further enhance its value and practicality.

Interview – 3

Background

The interviewee's extensive background in the energy industry, coupled with their experience in investment banking and energy transitions for sustainable practices, makes them highly relevant to the interview. As a qualified professional with over 20 years of experience, they have been involved in various aspects of the energy sector, ranging from operations and professional services to private equity investments. Their expertise spans across energy services, power, utilities, and industrial equipment and technology companies, providing them with a comprehensive understanding of the industry's dynamics on a global scale.

Given their current position as a Senior Executive, Non-Executive, and Investor in Energy Services, the interviewee holds significant decision-making authority within the sustainable practices and energy sector. They are well-equipped to provide valuable insights into the challenges and opportunities related to circular economy monitoring, especially concerning energy transitions and sustainable practices.

Additionally, the interviewee's involvement on multiple public and private boards, including one board related to waste-to-product in the sector positions them at the forefront of key strategic discussions and policies shaping the industry's future. Their experiences and perspectives as a board member further contribute to their relevance and authority in discussing the potential of open data for circular economy monitoring.

Comments on the Framework

The interviewee found the "Stakeholder engagement" aspect of the framework particularly noteworthy. By putting the industry on a reporting basis, the framework can facilitate improved circularity and transparent reporting practices. This is crucial as it encourages active engagement from stakeholders, enabling them to better understand and enhance their circular economy initiatives.

Another positive aspect highlighted by the interviewee was the framework's comprehensiveness. Its ability to capture multiple aspects of circular economy monitoring ensures a holistic approach, providing a more complete understanding of the sustainability performance of products and processes.

Additionally, the framework was seen as providing valuable insights to companies to help them meet legal obligations and align with regulatory requirements. By providing a structured approach to circular economy monitoring, it assists companies in aligning with regulatory requirements and demonstrating their commitment to sustainable practices.

Challenges

One challenge identified by the interviewee is the difficulty of providing measurable metrics for certain elements within the framework, such as disassembly compatibility. These elements may be subjective to some extent, making it challenging to define precise and quantifiable metrics.

The novelty of the sector and the emerging nature of circular economy practices were also cited as challenges. With limited existing expertise, the interviewee pointed out that experts in the field are continuously evolving and being shaped through the development of the sector.

Further development

The interviewee recommended defining the specific stakeholders who would benefit most from the framework's implementation. While the government may drive certain sectors like the battery industry, understanding the value of the framework for other stakeholders is crucial to encourage broader participation and collaboration.

Implementing measurable metrics within the framework was proposed as a means to enhance its interpretability. This would not only make the framework more accessible but also reduce the level of subjectivity, increasing its reliability and applicability across diverse contexts.

I. Screenshot: RDW Dataset

Table Preview

View Data | Create Visualization

Kente...	Voert...	Merk	Hand...	Verva...	Datu...	Bruto...	Inrich...	Aanta...	Eerst...	Twee...	Aanta...	Cilir
0001ES	Personen...	OPEL	KADETT				Niet gere...		GRIJS	Niet gere...	4	
0001TJ	Personen...	FORD	ESCORT ...		20130725		Niet gere...		ROOD	Niet gere...	4	
0001TV	Personen...	MORGAN	4/4		20170516		Niet gere...		Niet gere...	Niet gere...	4	
0001VH	Personen...	TOYOTA	CELICA ST		20201203		Niet gere...		WIT	Niet gere...	4	
0001VM	Personen...	MERCED...	250 C		20201028		Niet gere...		WIT	Niet gere...	6	
0001WF	Aanhang...	ABLAS	P 2		20030726		veewagen		N.v.t.	N.v.t.		
0001WK	Aanhang...	SCHWEIK...	E 456		20030721		caravan		N.v.t.	N.v.t.		
0001WL	Aanhang...	SAFEC	S 1300 B		20230628		open wag...		N.v.t.	N.v.t.		
0001WP	Aanhang...	WESCO	P 2015				veewagen		N.v.t.	N.v.t.		
0001WZ	Aanhang...	PEKAWEE	A8 KRG		20070719		voor verv...		N.v.t.	N.v.t.		
0002GV	Land- of ...	RENAULT	551		20220131		Niet gere...		N.v.t.	N.v.t.		
0002MJ	Personen...	CHEVROL...	CHEVELLE		20080625		Niet gere...		GROEN	Niet gere...	8	
0002UJ	Personen...	MERCED...	280 SE A...		19920925		Niet gere...		GRIJS	Niet gere...	6	
0002VK	Personen...	VOLKSW...	135031 ...		20230313		sedan	4	GROEN	Niet gere...	4	

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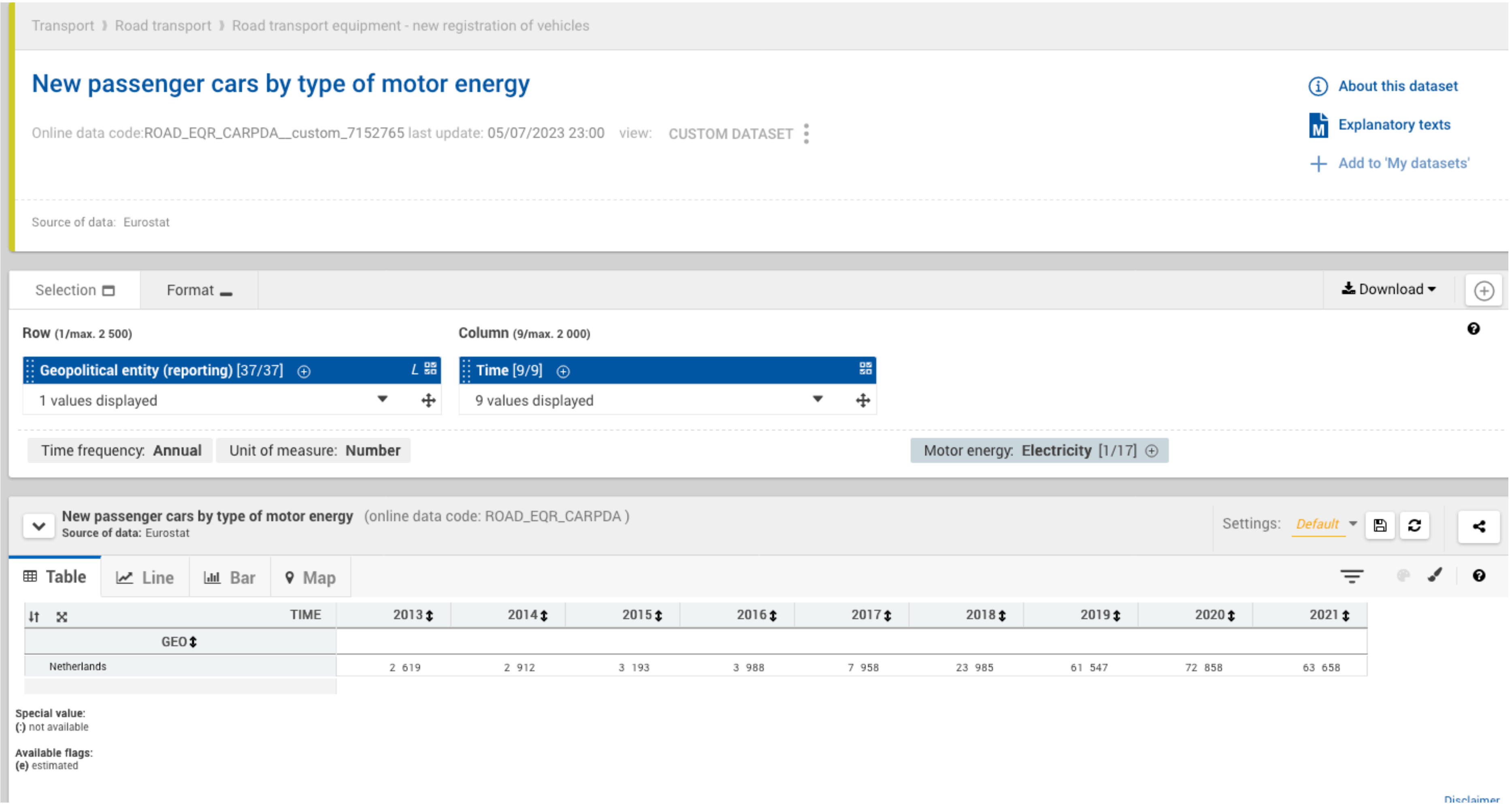
J. Screenshot: Eurostat



TIME / GEO	2013	2014	2015	2016	2017	2018	2019	2020	2021
Netherlands	2 619	2 912	3 193	3 988	7 958	23 985	61 547	72 858	63 658

K. Screenshot: BatteryPass Attribute List

Battery Passport Data Attribute Longlist

April 2023

Version 1.0

Changes to this list might occur as the technical working group of the Battery Pass proceeds its work. These will be published in an update to this version.

Battery Pass

Battery categories: x = mandatory per

#	EV	Attribute category	Attribute sub-category	Attribute	Framework Category	Framework Sub-category	Definition/Understanding by Battery Pass consortium	Requirem
14	x	Battery materials and composition	Materials	**Critical raw materials**	Resource Evaluation	Quality of the Material	Commission is subject to updating, at least every three years to reflect production, market and technological developments. The latest list will be made available via the Raw Materials Information System (RMIS) of the EU Science Hub. In the battery passport, all critical raw materials above a concentration of 0.1 % weight by weight within each (sub)-component of the battery should be specified in an aggregated way for the entire battery. For anode, cathode, and electrolyte critical raw materials can be derived from "cathode materials", "anode materials", and "electrolyte materials".	Critical raw weight. Re economica lists 30 raw the EU Cri
15	x	Battery materials and composition	Materials	**Battery chemistry**	Resource Evaluation	Quality of the Material, Regenerative Resources	Composition of a battery in general terms by specifying the cathode and anode active material as well as electrolyte.	Battery ch
16	x	Battery materials and composition	Materials	**Name of the cathode, anode, electrolyte materials**	Resource Evaluation	Quality of the Material, Regenerative Resources	Component materials used (No. 16-18): Naming the materials (as a composition of substances) in cathode, anode, electrolyte according to public standards, including specification of the corresponding component (i.e., cathode, anode, or electrolyte). We suggest a reporting threshold of 0.1 % weight by weight.	Detailed co
17	x	Battery materials and composition	Materials	**Related identifiers of the cathode, anode, electrolyte materials**	Resource Evaluation	Quality of the Material, Regenerative Resources	Component materials used (No. 16-18): CAS numbers of the materials (as a composition of substances) in cathode, anode, electrolyte.	Detailed co
18	x	Battery materials and composition	Materials	**Weight of the cathode, anode, electrolyte materials**	Resource Evaluation	Quality of the Material, Regenerative Resources	Component materials used (No. 16-18): Specifying the weight in grams of the material (as a composition of substances) in anode, cathode, electrolyte.	Detailed co
19	x	Battery materials and composition	Substances	**Name of hazardous substances**	NDR	NDR	Hazardous substances (No. 19-23): Name (agreed substance nomenclature, e.g. IUPAC or chemical name) all hazardous substance (as "any substance that poses a threat to human health and the environment"). Suggested above 0.1 % weight by weight within each (sub-)component.	"Hazardou Substance manufactu under defi
20	x	Battery materials and composition	Substances	**Hazard classes and/or categories of hazardous substances**	NDR	NDR	Hazardous substances (No. 19-23): Specify hazard classes and/ or categories of hazardous substances (as "any substance that poses a threat to human health and the environment") as defined by the CLP Regulation.	"Hazardou Substance manufactu under defi

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