Developing a framework to assess ELSA design points that contribute towards a Circular Economy in the industrial automotive manufacturing sector: *An exploratory research applied to the case of the circular economy project "ALICIA"*

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by

Marvin Owens Ikedo

Student number: 5627370

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Graduation committee

Chairperson	: Dr.ir. G.A. de Reuver, Information and Communication Technology
First Supervisor	: Dr.ir. J.N. Quist, Energy and Industry
Second Supervisor	: Dr.ir. G.A. de Reuver, Information and Communication Technology
External Supervisor	: Dr. R.B. Larsen and Dr. S. Noori, YAGHMA B.V.

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Marvin Ikedo

TU Delft

YAGHMA

Executive summary

Circular Economy (CE) aims to achieve sustainability through recycling, refurbishing, reusing, and other similar activities. Even though the concept of CE has gained considerable interest throughout the previous years and yielded significant research contributions, many critics stress the lack of incorporating ethical and social considerations into CE. This thesis researches how to facilitate such embedding of socio-ethical aspects into CE through the support of the Responsible Research and Innovation (RRI) methodology. Thus, this thesis addresses the main research question ***"How can the RRI methodology complement the CE framework to assess ethical, legal, and social aspects (ELSA)?"***. Within this study, a conceptual framework was developed that allows for embedding socio-ethical aspects in terms of assessing ELSA (aspects) that are seen as design points contributing to a socio-ethical responsible and just CE. This framework contains substantial elements of RRI, including its four dimensions (*Inclusion*, *Anticipation*, *Reflexivity*, *Responsiveness*) suggested by Stilgoe et al. (2013). Furthermore, the conceptual framework is inspired by a draft framework of Purvis et al. (2023) for a responsible CE, claiming their framework as a starting point and suggesting future recommendations for its further refinement. The conceptual framework developed in this thesis allows for an inclusive assessment procedure of (bounded) CE systems by addressing its various components and all involved stakeholders by actively communicating with them. The system's components, such as of technical or organizational nature, must be thoroughly assessed to recognize potential ELSA risks/impacts that can harm a responsible CE. Defining appropriate design points serve to mitigate such risks.

In order to test and evaluate the conceptualized framework, it got applied to a case study. The Horizon Europe granted project ALICIA represents the case study environment. ALICIA intends to establish a CE for industrial automotive manufacturing equipment (machinery and robots) within Europe. Since circularity for industrial automotive manufacturing equipment constitutes, especially on this scale, an under-researched field, this research also investigates such an automotive CE approach. Through the framework's demonstration, significant findings could be obtained. First, even though the framework manifested as effective due to the achieved insights, which are subsequently further expressed, future recommendations for further development regarding the framework's recognized limitations are suggested. Another crucial insight the case study provided emphasizes the major challenges that exist in realizing a CE for automotive production equipment. Those challenges were identified by assessing the ELSA risks of ALICIA and the design points to mitigate such. To realize equipment circularity, detailed data must be shared by companies that often contain sensitive corporational

information. Originating from the automotive industry's competitiveness, such data exchange is hard to realize as it can jeopardize companies' privacy. To overcome this, it requires collaboration between the companies and clearly defined data-sharing policies to enable such data exchange. Such ideal data exchange should ensure that still, sufficient data is shared to realize equipment circularity but simultaneously does not infringe a corporation's privacy which could harm their market position by disclosing it to competitors.

Additionally, since the automotive industry is a profit-driven one, socio-ethical dimensions must also be incorporated into such equipment CE from the beginning. Compared to the electric mobility transition, which is another sustainability endeavor of the automotive industry, socio-ethical dilemmas that refer to unethical origins of certain parts (e.g., lithium batteries), such as child labor or farm desiccation, are prevalent. To prevent such or similar dilemmas within the sustainability agenda of an automotive CE, it requires the embedding of socio-ethical considerations that were detected throughout the case study. These considerations contain to ensure, inter alia, an ethical origin of parts used for equipment refurbishment. Otherwise, if these socio-ethical issues are neglected from the start, potential drawbacks might be difficult to remedy during an already ongoing CE implementation. These both outlined challenges with their socio-ethical considerations must be more precisely addressed in the future by relevant experts.

Thus, this research's key findings cannot only be seen as beneficial for the methodology of assessing socio-ethical considerations in CE from the context of RRI but also for the circularity of automotive production equipment. Both results constitute fundamental groundwork for further recommended research in these lacking research fields.

Keywords

Circular Economy, CE, Responsible Research, RRI, ELSA, automotive manufactur, automotive equipment*

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List of abbreviations

AI	Artificial Intelligence
ALICIA	**A**ssembly **L**ines **I**n **CI**rcul**A**tion
BE	Business Ecosystem
CE	Circular Economy
CNC	Computerized Numerical Control
DBE	Digital Business Ecosystem
DE	Digital Ecosystem
DP	Digital Platform
DS	Digital Shadow
DT	Digital Twin
ELSA	Ethical, Legal, and Social Aspects
IoT	Internet of Things
LCA	Life Cycle Assessment
RRI	Responsible Research and Innovation

1 Introduction

1.1 Research problem

Due to climate change, our society has gained more awareness of activities that contribute to it and can cause harm to the environment. These activities can originate from multiple operational sectors, such as transport, energy, and production, which all urgently need to become more sustainable. While emphasizing the latter, production activities cannot be deemed sustainable if they follow the principles of the linear model of production (Fontana et al., 2021). This linear model can be described as a “take-make-dispose” economy where companies utilize materials to manufacture a specific product that gets sold to a consumer. Afterward, when the consumer recognizes that this product no longer serves its purpose, it simply gets discarded without any thought about its further processing. This pattern causes, on the one hand, severe environmental consequences, while on the other hand, also organizational ones for a company. These organizational ones can be increased exposure to risks like higher resource prices or supply disruptions. More specific examples are an increased bill of materials or additional costs due to the premature obsolescence of production assets (Ellen Macarthur Foundation, 2013).

Hence, stricter environmental standards, resource scarcity, and shifting consumer expectations put pressure on organizations to undergo a transition that facilitates a move away from this linear production scheme. Also, Industry 4.0 with its emphasis on Lean Production, takes nowadays a more sustainable production into account, but still not in a complete manner (Enyoghasi & Badurdeen, 2021). To further boost the concept of sustainable production, the idea of a Circular Economy (CE) was integrated (Fontana et al., 2021). CE can be defined as an intentionally designed restorative or regenerative industrial system. It substitutes the “end-of-life” concept while focusing on disassembly, restoration, and reuse. Moreover, the main goal of CE is to eliminate any kind of waste through improved resourced utilization (Ellen Macarthur Foundation, 2013; Prendeville & Sherry, 2014).

To ensure a CE system’s performance, each system requires an appraisal that can be instrumental in the CE’s design, implementation, or development phase. Since CE research has been steadily evolving in the last years, researchers and practitioners seek to understand how to quantify and measure the impact of CEs in a real context (Sassanelli et al., 2019). This resulted in the emergence of corresponding frameworks (Kanellou et al., 2021; Sassanelli et al., 2019). Many of these frameworks serve to assess CE performance aspects like product lifecycle stages, energy or material consumption, or other economic ones (Sassanelli et al., 2019).

However, the operationalization of CE as a sustainability model has received much criticism for neglecting social and ethical issues while shifting too much focus on the economic and environmental pillars of sustainability (Inigo & Blok, 2019; Kirchherr et al., 2017; Murray et al., 2017). However, precisely for the successful development and implementation of a CE and to reach its sustainability goals, these socio-ethical aspects also need to be considered by organizations or people involved in CE approaches (Inigo & Blok, 2019). A concept that allows for such an assessment of social and ethical aspects of (technological) innovations, including CE, is Responsible Research and Innovation (RRI), which "is built on an idea of research as a multi-stakeholder process, in which science, industry, and society collaborate to deliver innovations that reflect societal values" (Inigo & Blok, 2019, p. 282).

1.2 Case study link and description

While the general public associates a circular economy in the automotive manufacturing industry with the product flows of the produced goods' materials, this research field has been a quite established one with numerous publications (Buruzs & Torma, 2018; Suzanne et al., 2020; Turner et al., 2022; Wurster, 2021; Yu et al., 2022). Nevertheless, the automotive production sector still comprises more than just production materials; thus, many dismiss the assets like machinery or robots that actually manufacture and process these goods. About 60 to 70% of manufacturing line equipment (e.g., robotic parts or machinery) are prematurely taken out of operation and mostly scrapped while they would still function properly (Horizon Europe, 2022). Many manufacturers, therefore, constantly acquire new production equipment, which causes, as described above, substantial negative impacts on the environment. Furthermore, many companies, especially in Europe, have suffered in recent years from production disruptions due to their dependencies on suppliers outside of Europe that provide essential raw materials for building production equipment. One example would be the dependency on China's rare earths, which are key components of industrial robots (Mitchell, 2022). Thus, the notion of a CE for production equipment (e.g., manufacturing robots or machinery) is a topic with increasing awareness that still needs further research (Acerbi et al., 2020; Fontana et al., 2021).

To realize this idea, the Horizon Europe CE project ALICIA (**A**ssembly **L**ines **I**n **CI**rcul**A**tion) was initiated on February 2023. Its central vision is to create, within five to ten years, a CE for European automotive factories that allows them to trade and reuse manufacturing equipment tailored to their industrial requirements until they reach their maximum utility. Doing this contributes to closing the loop of production assets and seeing them as CE subjects (second-hand equipment). In addition, several components, such as an AI-based equipment matchmaking engine algorithm, equipment interoperability adaptors, a digital marketplace platform, and other smart digital tools are part of ALICIA's bounded CE system for facilitating its CE operations. These technological innovations have the purpose of supporting ALICIA's CE in terms of, e.g. distribution network facilitation and equipment matchmaking through the creation of a Digital Shadow (DS) and Digital Twin (DT) so that it can operate functionally and efficiently within the company's production line. It is proven that digital technologies, particularly AI, can enhance many operations of CE projects, such as monitoring information about the equipment's availability (Ghoreishi & Happonen, 2020). To better understand the ALICIA project with its aimed bounded CE system, Figure 1 depicts its structure with its components and envisaged functionalities.

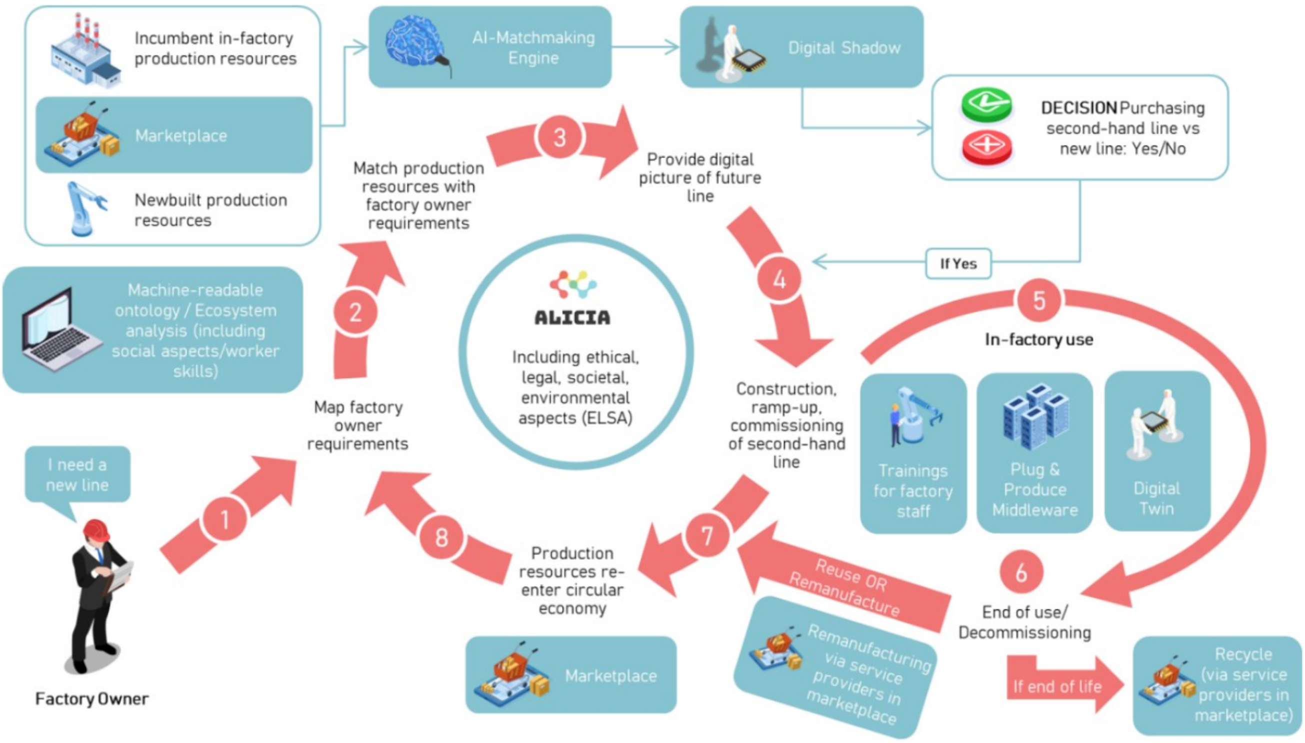

Figure 1: Structure and operating principle of ALICIA's bounded CE system (Horizon Europe, 2022)

1.3 External company for the thesis project

The in Delft located consultancy company "YAGHMA" is currently part of the ALICIA project. Thus, YAGHMA enables the possibility to collaborate with them on this project concerning the master thesis. YAGHMA's general scope of work is the offer of different assessment services for different aspects (sustainability, ethical and social, environmental, governance, etc.) and responsible innovation in innovative and/or AI-related projects that consist of complex socio-technical systems with multiple stakeholders. YAGHMA aims to minimize the projects' risks that are related to the innovations and, at the same time, maximize their benefits by setting the right goals (YAGHMA, 2023). The task YAGHMA has within the ALICIA project is the assessment of ethical and social aspects of ALICIA in terms of ELSA (ethical, legal, and social aspects) to ensure that ALICIA is a human-centered CE system. ELSA is connected to the RRI methodology (further explained in Chapter 2.1.2). Since an automotive industrial environment involves many different people (from factory managers to shop floor managers and production workers), paying attention to each needs is significant. Hence, these assessed ELSA aspects serve as design points contributing to the CE system's performance by proactively tackling potential risks.

To examine this in more detail, a use case of the ALICIA project is integrated into this research. This use case occurs in an industrial automotive environment provided by an Industrial Partner of the project consortium during the project's end in approximately three years. It intends to evaluate ALICIA and test its functionality at all levels. Therefore, it is necessary to assess, in terms of identifying and determining, ELSA design points for each area of ALICIA's bounded CE system that serve as a benchmark to later evaluate the use case's execution as also ALICIA's potential future operation on a larger scale. Hence, is not only the mentioned use case during ALICIA's design phase considered but also the future scenario when ALICIA operates in 5-10 years on a larger scale. This enables an anticipatory approach during the case study and not being restricted by only one use case. Of course, since the project is still in its beginning design phase, this future scenario cannot be specifically addressed, but during this research tried to be elaborated as realistically as possible.

Regarding the use case, ALICIA aims to support the Industrial Partner in designing a new production line for their new product generation through second-hand equipment. Such a shift towards a new product generation often requires significant changes to the existing production line, which embraces numerous manufacturing robots and machinery. As this company has faced from past experiences numerous dilemmas concerning purchasing new equipment for their production line redesigns (e.g., time and cost-intensive processes, different equipment compatibility, or problems with the workers' adaptions to specific machinery types (Horizon Europe, 2022)), they aim to remedy these dilemmas through ALICIA. This use case will be practical since real people, such as factory workers, are involved that will later operate with the second-hand equipment purchased through ALICIA.

1.4 Research questions

Based on the previously given descriptions, it is interesting to research how ethical and social dimensions can be incorporated into the CE framework to assess ELSA aspects in the context of RRI. That wants to be achieved by understanding the current knowledge level for this kind of CE assessment and developing a conceptual framework. In the form of a case study, this research aims to apply the conceptual framework and asses such ELSA aspects within a CE for automotive manufacturing equipment comprising many digital and operational components. The ALICIA project constitutes the case study environment. Furthermore, it must be investigated how these ELSA aspects contribute to ensuring the CE system's performance and can be translated into design points. Since this has not been sufficiently done yet, it needs to be explored in which way this can happen and what insights can be won into the circularity of automotive industrial manufacturing equipment, as this is a relatively underresearched field. Given that CE in the manufacturing industry embraces many stakeholders, innovative technologies, and other socio-technical factors, there is a need for comprehensive research that considers all these issues. Based on this, the master thesis aims to answer the following research questions:

How can the RRI methodology complement the CE framework to assess ethical, legal, and social aspects (ELSA)?

SQ1: What is the current state-of-the-art methodology for assessing ethical and social aspects in CE in the context of RRI and CE activities for industrial manufacturing equipment in the automotive sector?

SQ2: How can the responsible innovation framework with its four dimensions by Stilgoe et al. (2013) be incorporated into the assessment of ethical and social aspects in CE?

SQ3: To what extent is the designed framework applicable in the form of a case study within a real-life automotive industrial CE environment?

SQ4: What value do these gained insights of the case study add to the circularity of industrial manufacturing equipment in the automotive sector?

1.5 Societal and scientific relevance

Sustainability is an overall goal of our society and, thus, a central pillar of many societal endeavors. Many means to realize such sustainability exist, with one of them being CE. The CE's entire concept requires completeness in all fields to guarantee its successful implementation. Since ethical and social aspects are areas that have not been covered sufficiently within CE assessment, it is necessary to enhance their state-of-the-art assessment (Inigo & Blok, 2019; Pla-Julián & Guevara, 2019). Moreover, CE strategy for industrial production equipment is an aspiring research field that lacks research and, thus, needs further examination as well (Acerbi et al., 2020). Especially, in the automotive sector, which relates to the conducted case study, no relevant insights exist. Hence, this research aims to contribute to a more holistic assessment of CE frameworks by emphasizing the socio-ethical aspects of CE and providing new findings into CE strategies for automotive manufacturing equipment in this context. Due to the exploratory nature of this research, first insights into these relatively underdeveloped research fields can be obtained that can serve as a helpful contribution to further research. Thanks to the established conceptual framework and applied case study, these findings are not only theoretical but also practical. This can support sustainability endeavors where, besides scientific contributions, also societal ones can be achieved. If a CE that embeds socio-ethical values is established, it can positively impact the environment and the directly or indirectly affected society. This can then contribute to the transition towards a just CE (Purvis et al., 2023).

Even though CE consists of a holistic socio-technical system, this research only focuses on the ethical and social dimensions of CE and not on the other non-socio-ethical of CE that are already further researched (e.g., CE implementation strategies or business models). The emphasis of this study is solely on exploring how ELSA can be assessed in CE.

1.6 Link to CoSEM MSc. program

As this research topic covers the examination of a complex-socio technical system with its diverse interrelating aspects and multiple internally and externally involved stakeholders that constitute a bounded CE system, it represents an ideal subject for the CoSEM program. Within the research, the developed conceptual framework is applied to a case study (ALICIA) to evaluate the framework's theoretical and practical implications. Moreover, this case study allows the assessment of crucial ELSA aspects, considered design points contributing to socio-ethical responsible CE. Doing so requires the investigation of the technical as well as the social components of CE. Moreover, current policies relating to the components of the case study's environment must also be analyzed. Further frameworks and methods that the research utilizes are integral constituents taught throughout the CoSEM master program.

1.7 Outline

This introductory chapter is followed by a literature review (Chapter 2), which more precisely presents the knowledge gap and core concepts concerning the research subject. This second chapter also includes the development and elaboration of the conceptual framework influenced by the literature review results. After this, Chapter 3 emphasizes the methodology with the research approach, data collection, and data analysis. Chapter 4 presents the case study where the conceptual framework gets applied to the ALICIA project. Next, the research's entire outcome, with its scientific contributions, imitations, and recommendations for future research, is discussed in Chapter 5. Finally, Chapter 6 covers the conclusion that can be drawn from the Master's thesis research.

2 Literature review

This chapter presents the literature review, which aims to identify the knowledge gap and the core concepts of the research subjects that are elementary for establishing the conceptual framework.

2.1 Exploring the state-of-the-art methodology for socio-ethical assessment in Circular Economy and industrial automotive production equipment circularity

Developing the intended conceptual framework requires a fundamental knowledge of the current state-of-the-art methodology of assessing socio-ethical aspects in CE and the thesis research's core concepts. To facilitate this, the researcher conducted a literature review. Thus, this sub-chapter comprises three sections. First, the methodology of the literature review process is described. Then, the following section discusses the findings and core concepts. The final section elaborates on how these findings are translated into a knowledge gap, which contributes to formulating the main and sub-research questions, and the necessity and groundwork of the conceptual framework to be developed.

2.1.1 Literature review

In order to achieve the objectives mentioned above, a review of the current state of literature concerning the general CE methodology, CE assessment with its indicators/drivers, the consideration of ethical and social issues within CE, CE for production equipment in the industrial general and automotive production sector, and the RRI and ELSA methodology was executed.

The literature review process was done within three main phases, which are: 1) Planning, 2) Conducting, and 3) Reporting according to (Kitchenham & Charters, 2007). Initially, the planning phase identified the necessity to review the chosen topic (Kitchenham & Charters, 2007). As already briefly mentioned in Chapter 1, this necessity consists of the lack of addressing ethical and social aspects within the CE methodology and CE activities for industrial production equipment.

Next, the second phase (Conducting) determined the search strategy to find relevant literature. This action is a multistage process with determined selection criteria (Kitchenham & Charters, 2007). To ensure that the corresponding and helpful literature could be found, scholar.google.com and scopus.com were utilized by searching the following keywords:

("circular economy" AND ("framework" OR "performance" OR "assessment" OR "success factor"))* OR

("circular economy" AND ("responsible innovation" OR "ethic" OR "social*" OR "societal" OR "ELSA" OR "responsible innovation"))* OR

("circular economy" AND ("production" OR "automotive") AND ("machine" OR "robot*" OR "equipment"))* OR

("responsible innovation" OR "ELSA" OR "RRI")

The only determined selection criteria were that just articles written in English were considered. As the RRI and CE methodologies, both, are steadily evolving research areas, there were no specific selection criteria, like publication year. This aimed to get as many insights as possible through the literature on the research fields. Moreover, backward and forward snowballing on the found publications was performed, which helped to receive more in-depth literature on the research subjects.

The literature review process led to 58 preliminary documents which were after a careful selection reduced to 31. Figure 2 illustrates the entire literature review process in detail. The selected articles deal with the following topics: general CE concept, state-of-the-art assessment frameworks and methods for CE, CE drivers and indicators, consideration of ethical and/or social aspects in CE methodology, utilization of robotics in production, CE in the automotive industry, definitions RRI and ELSA with related frameworks and methods, and the connection of RRI to CE. Table 3 in Appendix A presents an overview of the selected and analyzed publications with associated information (author, title, date, and focused research field).

Lastly, the literature review's third phase, Reporting, consisted of extracting the results, which then assisted in defining the core concepts, knowledge gap, and main/sub-research questions (Kitchenham & Charters, 2007). All this is elaborated in the subsequent two subsections.

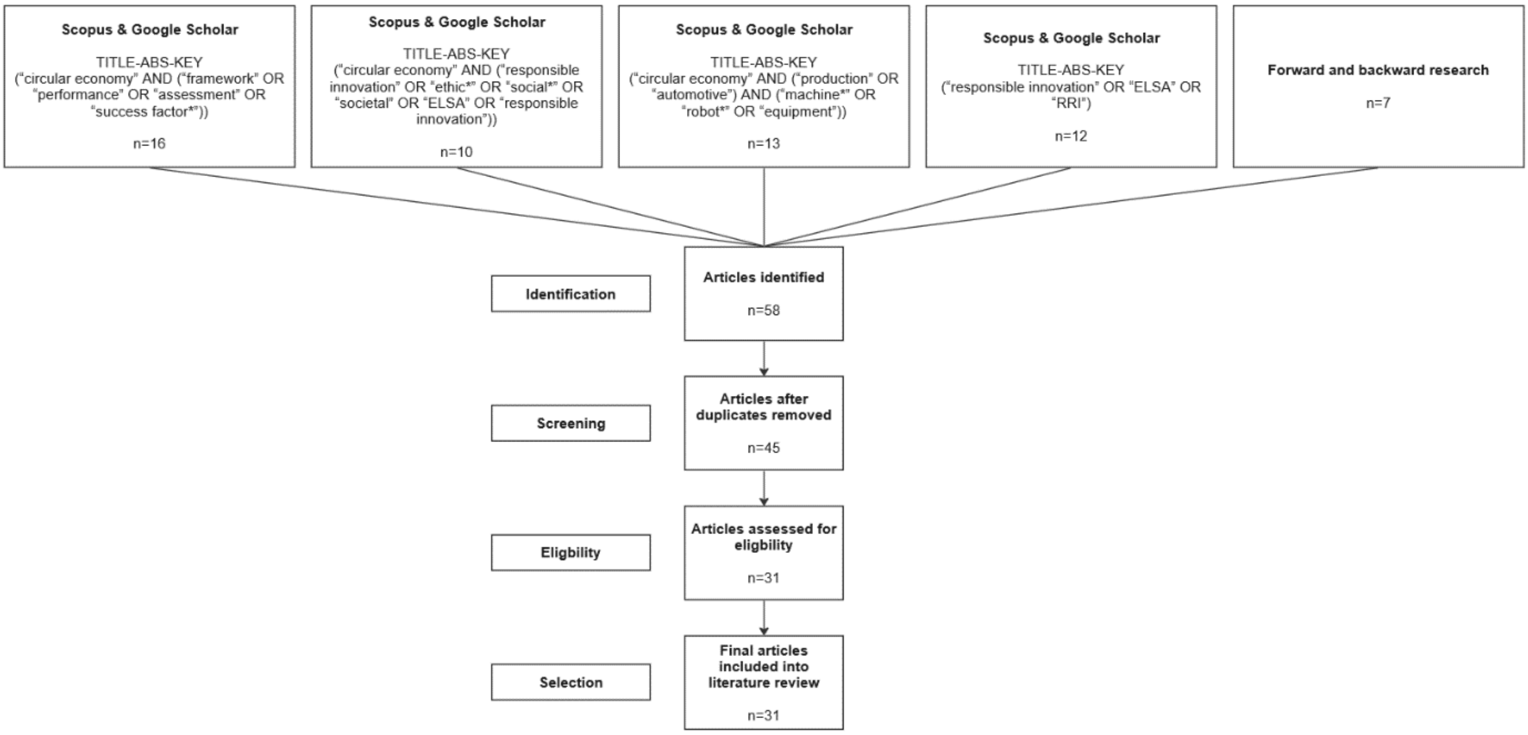

Figure 2: Visualization of the literature review selection process

2.1.2 Results

Subsequently, the results of the literature review are presented. These results are grouped per topic to ensure a clear overview.

CE methodology core concepts

CE has gained significant interest within policy, business, and research sectors for designing various methods and undertakings that promote a move away from the linear models of production and consumption in the context of the CE concept (Purvis et al., 2023). While the primary goal of CE in the production sector is already explained in Chapter 1.1, a more general and precise definition describes CE "as an economic system that replaces the 'end-of life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers"

(Kirchherr et al., 2017, p. 229). To implement CE, multiple different R frameworks have been established that guide how CE should be performed through divided strategies or implementation sequences. The most common frameworks are the 3R (with the strategies: Reduce, Reuse, Recycle), the 4R (Reduce, Reuse, Recycle, Recover), or even 9R (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover) (Kirchherr et al., 2017).

CE for manufacturing equipment in relation to automotive sector

These days the manufacturing sector, particularly the automotive one, is the largest in Europe automated by robots (Haarburger et al., 2021). Manufacturing robots, as also semi-automatic machinery, perform many tasks (e.g., assembling, welding, or pressing) in comparison to humans more efficient, faster, and more reliable. Thus, their application causes an increase in prosperity, for example, by improving productivity and assisting factory line workers during heavy work or taking it entirely off their hands (Reinhart et al., 2012; Zhang et al., 2021). Once automotive OEMs or part manufacturers must adapt their production line due to changes in their production series or consider their production equipment as old, there is no clearly defined procedure to manage this decommissioned equipment. Consequently, they most often get scrapped due to the lack of standards, knowledge, and technology on how to handle them further (Chang et al., 2020).

Research on circular activities that do exist within the automotive industry refers more to the consumables required for the cars' manufacture, like raw materials or parts (e.g., tires or cables), or to the car as a product itself (Buruzs & Torma, 2018; Turner et al., 2022; Wurster, 2021; Yu et al., 2022). Hence, no helpful specific literature was found in the literature review that entirely focuses on the circulation of automotive equipment as in production robotics or machinery. Detected articles that conducted direct research on CE in the context of production assets and their further management are not narrowed down to a specific production sector but to the general industrial production sector (Acerbi et al., 2020; Fontana et al., 2021). Hence, this type of research concerning a CE for production equipment within the industrial manufacturing sector still requires further research (Acerbi et al., 2020).

Criticism of CE methodology concerning ethical & social considerations

Even though it has gained growing attention throughout the years, the entire concept of CE and its related research is still in a process of development (Inigo & Blok, 2019; Sassanelli et al., 2019). The most commonly addressed drivers for the notion of functioning CE, connected to promoting sustainability, are mostly related to environmental profit (Purvis et al., 2023). Such example drivers are the elimination of wastes, replacement of the end-of-life notion through restoration, and closed-loop product lifecycles, including retention of value embedded into materials and products (Sassanelli et al., 2019). Due to the CE concept's still ongoing research, the concept of CE as a whole with its existing approaches for assessing and realizing CE, focuses mainly on the just-mentioned environmental aspects and hence lacks the covering of a more holistic approach that also includes ethical and social dimensions (Kirchherr et al., 2017; Negri et al., 2021; Pascale et al., 2021; Pla-Julián & Guevara, 2019; Purvis et al., 2023; Sassanelli et al., 2019). As CE can be seen as a multi-faceted paradigm by nature (Negri et al., 2021), it includes a continuous engagement of all stakeholders that mostly originate from different groups, which makes it inevitable to pay attention to social dimensions for enabling this stakeholder inclusion (Chrispim et al., 2023; Inigo & Blok, 2019). By doing so, all participants of a CE system can obtain a general awareness of the CE, including its goals and the different expectations and needs of every involved individual (Mies & Gold, 2021).

Furthermore, ethical and social aspects are accountable for social responsibility, such as the guarantee of the well-being, safety, and access to education and training regarding the CE system of all existing stakeholders (e.g., factory workers), ethically and sustainably (Mies & Gold, 2021). Additionally, access to the CE's physical or digital structures in terms of resources like material or information procurement should be fair and inclusive to everybody that participates in it (Mies & Gold, 2021). Since many CE systems include technological innovations and other digital solutions (Chrispim et al., 2023; Sassanelli et al., 2019; Thakker & Bakshi, 2021), a proper assessment of these technologies is required (Inigo & Blok, 2019; Stilgoe et al., 2013). Especially nowadays, in our digital age, where technological components like Artificial Intelligence (AI) are pretty advanced, it is essential to perform such technological evaluations. Hence, the CE must be regarded as a socio-technical transition concept that includes diverse interrelating technical and non-technical components (Purvis et al., 2023). Therefore, the all just described, and further ethical and social-related CE aspects need to be thoroughly taken into account to contribute towards a more holistic CE approach that can add to a sustainable and inclusive CE. Because as long as the CE concept lacks these aspects, it is not clear how it can contribute to greater social equality (Murray et al., 2017).

Until now, there only exists a limited amount of publications that focus on a CE approach that also covers ethical and societal aspects (Pascale et al., 2021; Pla-Julián & Guevara, 2019). However, publications that do cover these aspects, emphasize them more in terms of environmental life cycle or social costs (Thakker & Bakshi, 2021). Thus, the bigger picture of entire social and ethical concerns, as described above, is omitted as well. For this reason, numerous authors recommend a further research effort that develops the CE methodology by determining and integrating socio-ethical aspects (Kalioujny & Ermushko, 2017; Negri et al., 2021; Pascale et al., 2021; Sassanelli et al., 2019).

RRI & its relation to CE

Another concept that is steadily gaining relevance and is also still in a process of development is RRI (Inigo & Blok, 2019). RRI can be defined as a transparent and interactive process where both the societal stakeholders and innovators become mutually responsive to each other with a view to the ethical acceptability, sustainability, and societal desirability of the entire innovation process with its related products to allow a proper embedding of the scientific and technological advances into our society (von Schomberg, 2012). Foreseeing the socio-ethical consequences that innovations might entail and developing preventive strategies to mitigate them is one of RRI's main purposes (Burget et al., 2017). The integration of RRI into technological innovations has received wider interest within the last years, especially for innovations that strive for sustainability (Zwart et al., 2014), which includes CE (Inigo & Blok, 2019).

Furthermore, RRI aims to promote discussions concerning innovation goals and what can be seen as socially desired and ethically acceptable between all different kinds of stakeholders within a CE system (Inigo & Blok, 2019). This could be beneficial to overcome this conceptual fragmentation in the evolution of the CE methodology concerning the neglect of ethical and social issues (Inigo & Blok, 2019). Nevertheless, although both CE and RRI share common goals, they have been operationalized as two separate concepts in policy and execution (Inigo & Blok, 2019). To facilitate the inclusion of social and ethical aspects in CE it is advantageous to merge these two concepts to close this gap, as "RRI could be a powerful tool in the transition to a more reflexive, inclusive and socially oriented CE" (Inigo & Blok, 2019, p. 287).

A fundamental role of RRI plays the ELSA methodology on which RRI builds (Inigo & Blok, 2019; Zwart et al., 2014). ELSA aims to focus on social and ethical consequences and impacts of innovations through an anticipatory approach and a concentration on the agenda-setting and design stages of innovation trajectories instead on the product stage itself (Oftedal, 2014; Zwart et al., 2014; Zwart & Nelis, 2009). In addition, legislative support, which is also part of ELSA, was identified as another essential primary lever for social sustainability development in CE projects (e.g., for contractual agreements) (Mies & Gold, 2021). Even though RRI is by some authors defined as a developed ELSA approach (Inigo & Blok, 2019), these two concepts tend to resemble in their stratagem (Zwart et al., 2014). Nevertheless, the methodology of RRI facilitates, compared to ELSA, a more holistic view of ethical and social aspects of transition activities in terms of stakeholder involvement and reflexivity (Oftedal, 2014). However, since the RRI methodology is still in a development process (Inigo & Blok, 2019) it can be advantageous to combine both intertwined approaches, which can complement each other and promote responsible innovation campaigns (Burget et al., 2017; Zwart et al., 2014).

One main framework that got developed in the context of the RRI methodology is the responsible innovation framework (here called: RIF) with its four dimensions which has the purpose to understand and support endeavors that are aimed to facilitate responsible innovation within innovative projects (Stilgoe et al., 2013). The practical execution of this framework occurs through its four fundamental dimensions of responsible innovation, which according to (Gammon, 2022; Stilgoe et al., 2013) are:

- ***Inclusion*** *– "Are all relevant participants, values, and considerations included in the process of innovation?":* As already mentioned above, stakeholder engagement is an inherent part of RRI to be aware of all existing stakeholders of the innovation, which is the foundation of enabling a participatory approach. That inclusion can be enabled; it is essential to address these several participants of the innovation to comprehend their position and assumptions within the innovation (project) and consider them accordingly.
- ***Anticipation*** *- "Are potential risks of the innovation (with its technologies and other processes) and its utilization anticipated and fed back to the design/development process?":* This dimension has the purpose of thinking already in advance about what might happen to avoid bad outcomes. Discovering unforeseen implications can happen through scrutinizing the innovation with questions like "what is known?", "what is most likely to happen", or "what is possible?".
- ***Reflexivity*** *- "Do the involved stakeholders reflect on the innovation's impacts, purposes, motivations, and values?":* Responsibility requires reflexivity from the involved individuals and organizations. The dimension of reflexivity allows them to look at themselves with their actions and assumptions while at the same time being aware that this might not be shared with everybody who is also involved in the innovation. Specific rules or code of conducts that exist within the innovation project's environment itself but also institutional ones such as (inter)national laws or governmental policies must be reflected here and can be a helpful orientation (Paredes-Frigolett et al., 2015; Paredes-Frigolett, 2016; Purvis et al., 2023).
- ***Responsiveness*** *– "Is the innovation responsive to ethical and social needs and its process organized in such way that it is able to respond to new developments and insights, including unexpected ones?":* This dimension is described as an outcome of the processes from the previous three dimensions by responding to them in terms of their emerged feedback, issues, or requests (Owen & Pansera, 2019; Purvis et al., 2023). This enables responding and shifting courses that lead to responsibility and consequently ensure successful RRI (Paredes-Frigolett et al., 2015).

For the RIF's application in practice, it must be understood that these dimensions do not operate independently but must be connected and applied as an embedded whole (Stilgoe et al., 2013). Within their publication, the creators of this framework applied it to the case of an innovation project in the field of geoengineering. There, they combined it with a stage-gating approach to evaluate RRI by relating the relevant dimensions to each stage/milestone of the project. Furthermore, the authors concluded that the RIF could have a more general application and relevance for various innovative projects from different research fields. They also stated the fact that the RIF is in its beginnings and is hence, not a completed tool but rather an input for further development. Their application of the framework on their case should not be seen as evidence of how exactly the RIF should be implemented. Rather, they motivate researchers to see it as a starting point for developing further guidance to govern innovative trajectories based on their established RIF with its dimensions (Stilgoe et al., 2013).

This recommendation has led researchers to implement the RIF in different fields, develop it further, and create frameworks intending to govern or model RRI (Paredes-Frigolett et al., 2015; Paredes-Frigolett, 2016). All of these frameworks facilitate functions such as strategic decision-making in innovation systems from an RRI point of view or the evaluation of RRI in specific stages of general innovation projects within a broader context (Paredes-Frigolett et al., 2015; Paredes-Frigolett, 2016; Stilgoe et al., 2013), endeavors within the field of geoengineering (Stilgoe et al., 2013), data analytics (Patterson et al., 2023) or the health sector (Pearson et al., 2016). However, a framework that focuses explicitly on how to incorporate the RIF with its four dimensions by (Stilgoe et al., 2013) for assessing, in terms of identifying and determining, ethical and social aspects within CE lacks research. Until now, only one CE framework in the context of RIF and its four dimensions exists (Purvis et al., 2023), which is explained in more detail hereafter.

The framework proposed by (Purvis et al., 2023) responds to the critical literature concerning CE and its missing incorporation of socio-ethical issues. The authors address this issue by suggesting the RIF’s embedding into CE to provide better insights into CE from a socio-ethical point of view and achieve a (socio-ethical) equitable CE through this. Furthermore, they link the four RIF dimensions to existing socio-ethical CE dilemmas and want to inspire researchers to overcome them through proposed strategies and techniques per relevant RIF dimension (e.g., stakeholder mapping and dialogues for “Inclusion” or socio-literary techniques for “Anticipation”). Hence, the authors' (Purvis et al., 2023) approach of combining CE with RRI and its four dimensions to ensure that CE actions become responsible and inclusive from a socio-ethical point of view, in terms of paying attention to the needs and values of all participating stakeholders, is one of their proposed framework’s main goals (Purvis et al., 2023). Still, for several reasons (further addressed in the subsequent paragraph) their framework should not be regarded as a finished solution to incorporate the RIF into CE but rather aims to support and facilitate “a developing discourse on CE within the context of the notion of RRI” (Purvis et al., 2023, p. 11).

First, the authors claim that their established framework does not indicate how their outcomes elaborated through the RIF dimensions, such as values or visions that can be seen as crucial RRI elements, should be applied to CE in practice. Besides their recommended further research on this subject, they advise a more practical undertaking concerning the RIF in terms of an actual implementation through case studies rather than solely a theoretical exploration. They claim that doing this is necessary to test the feasibility of the theoretical assumptions made by CE with the RIF (Purvis et al., 2023). Furthermore, this aspect also leads to the next gap on how to address *Reflexivity* and *Responsiveness* and communicate them to stakeholders in real-life CE systems that experience, due to their dynamic nature, constant shifts and changes in their environments (Purvis et al., 2023). What also must be paid attention to are the different outcomes that can be expected depending on the different CE sectors (e.g., automotive or renewable energy industry) where the RIF dimensions are applied. Likewise, these insights can be facilitated by a case study approach as well (Purvis et al., 2023).

2.1.3 Knowledge gap

Derived from the literature review process results that serve to comprehend the core concepts of all relevant topics and identify the currently existing research deficits, these findings are now aggregated into the knowledge gap with the related research questions.

It can be concluded that it is crucial to assess ethical and social dimensions within the current CE approach. Until now, this has seldom been done and there is no leading framework for doing so. Facilitating this could help potentially contribute to a more holistic overall concept of CE. Stakeholder engagement, which is fundamental in the RRI methodology, is one of the key means that can enable this consideration of socio-ethical aspects in CE and must be taken more into account. As RRI consists of various concepts/tools like ELSA and RIF, they have been proven instrumental in incorporating socio-ethical aspects into CE methodology. However, all proponents who have studied this notion in more detail recommend a follow-up research approach to develop this further. This is due to factors like the research's infancy on CE combined with RRI and the RIF with its four dimensions. In addition, to the necessity of more theoretical research, there is also the need for a missing practical approach, which can provide new insights for the specific integration of the four RIF dimensions into CE. This could happen through the application of case studies in real CE environments.

Another emerging field that requires further research is the feasibility of CE for manufacturing equipment in the automotive industry. As the previous section explains, a contribution on how to further handle production assets in terms of robots or machinery to enable circularity actions is, therefore, necessary and can contribute to a more general understanding and set the foundation for further CE research in this field.

Thus, this research wants to contribute to incorporating (assessing) ethical and social dimensions in CE in the context of RRI with its ELSA and RIF concepts to support the realization of a well-working industrial manufacturing CE. The aim of doing this is to establish a framework within the master's thesis research that is then applied to the real-life case of ALICIA. Due to the ALICIA case that provides a real-life environment, the focus is here on the CE "R-phases" Refurbish, and Reuse, which are also the most relevant phases that ALICIA focuses on, as ALICIA's emphasis is on the provision of second-hand equipment that is refurbished and re-used by the companies (in this case the respective company for the use case and the possible future scenario when ALICIA is implemented on a large scale). Doing this aims to gain the best possible insights regarding the defined knowledge gap.

In conclusion, the two general main fields that lack research, which are the criticism of socio-ethical considerations in CE and missing insights into CE activities for automotive industrial production equipment, constitute two novelties that are formed into one knowledge gap, which the in Chapter 1.4 addressed main and sub-research questions aim to tackle.

The thesis' goal is to establish a framework that can be used to assess ELSA aspects within CE. This part of the research can be seen as conceptual concerning the framework development. Through the literature review, a clearer understanding of the state-of-the-art literature on the assessment of socio-ethical aspects in CE, the general concept of RRI, and the circularity of automotive manufacturing equipment was obtained, which serves as the groundwork for the conceptual framework's development.

As mentioned in the previous results section, many authors researched how RRI with its related frameworks can be implemented into CE to address its socio-ethical aspects. As the RIF framework with its four dimensions has proven itself as a supportive tool for doing so, it still requires further theoretical and practical research for its utilization, as just one publication was found that specifically addresses this approach (Purvis et al., 2023). Additionally, due to further recommendations on exploring its incorporation into CE, it must be examined how this can be done while focusing on the main principles of CE and RRI, such as stakeholder engagement in a real-life CE environment.

2.2 Establishing the conceptual framework

The conceptual framework will now be developed and elaborated based on the elaboration throughout the previous sub-chapter.

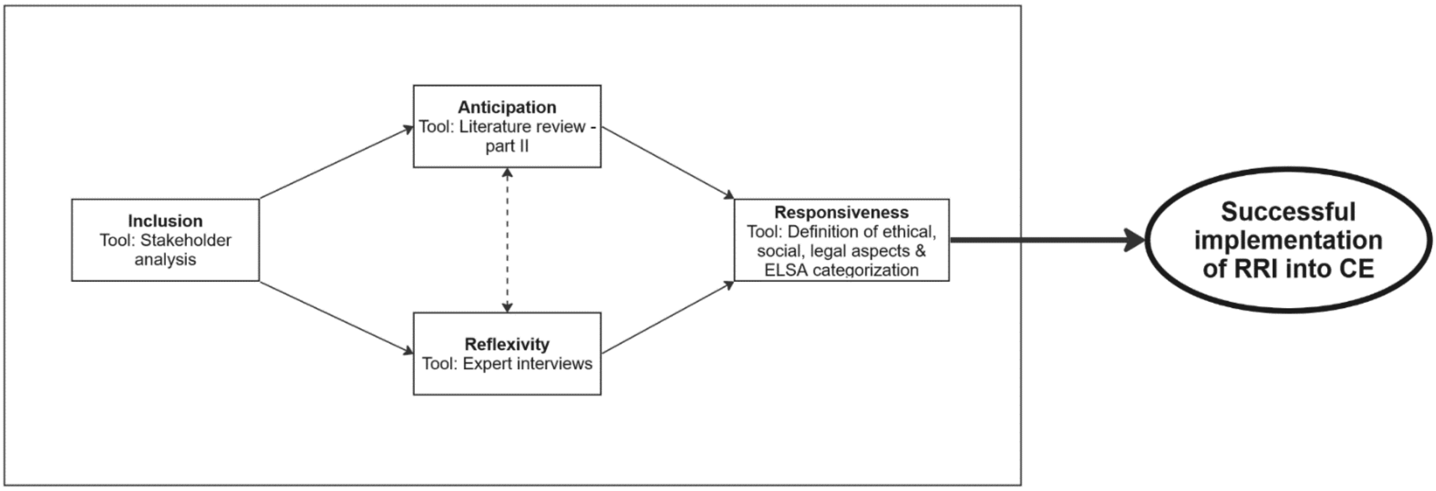

Figure 3: Established conceptual framework for assessing socio-ethical ELSA aspects in CE based on the four dimensions of RRI (own representation based on (Paredes-Frigolett et al., 2015) with improvements made)

The developed framework begins with the dimension of *Inclusion* which refers to stakeholder inclusion for guaranteeing a successful RRI process (Stilgoe et al., 2013). This dimension constitutes the conceptual framework's foundation and influences its next two dimensions, *Anticipation* and *Reflexivity*, which also both affect each other as "reflexivity is also highly related to anticipation since it reflects the anticipatory capacity to deal with unexpected occurrences" (Purvis et al., 2023, p. 7). The outcome of these previous three dimensions' implementation is the final dimension, *Responsiveness* which, in the end, serves to guarantee the successful implementation of RRI into CE. The process of what kind of tools will be used per dimension so that the framework's performance can be ensured is influenced by the literature review findings orientating on the recommendations on which technique (here: tool) can be utilized per dimension by (Purvis et al., 2023). This framework with its tools and order of dimensions gets further explained in the following sections. Moreover, Figure 3 displays the conceptual framework and how the four RIF dimensions are applied in the context of the conceptual framework. It shows the related tools per dimension to achieve a successful RRI process in CE that safeguards the embedding of socio-ethical aspects by assessing ELSA aspects.

It is important to note that this conceptual framework was designed to be explicitly applied to CE systems for assessing their socio-ethical ELSA aspects. Therefore, applying this framework regarding the tools used per RIF dimension varies to a certain extent depending on the CE system to be assessed. For example, the stakeholder analysis must be carried out according to the given CE environment, which also affects the definition of the keywords employed in the desk research, and then the planning and conducting of the expert interviews. In sum, the framework's implementation occurs concerning its sequence and tools everywhere the same; only how the tools are executed is different. This can be seen in more detail later in Chapter 4 with its related case study where the conceptual framework is applied. By applying this conceptual framework to the ALICIA project, this research provides essential insights specific to the ALICIA CE system. However, these findings are not only of benefit to the ALICIA project. Rather, they also provide critical socio-ethical implications for CE systems in general. Those are elaborated in the Discussion Chapter towards the thesis' end.

2.2.1 Inclusion dimension

It is assumed that RRI can only occur if, from the beginning, all stakeholders (internal & external) are involved to ensure nobody's shortcomings and design trade-offs for their actions, assumptions, goals, morals, and values (Stilgoe et al., 2013). This also counts for CE since it involves, by nature, many stakeholders whose inclusion is critical to the consideration of socio-ethical aspects which contribute to a successful CE (Chrispim et al., 2023; Mies & Gold, 2021; Pla-Julián & Guevara, 2019; Purvis et al., 2023). Hence, this *Inclusion* dimension is chosen as the beginning one that sets the foundation as it is crucial for the intended framework and its methodology. Many times a long list of stakeholders involved in a CE system can be seen as a boundary to fulfill this aim of a socio-ethical assessment. Thus, it is necessary to define the stakeholders (internal, external, functions, roles, etc.) as clearly as possible (Purvis et al., 2023). To make this happen a stakeholder mapping is their suggested tool for this dimension which is extended by the thesis researcher with a stakeholder analysis. This has the purpose to identify all types of stakeholders with their roles, purposes, and functions that lead to understanding the environment and relevant components (technical as also operational) the CE system consists of. Moreover, (Purvis et al., 2023) proposed to structure CE stakeholders into the following major categories: *policies* (e.g. governance structure at several levels that are responsible for regulations), *institutions* (e.g. businesses that produce products and materials that can be seen as CE objects), and *society* (e.g. consumers or NGOs who are indirectly affected by the CE). This gained overall input through the stakeholder analysis serves as a basis for the next two dimensions.

What also provides additional inputs to understand better the corresponding CE environment with its stakeholders occurs through observations during e.g., project meetings and discussions or self-study of the project's circumstances.

2.2.2 Anticipation dimension

For anticipating (unforeseen) risks and impacts, desk research is the following tool of the conceptual framework's methodology. Everyone that applies this framework must conduct this desk research according to their CE system and determine the appropriate relatable searching keywords and/or selection criteria. To illustrate this better, concerning the third sub-question, the desk research within the case study was conducted based on the case of ALICIA to explore socio-ethical issues and ELSA design points for the different components that ALICIA consists of (e.g., AI equipment matchmaking algorithm, DS/DT generation, implementation, refurbishment, reuse, handling, and operation of production equipment, worker adoption of the equipment, or state-of-the-art knowledge on digital platforms/marketplaces that enable the offer and trading of production equipment in a CE context). The chosen searching keywords are based on the just mentioned aspects and influenced by the utilized technologies within the analyzed CE system and its components identified in the *Inclusion* dimension (e.g., for the case of ALICIA: ethical compliance with AI matchmaking tools or other digital innovations such as digital marketplace tools).

Conducting such desk research facilitates discovering the first ELSA aspects and assessing components (as in technologies or other activities) that exist in the analyzed CE system. Thus, this tool focuses on findings of ethical, legal, and social issues that refer to the analyzed CE system with its components. As already mentioned, these can all be seen as (unforeseen) risks and impacts that must be preventively mitigated to ensure a responsible CE by developing ELSA design points.

2.2.3 Reflexivity dimension

Of course, only desk research does not provide sufficient insights into this study. Hence, the repeatedly underlined inclusion and participation of stakeholders within a CE system are crucial and support the consideration of the ethical and social aspects (Chrispim et al., 2023; Inigo & Blok, 2019). This stakeholder engagement is helpful to gain more insights concerning further socio-ethical aspects where literature only gives limited insights, especially in this under-researched field. To achieve this, the tool of the *Reflexivity* dimension provides further support, which is: conducting expert interviews with stakeholders that exist within and outside the CE system. Performing interviews can be seen as beneficial since active communication among CE participants is vital (Purvis et al., 2023). This chosen tool refers to the multidisciplinary collaboration for critical third-party appraisal that (Purvis et al., 2023) propose in their framework. Still, the possibility of interviewing people outside the CE system who are experts in the related fields can facilitate a bigger picture of the entire assessment. It is important to design the interview questions in a way that they provide insights into the participants' views and understandings of CE in general, as well as on the assessed CE system.

Thus, the *Anticipation* dimension allows for broad insights into the entire CE system, while Reflexivity delivers insights more objectively by communicating with the individual stakeholders and experts. These combined individual opinions can then be analyzed and translated into more general aspects, which occurs in the following dimension *Reflexivity* with the ELSA criteria categorization. Furthermore, during the *Inclusion* dimension process, observations throughout the CE project meetings, discussions, etc., are beneficial opportunities to gain insights that support this interviewing technique in terms of designing the questionnaires; so does as well the desk research during *Anticipation*.

2.2.4 Responsiveness dimension

This dimension serves to merge the outcome of the previous dimensions' processes to fully understand the potential impacts of the CE system's current and future development (Purvis et al., 2023). From the perspective of the *Responsiveness* dimension, the detected societal and ethical challenges can be utilized as opportunities for establishing changes in the context of the RRI methodology by communicating and defining societal right processes and impacts so that they can be implemented into the practice (Purvis et al., 2023; Zwart et al., 2014). To realize this, all these final findings are, in this final dimension's procedure, merged, analyzed, and translated into ELSA aspects that serve as design points to ensure a responsible CE. For that purpose, ELSA is used to categorize the detected aspects into the sections ethical, social, and legal. The legal aspect is also included here because legislative support is a key driver for social sustainability and its progress in CE practice (Mies & Gold, 2021), as mentioned in Chapter 2.1.2. This ELSA categorization process provides a better visual overview to communicate the detected socio-ethical aspects to all CE participants in a structured and organized way. Moreover, it contributes through these clearly defined socio-ethical aspects that serve as requirements for a more responsible CE in the context of RRI.

As the development and description of the conceptual framework is considered finished, the upcoming chapter elaborates on the research methodology.

3 Methodology

This chapter covers the thesis research approach and explains the data collection and analysis methods. A part of the research method already happened in Chapter 2.2 by developing the conceptual framework. The other part which covers the case study approach with all the executed methods is now given in the following.

3.1 Research approach

A qualitative exploratory research approach with an afterward performed case study on the ALICIA project is selected to answer the main research question and the related sub-questions. This sub-chapter presents the research approach with its associated elements.

Briefly, to summarize the research approach at the outset of this methodology chapter, the aim is to establish a framework (already done in Chater 2.2) that can be applied to assess ethical and social aspects within CE systems. The first part of the research is considered conceptual concerning the framework development and is elaborated on in the previous chapter. A literature review of the state-of-the-art assessment of ethical and social aspects in CE, the concepts and conjunction of RRI and ELSA, and the circularity of industrial automotive manufacturing equipment provides a clearer understanding of the current state, which serves as a starting point for this research. Then, the established conceptual framework is applied to the case of ALICIA. This is supported by research methods such as participant observation and expert interviews. Finally, the results derived from this case study serve not only as beneficial insights for the ALICIA project but also contribute to the general assessment of socio-ethical aspects in CE and the circularity of industrial automotive manufacturing equipment.

3.1.1 Exploratory research

Exploratory research has the purpose to explore, mostly, novel problems within a research field that have not been sufficiently researched yet (BRM, 2023; Brown, 2006). Since the presented knowledge gap concerning the CE methodology has gained emerging attention within recent years but is due to its novelty not adequately researched, this exploratory approach is deemed useful to gain more insights. Accordingly, the research questions exploratory research approaches aim to tackle can be “what”, “why”, and “how” questions

(BRM, 2023). Because exploratory research activities usually serve to study a not yet clearly defined problem, it is possible that the researcher might change the direction during the research. This can be because of newly upcoming insights. Still, many kinds of research that follow an exploratory approach do not always aim to precisely answer the existing questions with final results but more to provide a fundamental basis for future research in their corresponding novel field. Methods for data collection in exploratory research can be interviews, observations, or focus groups (BRM, 2023) but also literature reviews and informal discussions with internal and external stakeholders (Singh, 2007). These qualitative research methods lead straight on to the next section, qualitative research.

3.1.2 Qualitative research

The need for expanding the scope and rigor of engineering research qualitative research methods has become more significant, which helps to answer research questions that cannot be answered through quantitative research approaches (Koro-Ljungberg & Douglas, 2008). Different than in quantitative nature, where numerical data is integral, non-numerical and textual data are the main components of qualitative research (van Chism et al., 2008).

Moreover, qualitative research facilitates the penetration of various study areas because it enables seeing and understanding empirical environments alternatively. It also allows us to grasp the complexity that human behaviors entail in such a way that better insights can be gathered, which would be through (quantitative) research methods, that are based on randomized controls and prediction, not possible (Koro-Ljungberg & Douglas, 2008). According to (Teherani et al., 2015), the paradigms that underpin qualitative research are based on post-positivism and constructivism. Post-positivism builds on the general understanding of positivist convictions that exist in quantitative research and stands for the fact that through appropriate experimental methods, an unparalleled reality can be detected. However, in addition, it refers that environmental and individual distinctions are crucial and can have an influence on this reality. Researchers that strive for constructivism assume that a singular reality does not exist, but rather many different perceptions of such reality by the participants involved in the research (Teherani et al., 2015). Because qualitative research enables such “systematic inquiry into social phenomena in natural settings” (Teherani et al., 2015, p. 669) valuable insights into how individuals experience certain things, how they behave, or how organizations operate and in which way these interplays form their relations.

For assessing ELSA aspects in CE, it is necessary to have a comprehensive overall view of a given CE project with its entire environment that involves many different individuals with their various views, different organizations, aspects, and their relationships. All these mentioned aspects continuously influence each other. To achieve such a comprehensive understanding, a qualitative research approach with its just-described characteristics is chosen.

Further elements of qualitative research are the collection and analysis of data in textual form that can happen, through the methods mentioned above, such as interviews (Borrego et al., 2009). In qualitative research, the researcher alone is mainly responsible for collecting the data, which helps the researcher to investigate what things happen and why and what exactly these findings mean to the participants that are involved in the study (Teherani et al., 2015). More emphasis on the data collection, processing, and analysis reads in Chapters 3.2 and 3.3.

3.1.3 Case study

Additionally, a case study is conducted within this research. In general, a case study can be defined as an "in-depth study of a bounded system" (van Chism et al., 2008, p. 12). In this research, the case study consists of applying the developed conceptual framework (Chapter 2.2) to the ALICIA project, which represents a real-life bounded CE system. This serves to demonstrate the conceptual framework. Performing such a case study allows in-depth and multi-faceted explorations of complex issues and their real-life context (Crowe et al., 2011). Focusing during this approach on a case can deliver a significant contribution to knowledge and theory building by challenging or extending the theory. In addition, it can even support refocusing future research in this entire field (Yin, 2018). Deploying the conceptual framework to a single case helps to review the framework's functionality and gain better insights into its limitations and the assessment of socio-ethical aspects and how they can be seen in the CE methodology. In addition, insights can be won concerning the circularity of automotive manufacturing equipment. Obtaining all these findings can, additionally, help in formulating future research recommendations. Furthermore, a case study offers flexibility concerning the design of the research by utilizing data collection methods such as interviews, observations, and the use of archival materials (van Chism et al., 2008).

3.2 Data collection

In the following, all methods regarding the collection of the data are described. The intended collected data should deliver essential insights into the ELSA design points of the ALICIA project. These methods are observations, desk research, and expert interviews and are substantial parts (tools) of the in Chapter 2.2 developed conceptual framework that are used within the case study.

3.2.1 Observations

Carrying out observations during e.g., gatherings in a project allows one to get an unfiltered view of a specific environment with its involved persons. In this research, a participant observation occurs, as the responsible master thesis researcher is, through YAGHMA, part of the case study environment of ALICIA. While doing this observation and being a participant, it is important to be as objective as possible, as subjectivity can overweigh many times from the participant's point of view. These observations require records documenting the observed event, which can happen by taking notes (van Chism et al., 2008). During the case study, the participant observation occurred during the kick-off meeting of the ALICIA project that took place in February 2023 in Munich. More precisely, field notes in written form were taken during this observation. According to (Tenzek, 2017), such field notes can happen in different forms, such as diaries or scratch notes. Moreover, field notes can be understood as essential to understanding phenomena within the researched field which support the further research approach with its following methods (Tenzek, 2017). The field notes taken from the ALICIA case study are visible in Appendix B.

3.2.2 Desk Research

Desk research refers to secondary research that investigates collected data from existing, already-conducted research documents done by other people (Aela, 2022). These research findings can be used for own research purposes to approach a particular research endeavor by analyzing this retrieved data in a way that supports the research (Aela, 2022). The desk research in this thesis aims to gain further insights within the case study regarding the conceptual framework's dimension *Anticipation* to receive a broader understanding of the core concepts for ALICIA's components (especially certain technologies) and their potential risks and impacts. More on this is given in the course of Chapter 4.

3.2.3 Expert interviews

As described in the chapters above, interviews are a common and valuable method for collecting data in qualitative research. The interviews in this research took place during the case study. According to (van Chism et al., 2008), through interviews, data can be collected from the participants by focusing their attention on a certain field of interest and gaining their opinions about it. An important aspect that must be kept by the interviewer in mind while interviewing the participants is that the obtained insights are not a legit definition for the areas addressed in the interviews. In fact, this interview data can be seen as personal views regarding how the interviewees consider certain fields, areas, or topics (van Chism et al., 2008).

The three main phases of the interviewing process are planning, conducting, and analyzing (Bolderston, 2012). While the first two are discussed in this chapter, the upcoming data analysis sub-chapter elaborates on the interviews' analysis. Before conducting the interviews, the interviewing process must be planned. It is necessary to select suitable participants that represent the studied field while still aiming to interview an appropriate cross-section of persons, especially in qualitative research which does not has the purpose to achieve generalizability (Bolderston, 2012). This is also why the selected interview participants of this research are experts within a particular field that is related to one of the components of ALICIA's bounded CE system (e.g., AI-matchmaking equipment algorithm, digital marketplace platform, or operating production equipment). Sill, participants within and outside the ALICIA project environment were selected to gain a broader comprehension. Moreover, internet interviews through online video conferencing took place to still ensure a face-to-face experience (Bolderston, 2012).

After determining the suitable interviewees, the interview questions must be defined. For this, questions in semi-structured form are chosen, which allows through pre-defined but also open-ended questions for flexibility and, thus, explore tangential areas that might emerge throughout the interview by adjusting questions as well (Bolderston, 2012; van Chism et al., 2008). The questionnaires are developed based on the outcome of the previous two dimensions, mainly of the desk research (Bolderston, 2012) during *Anticipation*. The interview questions serve to address these findings further or even receive new insights that remained undetected throughout the desk research. The questions are categorized into seven different topic blocks, each representing one component of ALICIA's bounded CE system. Each topic block contains main, planned follow-up, and spontaneous follow-up questions (Bolderston, 2012). For the sake of visualization and the later occurring coding (data analysis), each topic block is assigned a specific color. Appendix D shows the interview protocol with the question lists. Chapter 4.4.1 explains this further. Of course, every interviewing process starts with an introduction phase where the researcher introduces himself/herself and then allows the participant to do the same. Next, introducing questions, part of the first topic block, serve as initial questions that allow the participant to depict the interview topic (van Chism et al., 2008) and gain insights into the participant's broader understanding of CE. This is important to start the interview from a more holistic perspective and then, afterward, zoom into the subject by asking more precise questions that occur in the following topic blocks.

The interviews were recorded with a device in the form of mp3 files which support the processing and analysis of the interview data. At all times, the participants agreed to the recording procedure while being aware of the interview's informed consent form (see Appendix C).

Further information on how the questions are specifically built up and how the interviewing process went are given in Chapter 4.4.

3.3 Data analysis

This sub-chapter shows the approaches for processing and analyzing the collected data from the utilized research methods.

3.3.1 Summarizing observations

As already elaborated in the data collection chapter, the during the observation taken field notes provide important input for the case study approach. The insights gained from the field notes can be combined with interviews and other data (Tenzek, 2017), which happens in this thesis by joining the data from the observations with the ones from the desk research to formulate the questionnaires of the expert interviews. In this research, the field notes are an essential fundamental structure to gain general insights into how the case study environment (ALICIA project) is established and which aspects must be considered during the stakeholder mapping, the desk research, and the expert interviews. Without the observation process with its field notes, these subsequent approaches would not have been possible in such an accurate manner. Especially to detect crucial issues of ALICIA's components that might relate to the aimed assessment of the ELSA design points. To achieve this, the field notes were examined and analyzed to create a meaning from the happened event (van Chism et al., 2008) and translate it into valuable input.

3.3.2 Synthesizing desk research results

After its collection, the data obtained through the desk research is carefully analyzed and disseminated in written form to elaborate on these findings and how they relate to the pursued research subject(s).

3.3.3 Transcribing and interpreting interviews

Further, another crucial part considering the research data is the transcription und summarizing of the expert interviews. Doing this can be seen as processing and analyzing the interview data. First, the collected data in a mp3 file gets transcribed into a text format. Bolderston states that even though interview transcription is a time-consuming action, it is superb to develop familiarity with the data (Bolderston, 2012). In this research, as agreed with the faculty's responsible data manager (data management plan) and the graduation committee, the transcripts are modified into anonymized interview transcript summaries that censor sensitive participant data (e.g., name, age, company, precise profession). Furthermore, the mp3 audio files and uncensored transcription files are property of YAGHMA as, again, agreed with all involved parties and documented in the data management plan. This alteration into anonymized summaries does in no way change the substance of the interviews and serves alone to ensure privacy and better clarity. Moreover, these summaries are necessary to analyze and interpret the interview data. This data can then be categorized into themes through coding which allows to examine the entire data to get important insights relevant for the results (Bolderston, 2012). In this case, the transcribed data's categorization, or coding process, occurs through marking the answers in the already described color themes that refer to each topic block. Furthermore, this coding procedure is done manually, and the interpreted interview insights are displayed in a respondent list table that presents all gained insights from this analysis. This analyzed and interpreted interview data gets then synthesized and discussed. More on this is given in Chapter 4.4 of the case study.

4 Case study – ALICIA project

This chapter covers the case study to which the established conceptual framework got applied.

4.1 Case study procedure

The developed conceptual framework was in the context of this master thesis research, as already mentioned, applied to a case study of the ALICIA project. Doing this serves to test and evaluate the developed framework and gain insights into the assessment of socio-ethical ELSA aspects in CE and the circularity for automotive manufacturing equipment with their limitations and recommendations for future research. Exemplary for this case study is the use case described in Chapter 1, which covers the design phase of ALICIA and the future scenario of a broad implementation of ALICIA's CE in 5-10 years. Considering these two aspects helps to formulate ELSA design points not only for the single use case but also for the aimed broader operation of ALICIA. In this case study, the conceptual framework's application is divided into four steps, each per RRI dimension with its associated tools.

4.2 Step 1: Inclusion

Beginning, the conceptual framework's first dimension *Inclusion*, which encompasses the techniques of stakeholder mapping and analysis, is performed on the ALICIA project. This allows to understand better the bounded CE system of ALICIA, its project environment, and the components it consists of to analyze each concerning possible socio-ethical risks or impacts for the assessment of ELSA design points.

4.2.1 Stakeholder mapping and analysis

To ensure a successful execution of the *Inclusion* dimension with all its before-elaborated purposes (Chapter 2.2), a stakeholder mapping and analysis is the starting method. This stakeholder analysis focuses on the internal and external stakeholders of the ALICIA consortium that contribute to designing and implementing its CE. Besides the internal ones, potential external stakeholders that could emerge when ALICIA is in the future in operation are discussed as well. Doing this allows for gaining a fundamental knowledge of the entire ALICIA CE project environment with its stakeholders, their roles, and the tasks that they fulfill within

ALICIA. Furthermore, the components that compose ALICIA and are responsible for implementing ALICIA's bounded CE system are defined in detail through this as well. It is elementary to have a clear understanding of all these aspects to further assess ALICIA's ELSA design points. The framework's following steps/dimensions (*Anticipation* and *Reflexivity*) with their tools build upon those detected components of ALICIA.

Figure 4, on the next page, illustrates a stakeholder map of ALICIA's internal and external stakeholders and the activities they fulfill within ALICIA, either designing the components or facilitating their operation. The figure's scheme is elucidated in more detail in the following paragraph. It must be noted that the stakeholder map only visualizes the most critical connections between the stakeholders. For the sake of confidentiality, all participating stakeholder organizations are referred to anonymously and in paraphrased form (e.g., Industrial Partner 1). Of course, all stakeholders are linked to each other in a certain way, such as the Ecosystem Analysis Partner and YAGHMA with all the others due to the analyses that both perform during ALICIA's design phase. However, for this research, only processes and connections related to the execution of CE activities are mapped. Focusing on this allows for forming the fundament for assessing the ELSA aspects of ALICIA's bounded CE system. Moreover, the in Figure 4 visualized data exchanges occur during both scenarios, the use case and the future operation scenario of ALICIA. The input for this stakeholder map and analysis was obtained from the participant observation during the project's kick-off meeting in Munich (see Appendix B for field notes) and during the thesis internship tasks at YAGHMA.

First, the internal stakeholders of the ALICIA consortium with their general roles are emphasized.

The Project Coordination Partner is the coordinator of the entire ALICIA project. Their main tasks are guiding the project with its including work packages and ensuring that the communication channels, data management, and file-sharing infrastructure work well. In addition to that, they fulfill project management-related tasks to guarantee that the project's milestones are reached. This stakeholder also serves as the contact point of the ALICIA project (Horizon Europe, 2022).

The Ecosystem Analysis Partner is responsible for capturing the technical requirements of all participants in ALICIA, especially those of the factory owners and the ALICIA bounded CE system itself. Furthermore, they elaborate on exploring various business model possibilities (e.g., servitization based-models) for ALICIA and perform other socio-organizational tasks about ALICIA's use case (Horizon Europe, 2022).

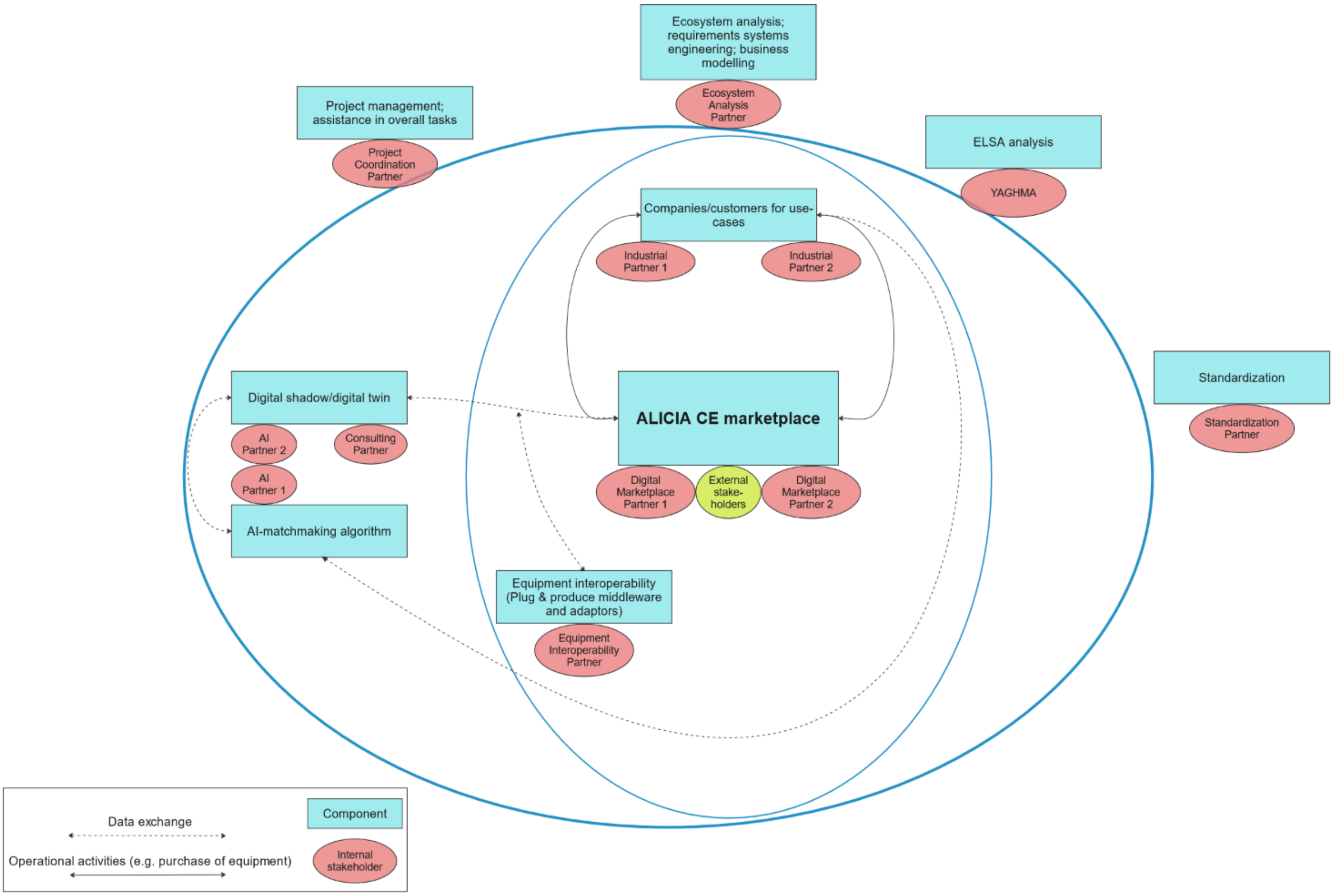

Figure 4: Stakeholder map of ALICIA with its embedded components

YAGHMA is in charge of assessing ALICIA's ELSA design points. Since this task is already explained in Chapter 1.3, it does not again get further addressed.

As one of the world's leaders in standardization, the Standardization Partner ensures that ALICIA's activities comply with existing standards. Moreover, this partner maps technology developments related to second-hand production reuse by giving an overview of the standardization landscape and examining whether selected project results align with existing standardizations or if new ones must be designed (Horizon Europe, 2022).

Industrial Partner 1 is a leading automotive tier 1 supplier and represents an ALICIA customer that purchases second-hand production equipment in terms of the in Chapter 1.3 explained use case. This stakeholder also includes further stakeholder groups, which are the production workers and managers that are also relevant for the use case and this case study. Industrial

Partner 2 also gives further support with their knowledge of establishing automation solutions for industrial companies in the automotive sector (Horizon Europe, 2022).

One of the largest European online marketplaces for industrial second-hand production equipment is provided by the Digital Marketplace Partner 1, whose expertise lies in evaluating, decommissioning, transporting the machinery, and everything else around the purchase transactions. Thus, this stakeholder contributes with its second-hand equipment and marketplace platform expertise to ALICIA (Horizon Europe, 2022).

Digital Marketplace Partner 2 is a software company specializing in developing software for the private and public sectors. Due to their strong knowledge on Industry 4.0, they contribute to the development of ALICIA’s digital operations, like developing the digital marketplace platform’s architecture (Horizon Europe, 2022).

AI Partner 1 is considered one of France's most highly esteemed engineering schools. Their specialization lies in digital technology, energy, and the environment. Within ALICIA, this stakeholder develops the AI-matchmaking engine that chooses suitable second-hand equipment for the purchasing companies based on their (factory-owner and worker) requirements (Horizon Europe, 2022).

The task of establishing the DS/DT that aims to design a more concrete assembly line or equipment composition based on the AI matchmaker’s findings and allows presenting the possible designed options to the potential purchaser is the responsibility of AI Partner 2. Hence, the DS/DT design also contains AI elements. Moreover, the Consulting Partner assists AI Partner 2 in developing the DT and supports the use case partner (Industrial Partner 1) in implementing the second-hand line equipment. The functionalities of the DS/DT are decisive concerning how the equipment interoperability plug and produce middleware adaptors should be designed, which is explained in the next paragraph (Horizon Europe, 2022).

The Equipment Interoperability Partner’s general activity field consists of digitalizing production resources and lines using Internet of Things (IoT) means. Within ALICIA, this stakeholder is responsible for developing digital solutions in the form of plug-and-produce middleware adaptors that facilitate the interoperability of second-hand equipment compiled by the AI-matchmaking engine and the DS/DT. Since such equipment mainly originate from different manufacturers/suppliers and hence run on different syntaxes, these adapters are necessary to facilitate their interoperability to trouble-free operate within the same production environment (Horizon Europe, 2022).

To improve sustainability in the industrial sector, the ALICIA project aims for a long-term operation. Thus, it must be not only paid attention to its design phase with the according use case but also already to its future implementation and operation in terms of the circularity activities and the corresponding components of ALICIA that facilitate such activities. These future activities reveal external stakeholders that are not, right now, part of the ALICIA consortium but can later be responsible for tasks like selling, evaluating (status of the equipment's current condition), decommissioning, or refurbishing/maintaining the second-hand production equipment. Since these external stakeholders are, for now, unknown during the project's design process (due to the nature of having limited use cases and a clearly defined project consortium), they are generally referred to as external stakeholders. This possible scenario, when ALICIA is in the future in successful operation, including these additional external stakeholder activities, can be seen in Figure 5. Another external stakeholder not involved in the development and operation of ALICIA is the general public, such as buyers in the automotive sector, citizens, or the media. If ALICIA contributes to sustainability, the general public typically perceives this as positive.

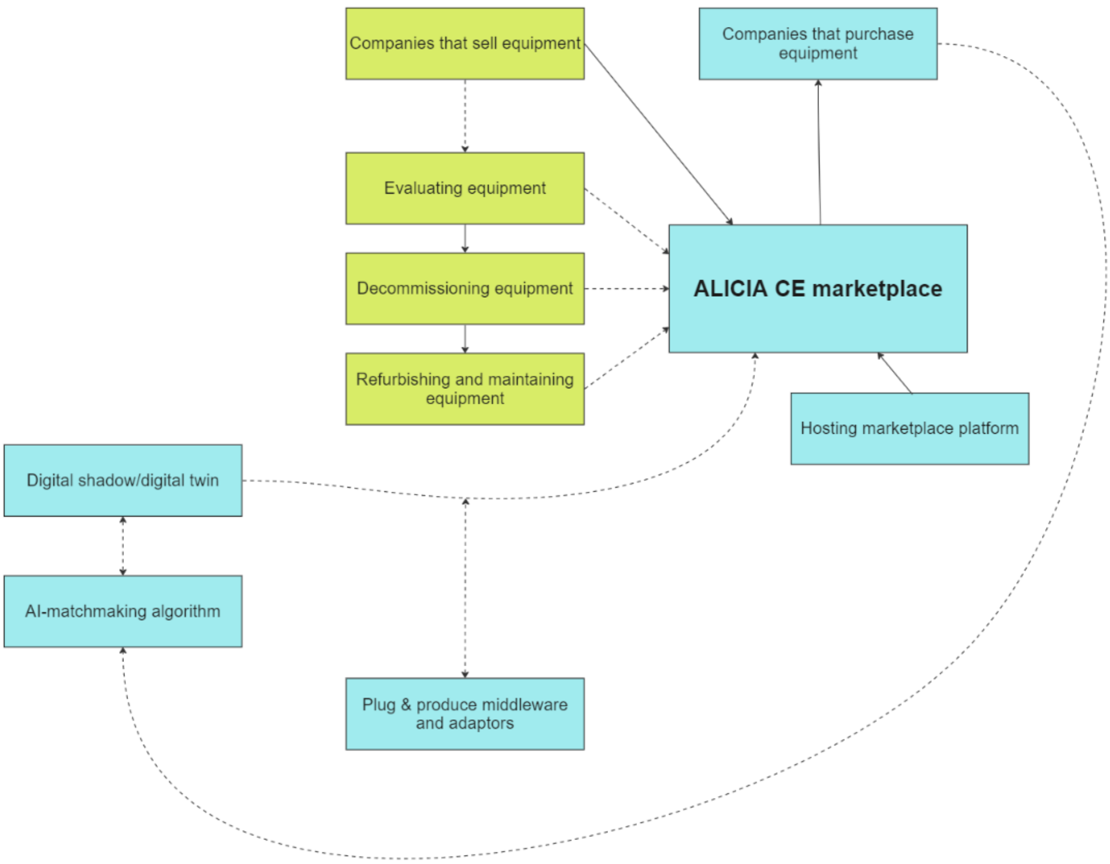

Figure 5: Representation of how ALICIA could operate in the future, including the potential CE activities of the external stakeholders (marked in green)

All these just elaborated stakeholders are categorized according to (Purvis et al., 2023), and as explained in the conceptual framework Chapter 2.2, into the following categories (Table 1):

Policies *(e.g. governance structure at several levels that are responsible for regulations)*	Ecosystem Analysis Partner, YAGHMA Standardization Partner, Project Coordination Partner
Institutions *(e.g. businesses that produce products and materials that can be seen as CE objects or contribute to CE activities)*	Industrial Partner 1 & 2, Equipment Interoperability Partner, Digital Marketplace Partners 1 & 2, AI Partners 1 & 2, Consulting Partner, external stakeholders
Society *(e.g. consumers or NGOs who are indirectly affected by the CE)*	General public

Table 1: Stakeholder categorization of ALICIA

Since all stakeholders equally contribute to ALICIA and the aim is to assess the ELSA design points of ALICIA as a whole, it can be said that there are no significant differences regarding their influencing power and interest.

4.2.2 Components of ALICIA

Hence, the from the stakeholder analysis resulting main components of ALICIA that are relevant during the design but also implementation phase and require an embedding of socio-ethical (ELSA) aspects to ensure a responsible innovation process of ALICIA's CE from an RRI point of view are:

- **AI-matchmaking algorithm engine** to find suitable equipment parts for the purchaser according to his factory owner requirements
- Generating the **DS/DT** for the required production equipment to fit into an entire (existing) production line
- Producing the plug and produce middleware **equipment interoperability** adaptors for the different equipment
- Hosting the ALICIA **digital marketplace platform** in terms of functionality, security, and other governance tasks
- **Selling the equipment on ALICIA's marketplace** by companies
- **Evaluating, decommissioning, and refurbishing/maintaining** the equipment by several providers, which are all together referred to as **CE activities**
- **Purchasing second-hand equipment through ALICIA's marketplace** by companies which also leads to the **adoption of the equipment by the workers**

- Steady **data exchange** that facilitates ALICIA's entire (above-mentioned) components functionality

All those components were detected throughout the Inclusion dimension with its stakeholder analysis and the performed observation.

It is also worth mentioning that it is essential to focus on all these main components of ALICIA, not just on the CE-related ones, such as refurbishing or decommissioning. Instead, all the technological and organizational components, like ALICIA's data flows, digital marketplace platform, and AI mechanisms, must be analyzed. Only through this can the aimed holistic assessment of ALICIA's ELSA design points occur. These just listed activities serve as a basis for the transition to the following dimensions of the conceptual framework: *Anticipation* (desk research) and *Reflexivity* (expert interviews), which in the end, influence *Responsiveness* (definition of ELSA design points and their categorization)

4.3 Step 2: Anticipation

The *Anticipation* dimension, which constitutes the second step of the conceptual framework, is applied to discover unforeseen ELSA risks and impacts within ALICIA. Based on the stakeholder analysis in *Inclusion*, ALICIA's examined project environment with its stakeholders and functional components form the foundation for this second step. The tool of this *Anticipation* step is a desk research that allows one to gain first insights into potential ELSA risks. Moreover, this desk research process also aims to support comprehension of the core concepts of ALICIA's components, such as technological functionalities or current regulations. This entire desk research process is discussed in the following sections.

4.3.1 Desk research

Potential or unforeseen ELSA risks that can harm the CE of ALICIA can be detected, which this desk research aims to investigate. Based on ALICIA's components yielded in the stakeholder analysis, and the performed observation with there being already discussed potential risks, the following keywords were chosen to conduct this desk research:

("AI" AND "production equipment" AND ("matchmaking" OR "ethic" OR decision"))* OR

("production equipment" AND ("digital twin" OR "worker" OR "implement" OR "adopt*"))* OR

("interoperability" AND ("production" OR "equipment" OR "machine"))* OR

("digital" AND ("marketplace" OR "platform") AND ("architecture" OR "host" OR "govern*") AND ("manufactur*" OR "production"))* OR

("digital" AND "marketplace" AND "challenge") OR

(("evaluate" OR "refurbish" OR "maintain") AND ("equipment" OR "robot" OR "machine*") AND ("worker" OR "ethic*"))* OR

("production" AND "worker" AND ("ergonomics" OR "handl" OR "safety"))* OR

("platform" AND "data" AND ("flow" OR "exchange"))

As a result, the desk research resulted in 38 publications and website articles that were analyzed. These findings cover information about the fields related to ALICIA's components and operational activities and their ELSA issues that must be considered for defining ELSA design points.

Hence, the desk research's results were analyzed and synthesized. Doing this made it possible to receive a first overview of ALICIA's ELSA risks and impacts that must be paid attention to.

4.3.2 Desk research results

After their analysis and synthesis, this literature's findings are now discussed. This happens within this section in the sequence of each component of ALICIA. To ensure a clear overview, the results are presented in a structured form by categorizing them per component.

AI-matchmaking algorithm engine

As manufacturing environments have become due to the incorporation of technological innovations (e.g., automation) increasingly complex (Leyer et al., 2019), the concept of intelligent manufacturing has contributed significantly assistance to it (Li et al., 2017). Through its key areas like AI, high-end computerized numerical control (CNC) machinery, industrial robots, cloud manufacturing services, and many other intelligent and innovative means, intelligent manufacturing can be integrated into the whole manufacturing system and life cycle (He & Bai, 2021). One of the main goals intelligent manufacturing pursues is achieving better quality, more sustainable production, higher productivity, and lower costs (He & Bai, 2021). This notion of intelligent manufacturing can as well be applied to the decision-making in manufacturing that enhances production optimization (Li et al., 2017). Overall, decision-making aiding systems serve to assist humans in decision-making processes.

Nowadays, the achieved advances in AI can promote automated decision-making, which allows decision-making systems to operate, if wanted, fully autonomously without any further required human intervention (Araujo et al., 2020). Within this context of decision-making, AI mechanisms are commonly understood as algorithms that process vast amounts of data using complex statistical and machine-learning models to achieve optimized decisions (Newell & Marabelli, 2015; Paul & Ahmed, 2023). ALICIA's entire technological infrastructure, with its functionalities already described within Chapter 4.2, falls under the category of intelligent manufacturing. ALICIA's AI matchmaking algorithm automatically generates solutions based on available second-hand equipment that suits the purchasing companies. This AI-based matchmaking engine can be described as a decision-making process that does not necessarily require human interventions. The only input that is human influence constitutes the into the algorithm entered factory owner requirements such as internal production-related data or preferences. These requirements serve as an orientation for the algorithm to generate the best possible tailored result.

Even though AI brings many advantages, it often receives criticism for being biased such as lacking fairness or constituting a threat. Because AI technologies function by using mathematical calculations and algorithms to process data and its related output, many people distrust AI. To counteract this, several ethics guidelines have been defined to mitigate the risks AI technologies and their potentials entail (Hagendorff, 2020). These guidelines can be utilized as a baseline by organizations or individuals that work with AI-based innovations (Paul & Ahmed, 2023).

That AI can be perceived as trustworthy; it should be lawful in terms of respecting all applicable laws and regulations, ethical concerning respecting ethical principles and values, and robust from a technical perspective while at the same time taking its social environment into account (European Commission, 2023b). The most frequently mentioned aspects in the established AI guidelines are accountability, anti-discrimination privacy protection, and safety (Hagendorff, 2020). The following describes these guidelines' aspects, including other common ones, in more detail. In order to establish a direct link to ALICIA's ELSA aspects, these guideline aspects are discussed in relation to ALICIA's AI component.

Accountability encompasses that the AI's technological mechanisms should be established in a way to ensure responsibility for their functionality and outcomes (Hagendorff, 2020). This enables a certain transparency that allows making the technology explainable to all stakeholders at any time. Moreover, this is also necessary since it is crucial always to ensure the AI's auditability for assessing the AI system's algorithms, data, and other mechanisms. In addition, all involved persons should be informed about the AI systems' capabilities and limitations, which can increase people's assurance while working with the technology (European Commission, 2023b).

Another decisive issue is to ensure the AI system's anti-discrimination nature. The AI matchmaker should avoid unfair bias toward all stakeholders without imposing disadvantages on vulnerable groups or minorities. Moreover, AI technology must be accessible to every stakeholder at anytime (European Commission, 2023b). Another additional criterion elucidates that algorithmic decision-making has reached such an advanced standard that it enables organizations to personalize their offerings to prospective customers more precisely. This includes that algorithms can as well assume that a potential purchaser prefers one product over another (e.g., based on previous purchases or similar trends) and consequently veils other products that the customer might even deem as required (Newell & Marabelli, 2015).

Regarding ALICIA, this should not be the case, and no company should be favored or disadvantaged by the AI matchmaker in getting production equipment allocated, regardless of the company's size, revenue, market share, or other similar factors. As well, workers with disability, a specific gender, or other physical characteristics (e.g., height) should not be discriminated against. ALICIA's AI matchmaking engine should benefit all companies and their involved individuals, select suitable equipment solely based on the entered requirements and data of the customers, and always be accessible for every user in the same way. Only if these aspects are considered, an appropriate second-hand equipment matchmaking process which later leads to the allocation and purchasing activities of the equipment, follows.

The data that the AI matchmaking algorithm processes must always be treated confidentially. Hence, appropriate data governance mechanisms must be ensured (European Commission, 2023b). Since the entire technological infrastructure of ALICIA operates through data streams, this and other data-related issues are further addressed at the end of this results section under the rubric "*Data exchange within ALICIA*".

Another decisive aspect is that AI systems should be empowering human beings to make informed decisions and promote their fundamental rights (European Commission, 2023b). This requires safety measures that should always be ensured so that AI systems can never affect human autonomy (European Commission, 2023a). As already mentioned above concerning the issue of anti-discrimination: the matchmaking engine should follow its given instructions in terms of the factory-owner requirements and other datasets. Moving away from them and creating a result based on its own technological assumptions can harm safety and must be avoided. A proposed means for such a risk is the interruption of AI systems. These can be certain "stop-buttons" that allow interrupting the AI's actions at any time and ensure human agency to prevent dangerous outcomes (European Commission, 2023a). Another critical point for safety is the AI's consideration of the workers. Their operation with the equipment should be considered by the algorithm, which decreases the risk of any potential harm through working with/on the equipment.

Nevertheless, it can be concluded that sometimes security can have a tension with privacy which requires the design of certain trade-offs. Increasing security can impact the aspect of privacy and vice versa (Newell & Marabelli, 2015). Even though the security of ALICIA's AI matchmaking engine should be ensured and the matchmaking should produce, as mentioned above, fair and secure outcomes so that companies can purchase the best possible equipment, they must share specific data for capturing their requirements. These requirements can include information about the production program, estimated output, produced goods, workers' conditions, etc., all containing sensitive information. Falling into the wrong hands, this information can harm companies' privacy. Hence, ALICIA's AI matchmaking architecture should be designed to embrace both values by constituting a safe system that also ensures privacy.

To ascertain all these mentioned aspects concerning a social and ethical AI matchmaking mechanism, adequate and accessible legal protection means can be supportive (European Commission, 2023b). These can, for example, occur in the form of contractual agreements, regulations, or other treaties.

Digital shadow/Digital twin generation (part of AI matchmaker)

Another important feature that supports the implementation of intelligent manufacturing is the simulation through DT and DS (He & Bai, 2021). Within ALICIA's infrastructural ontology, the generation of the DS and DT takes place right after the AI matchmaking process. Before delving deeper into this second component, both terms, DT and DS, must be defined as they differentiate from each other. Hence, the definition and distinction of them read as follows:

A DT is a real-time replica of a physical entity that can model or simulate the state of intelligent manufacturing systems and predict its failures (He & Bai, 2021). The same counts also for a DS, with the exception that the DS is a less advanced version of the DT and thus presents a more abstract version that contains fewer sensorical data. In general, a DS can be seen as a previous step before developing a DT (Bergs et al., 2021). In the manufacturing sector, these two concepts are utilized for simulating or evaluating production systems that operate through machinery or robots before actually physically constructing them (Bergs et al., 2021; Sepasgozar, 2021). Furthermore, the DT contains data that is helpful regarding an asset's entire lifecycle, from its design over the operation to recycling (Bergs et al., 2021). These aspects make the DT concept a facilitator for achieving sustainability (Sepasgozar, 2021), *which also includes CE, as is the case for ALICIA regarding the re-use of production equipment.*

The purpose of using DS and DT in ALICIA lies in virtually establishing production equipment selected by the AI matchmaking engine that operates individually or together with other equipment within an entire production line. This is helpful to, beforehand, simulate and evaluate the equipment's functionality in terms of efficiency, quality, or possible failures (He & Bai, 2021). Furthermore, it makes it more convenient and saves costs as the production equipment or entire production line can be virtually tested before building it in real life.

Since ALICIA aims for a human-centric CE system that takes socio-ethical aspects into account, it is vital to not only focus on the factory owners and managers that purchase the equipment but also put emphasis on the workers. A human-centric design of ALICIA by including the production workers is a must as, in the end, they operate with the purchased second-hand equipment and contribute to the production's success of a company. Thus, it most probably requires adjustments such as a higher level of knowledge by the workers to understand how to handle this technological equipment (Leyer et al., 2019). However, prior to the workers' operation with the equipment, it is imperative to determine beforehand the most appropriate production equipment based on the proposed DT designs. This process should also include the workers, where they can participate in choosing the equipment's DT design.

To facilitate such a human-centric design with shop floor worker involvement, four main criteria must be paid attention to. The workers must have 1) access to all resources that clarify to them what equipment or spare parts they could use, 2) access to information about the equipment and the through it newly emerging operational tasks, 3) access to support in terms of guidance and feedback how they operate with the according equipment, and 4) access to opportunities that allows them to learn and improve their skillset (Leyer et al., 2019). Paying attention to these aspects can positively contribute to the company's productivity and hence its success, as workers might develop a higher commitment, job satisfaction, and work effectiveness through it. If these aspects are neglected, in turn, negative side effects can occur for the company due to increased complexity of the workers' tasks or experiencing pressure while working. This can result in a less-efficient production (Leyer et al., 2019).

Subsequently, these just depicted aspects are now discussed with reference to ALICIA. The access to 1) resources and 2) information (Leyer et al., 2019) provides the workers with a detailed impression that is facilitated by the DT simulation model of how the equipment looks like and how they should operate with it (Leyer et al., 2019). For this, involving the workers in the decision-making process for which DT design should be chosen is essential. To make this happen requires that the entire participating staff understands the main concept of the DS/DT visually and theoretically (Delbrügger & Rossmann, 2019). Further, to support the decision towards the most effective DT, the decision should not entirely rely on the DT's technological characteristics. Efforts like workers' long travel times or unnecessary use of space along the shop floor that might result from working with the equipment cannot be thoroughly examined by means of the DT model. For analyzing such efforts, companies can carry out simple Lean Production tools like, for example, a "Spaghetti Diagram" that can be used to track and simulate the workers' walking paths along the production line while simulating the utilization of certain equipment (Sullivan et al., 2002). Moreover, considering such non-technical issues requires a consultancy process together with the entire parties involved in the production.

For guaranteeing the workers' access to 3) support of guidance and feedback and 4) opportunities to improve their skillset (Leyer et al., 2019), an increased technical skillset in areas like programming, engineering, or general equipment handling must exist, especially if the equipment is IT-enhanced (Bartel et al., 2007). Often, it is the case that workforces with further advanced skillsets are automatically deployed at machines that entail sophisticated technologies. To avoid this separation, all workers' knowledge must be aligned to ensure everybody's operation with the purchased second-hand equipment (Bartel et al., 2007). More elaboration on the required upskilling of the workers is explained further within this section under the category *"Second-hand equipment selection, purchase, and workers' adoption"*.

Equipment interoperability

Interoperability can be defined as the capability of equipment that originates from different manufacturers to communicate with each other while existing in the same infrastructure or system (van der Veer & Wiles, 2008). In the production sector, such interoperability is understood as the interaction of two or more production resources (Burns et al., 2019; Vogt et al., 2021). Progressive developments in IoT technologies joined with the achievements in intelligent manufacturing, have made such interoperability between production equipment in the manufacturing sector viable. Through this, an independent production is facilitated in which the equipment can autonomously sense the production quality and can fulfill prompt adjustments to it (He & Bai, 2021). Standardizations for making such interoperability possible are hence required and already partially exist in several architectural or design forms (Zeid et al., 2019), which allow production equipment to operate in a uniform language (Burns et al., 2019).

To make such interoperability of second-hand equipment established by different manufacturers possible, ALICIA's Equipment Interoperability Partner has the responsibility to produce plug and produce middleware adaptors that align the syntax of these different types of equipment so that they can operate after their second-hand purchase trouble-free within the same production environment (see Chapter 4.2).

Since interoperability of production equipment in the industrial sector with an emphasis on intelligent manufacturing and Industry 4.0 is a newly emerging subject, most publications that discuss this shift their focus on technical considerations (Burns et al., 2019; Vogt et al., 2021; Zeid et al., 2019). One finding that discusses the technological requirements of interoperability indicates that updates and further operations must happen correctly and fast enough without causing disruptions. Otherwise, an inconvenience for the end user (worker) can happen, who needs to wait until the device becomes compatible for interoperating with others (Burns et al., 2019). This can be translated into an ELSA aspect that addresses the workers' interaction with second-hand equipment through interoperability means. According to the desk research findings, any further research on what other kinds of ELSA implications can emerge through this has been insufficiently conducted.

Digital marketplace platform

One key component of ALICIA is its digital marketplace platform, which facilitates its CE activities by enabling companies to purchase or sell second-hand production equipment. Especially for CE practices, web-based marketplace platforms constitute an efficient implementation means as they promote the interaction of secondary material suppliers and buyers (Circular Economy Guide, 2023; Konietzko et al., 2019) and facilitate alternative utilizations of scrap material (Migliore et al., 2020). The previously discussed components of ALICIA, such as the AI-matchmaking, generation of the DS/DT, and plug-and-produce middleware interoperability adaptors, are all integral parts of developing tailored second-hand equipment on the way to the purchasing process that, in the end, takes place on the platform.

Over the years, many study fields and definitions got established that have investigated the concept of such digital marketplaces in the manufacturing sector (Jong & Mellquist, 2021; Moghaddam et al., 2019; Suuronen et al., 2022). Such a digital marketplace can be referred to as a digital business ecosystem (DBE). Business ecosystems (BE), digital ecosystems (DE), and digital platforms (DP) are described as one of the necessary main layers for a DBE in the manufacturing sector (Suuronen et al., 2022). While the BE can be explained as "a set of interreacting entities, organizations, and individuals that build their capabilities and roles and rely on one another for their overall performance and survival" (Suuronen et al., 2022, p. 417), a DE which provides the digital technologies, like in the case of ALICIA, the AI matchmaker or DT, represents one layer of the DBE. The last layer, the DP, enables collaboration and all other marketplace-related operations (Suuronen et al., 2022). Moreover, a DP can also be addressed as a socio-technical aggregation that includes technical components as also associated standards and processes (Reuver et al., 2018) in which actors can connect and offer products or services (Reuver et al., 2020). While the main points of ALICIA's BE and DE are already described in Chapter 4.2 with the stakeholder analysis and their ELSA risks/impacts in this section, this marketplace-related rubric addresses ALICIA's DP-related ELSA issues that require further clarification. It must be mentioned that the BE and DE of ALICIA during the *Inclusion* dimension are elaborated to a limited extent due to the thesis' research limitations and specific focus on assessing ELSA aspects, which does not allow for explicitly analyzing, for example, in-depth technological constructions of the components. To avoid any confusion with the different used definitions in the further thesis, this ALICIA digital marketplace platform is from now on referred to as 'marketplace'.

According to (Reuver et al., 2018), researching DPs, in general, already poses a challenge due to their distributed nature. This challenge is even further amplified if they exist in a business environment since the developments there contribute to it. Because platforms are merged into more extensive digital infrastructures, DPs progressively develop into complex research matters (Reuver et al., 2018). For designing such DPs, all stakeholders should be included and contribute to the design of it since DPs include several components that are allocated among the control of the multiple participating involved stakeholders instead of only one central platform provider (Reuver et al., 2018). But not only the design phase of DPs rather also policies and joint strategies for the competitive environment and interactions that characterize such a DP must be defined (Moghaddam et al., 2019). Governing the platform is a complex matter due to the paradoxical relationships of change and control (Reuver et al., 2018). On the one hand, concerning change, the platform's foundation must be a stable one but also, at the same time, allow for flexibility to support limitless growth, hence concerning the platform's control, it is beneficial if governance occurs simultaneously in a centralized and distributed manner (Reuver et al., 2018). Hence, relating to ALICIA's marketplace, it is significant to be aware of these paradoxes and their interrelations to guarantee its successful governance and facilitate a continuous evolving process.

(Suuronen et al., 2022) states that this continuous development can be achieved by the marketplace's technological leaders through opening the platform to other stakeholders. Having as a user easy and effortless access to the platform, openness can be promoted, which allows the user to participate. This, in turn, further boosts innovation, ensures appropriate resources, and promotes novel ventures that can positively contribute to the platform (Suuronen et al., 2022). What might also create an advantage is to attract as many users as possible to the platform, as greater demand can always have a positive effect on the success of the marketplace (Jong & Mellquist, 2021). Doing this also can benefit the sustainable development of industrial environments, which ALICIA aims for. Additionally, understanding the users' needs can contribute positively to the marketplace's growth. Otherwise, if this inclusive collaboration process does not take place, the technology leader might impede potential innovation and remains with its own insufficient knowledge (Suuronen et al., 2022).

Another relevant aspect involving the marketplace's users also relates to the commercial interactions they fulfill within it. The type of ways and purposes in which users operate with each other on a platform is many times not in the control of the platform's establisher (Reuver et al., 2020). In particular, in a digital marketplace environment where competition can occur, every participant must remain healthy, as already single weaknesses in critical areas can harm the entire marketplace (Suuronen et al., 2022). From this, it can be concluded that it is essential to ensure a fair buying and selling process in which everyone, regardless of any factors, has the chance to buy or sell second-hand production equipment.

CE activities (evaluating, decommissioning, and refurbishing/maintaining the production equipment)

Within the context of CE, digital technologies can enable activities' functionalities that are beneficial for a CE implementation, like the provision of technical support, evaluating a product's life cycle, and maintaining or enhancing a product (Antikainen et al., 2018). Also, decommissioning is a significant part of CE for industrial equipment, allowing refurbishing used ones and combining them or their spare parts into functional ones. All these just mentioned CE activities for production equipment have been mostly researched concerning their technical realization possibilities (Antikainen et al., 2018), cost optimization (Zacharaki et al., 2020), or operational implementation strategies (Acerbi et al., 2020; Fontana et al., 2021). As already concluded in this thesis literature review, this field requires further research, with almost none done in the socio-ethical dimensions, which also refers to the identified general lack of the incorporation of ethical and social dimensions within CE practices.

Still, two found issues can be classified to the legal area. First, the data-related challenges such CE activities entail need to be considered. Since multiple companies that are mostly present in the same industry (in the case of ALICIA: automotive) aim to operate with second-hand equipment, it is essential that a secure data-sharing process is guaranteed (Antikainen et al., 2018). As this also refers to ALICIA's data exchange, this issue is addressed like the other data-related ones in the rubric that covers ALICIA's data exchange. Second, many times companies within the same industrial sector underlie competition legislations that legally prevent them to collaborate to a certain degree with others which can be seen as a barrier to realizing circularity. One of many examples would be the sharing of knowledge concerning business-related processes (Rizos et al., 2016). To facilitate a successful operation of ALICIA, such strict competition regulations must be adjusted accordingly to not harm CE activities.

Second-hand equipment selection, purchase, and workers' adoption

According to (Ivascu et al., 2021), sustainable production comprises, besides its obvious aspects such as energy consumption or waste management as well human-related ones such as working conditions, workplace safety, and personnel health which all predominantly refer to the factory workers. Especially, ergonomic considerations of the workers should be integrated into the production planning process to prevent skeletal or muscular diseases which can result from an inconvenient operation of the production equipment by the worker. As many times such working conditions are addressed in the implementation or operation phase rather, a proactive approach should be performed already during the starting planning phase (Jensen, 2002). This also aligns with the insights gained in this section that the workers' considerations should be already taken into account by selecting the DT design of the equipment. Doing this can significantly improve the workers' ergonomics since they can already state their concerns early in this planning phase.

To ensure the workers' safety while working with the machinery, it is essential that they understand how the equipment functions so that a smooth collaboration can happen (Muthusamy et al., 2020). This also picks up the already described aspect regarding a required improvement or alignment of the workers' skillset (Leyer et al., 2019), which greatly contributes to the worker's conditions and the company's production efficiency. It is proven that respective qualifications can positively impact the adoption of information and communication technologies (Castel & Aleson, 2008). Thus, the workers must understand how the equipment works and why it makes certain decisions. This also influences the development of trust between worker and the handling equipment (Muthusamy et al., 2020) and the quality of the CE's strategical implementation (Gupta et al., 2021), which can have leverage on a successful CE implementation (Rizos et al., 2016). Unfortunately, in many CE undertakings that occur within companies, the manager is mainly responsible for authorizing such or similar strategic decisions. This may lead that not everybody in the organization has a positive attitude towards the CE implementation as some may perceive CE as a positive undertaking that motivates them while others remain insufficiently informed about the CE strategy and only consider it as an additional workload (Rizos et al., 2016).

To summarize these findings together with the ones from this result section's rubric *"Digital shadow/Digital twin generation*", it can be alleged that a consequent involvement of the workers within the entire ALICIA purchasing process that starts in selecting the equipment possibilities in the form of a DT to its adaption which includes tasks like training, is crucial to create a working environment that satisfies the workers and in turn supports the company's production goals.

Data exchange within ALICIA

As previously expounded upon within this result's section, ALICIA's components (e.g., AI-matchmaker or marketplace platform) inherently require data exchange, rendering it an inevitable part of the overall ALICIA environment. To guarantee the secure handling of data within ALICIA in terms of privacy, the incorporation of data privacy standards must be upheld consistently.

Data-related issues such as ownership, sharing, and integration pose major challenges for digitalization processes in CE and must be solved to facilitate a successful collaboration (Antikainen et al., 2018). Consequently, the within ALICIA shared dataset of each participating company should be restricted to a minimum regarding internal company data and sensitive personnel data. The data owner should always be and remain the party concerned, with no change occurring to this. Only for the CE activities, necessary data must be identified which can then be shared. Furthermore, policies that define who has access to the data are supportive means as well (Moghaddam et al., 2019). In addition, compliance with the GDPR (Koscina et al., 2021), EU Data Act Compliance, and data-related ISO standards must always exist (European Commission, 2023a).

4.3.3 Critical analysis of the desk research

The desk research based on the analyzed stakeholder and project environment done in *Inclusion* yielded significant findings that are fundamental for the assessment of ALICIA's ELSA design points. Based on these insights, the expert interview questions within the next step of the framework's dimension *Reflexivity* can be defined. This aims to receive more concrete insights into these detected ELSA issues and further ones that have not been detected yet throughout this research. To reflect the desk research process, it can be said that, again, valuable insights could be won for relevant ELSA aspects regarding ALICIA's components, such as the AI matchmaking algorithm and the DS/DT, the digital marketplace platform with its entailing matters, and the selection and adoption of second-hand equipment by companies and their workers. Findings ELSA aspects for components that were insufficient and must be extensively further explored within the interviewing process to establish a better understanding are about the equipment interoperability and CE activities (e.g., refurbishing of second-hand equipment). This is not a big surprise, however, when one considers concerning the defined knowledge gap that within the CE methodology a lack of embedding socio-ethical considerations and a shortage of research regarding the circularity of industrial (automotive) production equipment exists. Insights that could be gained but in a vague manner within this desk research are concerning the data exchange. For this reason, the expert interviews aim to receive further concrete insights that support the formulation of ALICIA's ELSA design points for these components as well. It is intended to gain this final decisive input through communication with the stakeholders through expert interviews.

Considering the second step of the conceptual framework as completed, the third step follows in the following subchapter within the framework of the dimension *Reflexivity*.

4.4 Step 3: Reflexivity

Following, the *Reflexivity* dimension, which represents the conceptual framework's third step, is elaborated. This implies the conduct of the expert interviews.

4.4.1 Expert interviews

The interviews serve the purpose of 1) reflecting the anticipated findings (risks and impacts) from the previous dimension with the stakeholders' assumptions, actions, goals, etc., and 2) figuring out further critical ELSA aspects not identified in the desk research. The aim is to interview seven participants whose expertise lies in the field of ALICIA's components. These participants range from the production manager/worker of companies that operate with production equipment to the developer of ALICIA's marketplace and AI mechanisms. Each internal participant of the project consortium is responsible for the design of one of ALICIA's components. Furthermore, one external participant outside the ALICIA project was also interviewed, which helped to get a more general opinion about this type of automotive equipment CE apart from the ALICIA project's context. This external participant is a production worker for a major European automotive manufacturer operating daily with equipment. Based on the gained insights from the observation, the stakeholder analysis, and the desk research, the interview questions were formulated to cover the dimension of *Reflexivity*. Throughout the thesis, abbreviations per interview participant are used, as for participant 1 (P1), participant 2 (P2), and further.

The expert interviews are of qualitative nature and conducted online. As already explained in Methodology Chapter 3, they were recorded with an audio device in a .mp3 format. To avoid the publication of sensitive data (e.g., discrete internal company information, age, name, exact working position) and ensure privacy, the raw .mp3 data file and anonymized summaries of the interview transcripts are stored at YAGHMA. This anonymized summary also includes the relevant coding themes for data processing and analysis.

The questionnaires are structured into topic blocks. For this interviewing process, seven topic blocks were defined. The first topic block contains introduction questions that address the more holistic picture of CE and its methodology, such as e.g., what the participants think a CE in industrial manufacturing is according to their own understanding, or the major developments of a CE in the automotive industry. The other topic blocks cover each component of ALICIA's bounded CE system while still always ensuring to receive a general view of this field. Still, some questions are specialized to each component; this is required to receive clear insights for the project, which are necessary to, in the end (*Responsiveness* dimension), obtain the aimed insights of ALICIA's ELSA design points. Confronting the participants with clear examples related to the ALICIA project additionally intends to get more precise insights that can be translated into a more general CE context. In this research, this context consists of the assessment methodology of socio-ethical CE aspects and the circularity of automotive manufacturing equipment.

In the following, the structure of the topic blocks is displayed, including the relevant color theme per questions' topic block, which is relevant for the coding process:

Topic block 1: Introduction questions (CE in general and participant information)
Topic block 2: ALICIA's AI-matchmaking engine algorithm
Topic block 3: Equipment interoperability
Topic block 4: ALICIA's digital marketplace platform
Topic block 5: Circular economy activities (de-commissioning, refurbishing, and maintaining production equipment)
Topic block 6: Second-hand equipment selection, purchasing, and workers' adoption
Topic block 7: Data exchange within ALICIA

The set of questions was adjusted to the participants' tasks and expertise. All participants were asked questions regarding all seven topic blocks, but for participants whose expertise does not lie within a certain ALICIA component, their questionnaires were adjusted. An example to this would be that a production worker cannot answer detailed questions on AI mechanisms while an AI expert can. The same counts as vice versa since an AI specialist has limited knowledge of operating machinery in a production line and what factors are decisive for doing so. That is why some questions were left out or adjusted for certain participants. Appendix D shows the interview protocol with all listed questions per participant.

Again, the interviews focus on achieving further insights for assessing socio-ethical aspects in the ELSA context, but some questions also have a nature outside of the ELSA scheme. This can be, for example, more about specific technologies, business strategies, processes, or other relevant fields, which all serve for a more holistic understanding that, in turn, also supports determining ELSA design points as accurately as possible.

4.4.2 Reflection on interview process and dissemination of insights

The interviews delivered valuable insights regarding the detected findings from the desk research and revealed even further new ones. This section reflects on how the interviewing process went and discusses the analysis done of the expert interviews.

First, the participants stated that they perceived the interviews as very positive. This comprised the structure of the interviews as also the type and build-up of the different questionnaire sets with the topic blocks. Moreover, they stated it could be of enormous benefit to gain different insights from people of different expertise, which can help to disseminate an overall picture of the ALICIA project, but also for CE in the automotive sector in general. The personal experience of conducting these interviews was positive since all participants were collaborative and eager to discuss the topics. Additionally, after analyzing the interviews, it was discovered that the insights gained through the interviews are beneficial for the specific formulation of the ELSA design points and further insights into circularity for industrial automotive equipment. Before the outcomes per component of ALICIA are elaborated, Table 4 in Appendix E shows the respondent list of the participants. This respondent list includes each participant (P1-7) and their general statements concerning the asked questions. According to the color theme of the topic blocks and coding process, the responses are structured and displayed in the respondent list. An overview of the participants and their functions reads as follows:

- **P1**: Production area manager of major European automotive components producer (internal ALICIA stakeholder; Industrial Partner 1)
- **P2**: Production worker of major European automotive manufacturer (external ALICIA stakeholder)
- **P3**: Engineer of major European industrial equipment manufacturer (internal ALICIA stakeholder; Industrial Partner 2)
- **P4**: Researcher with focus on AI of European research institute (internal ALICIA Stakeholder; AI Partner 1)
- **P5**: Computer engineer with focus on DS/DT design and simulation of European research institute (internal ALICIA stakeholder; AI Partner 2)

- **P6**: European Initiatives department leader of major European online auction provider for industrial equipment that operates through digital marketplace platform (internal ALICIA stakeholder; Digital Marketplace Partner 1)
- **P7**: Software developer for industrial production equipment of European company that offers digitalization solutions for industrial production equipment (internal ALICIA stakeholder; Equipment Interoperability Partner)

Cells marked in the respondent list table regarding specific questions/topics as empty with “-“ refer to the previously described fact that these questions were not asked a participant due to the mismatch of the question with their expertise.

The interview outcomes and their analysis are now synthesized and presented. Their discussion is structured according to the sequence of the questionnaires’ topic blocks.

CE in general

All participants similarly perceived CE in general for the industrial production sector. Mentioned terms were, among others, “sustainable production”, “crucial to tackle energy and resources crisis through reuse, remanufacturing, or recycling”, or “reduce waste and achieve through this higher efficiency regarding environmental aspects”. This showed that, from the beginning, all participants were on the same line, and their general understanding of CE in this field resembles. Moreover, many participants stated that they perform CE operations or similar circularity activities outside the ALICIA project through ongoing research or industrial operations. P2, the participant outside the ALICIA project, affirmed that the circularity of production equipment occurs internally within his corporation. Having this common comprehension of circularity was beneficial to facilitate a more in-depth discussion throughout the interviewing process without having to explain the background of CE extensively. This allowed to utilize the available time for actually addressing the planned questionnaires instead of using most of the time to explain CE’s core concepts. Concerning the main development of the CE methodology for automotive industrial production equipment, P3 stated that there is an increasing awareness within the EU to recycle and reuse production equipment. However, it still lacks development compared to other countries such as Japan. P1 and P2 stated that developments are ongoing and important for the reuse of second-hand equipment and a company's success.

The interviews revealed that three major challenges exist in realizing the CE of ALICIA. Those are making the different equipment interoperable by creating standards for their software and interfaces, the data unavailability of historic equipment data (e.g., expected lifetime), and the present competition between competing companies in the automotive field, which makes them reluctant to collaborate and share required data. It is attributed that the competition in the automotive sector drives the lack of interoperability standards and the unavailability of equipment data.

Conversely, they also recognized benefits that can emerge through realizing ALICIA. First, to overcome the mentioned challenge by developing ICT solutions that improve the required standardization for the equipment's software and interfaces, which are crucial to facilitate a CE approach. Moreover, P1 and P2 claimed the ALICIA project could be seen as a chance to bring competing automotive companies together by working on a common solution that can, in turn, boost circularity on a larger scale and positively contribute to the common societal welfare by, e.g., reducing negative environmental impacts. A more generally mentioned benefit is to increase the awareness of CE among all stakeholders in the automotive industry and learn more about CE technologies and practices (P6 & P7).

AI matchmaking algorithm engine

Next, the participants expressed their opinion about the asked questions relating to ALICIA's AI matchmaking algorithm. A general challenge the participants stressed is an unawareness by people involved in this AI matchmaking process, such as the companies with their managers or workers. P1 emphasized that such unawareness regarding AI must be overcome by making them aware of AI in general and its purpose in ALICIA's CE. Another central pillar that refers to the AI matchmaker's challenges is bias. P5 and P7 both expressed their worry that a bias by the AI itself could negatively influence this starting matchmaking process within ALICIA. The bias they referred to is one that can lead to unfair matchmaking and establishing a preference that can favor one supplier over another. Thus, it is essential to design this AI matchmaker so that the data is well-trained and such bias cannot occur. An interesting point is that the interviewed AI expert (P4) who is responsible for developing ALICIA's AI technology stated that this AI used in ALICIA will be intentionally constructed in a way that it only works based on the fed in dataset (factory owner requirements and equipment data) and thus, has no room to develop itself and create any bias. Still, since the other participants expressed this concern, it is assumed that other stakeholders within ALICIA might also have such bias. Thus, it is still required to pay attention to this and clearly communicate to all stakeholders or later users that such bias cannot occur. Especially people who may lack expertise in AI may see it with different eyes than an expert in this field; hence, an assurance for avoiding such bias must be transparently given and communicated. This also is connected to the other aspects the participants articulated, such as accountability (constant monitoring of the AI's black box), trustworthiness (this relates to the just mentioned assurance of non-bias), explainability (understanding why the AI technology made a certain decision of a supplier or equipment), and robustness (ensuring, in overall, a robust matchmaking process that preferably does not make mistakes).

Concerning which worker-related aspects should be integrated into the factory owner requirements that serve as input for the AI matchmaker, all participants agreed that the workers' ergonomics must be respected here. Since this increases the workers' comfort and concentration, which positively influences the production's efficiency (e.g., fewer defects), it is also crucial for ensuring the safety of the workers. P2 mentioned incorporating people's height and body stature to ensure such ergonomic considerations, which are relevant for certain production areas while operating with equipment. P3 and P7 even went a step further by proposing integrating disabilities that workers have, to ensure for example an interface with a color-blind mode. Concerning language, there was also compliance to include the workers' language. To ensure this, the native one where the production plant is located and English, which is a world language, should always be considered.

The in the desk research detected tension between security and privacy of the AI technology's functionality resulted in discrepancies. While P1 and P5 valued security higher, P3 and P4 emphasized that privacy is more critical since disclosing too much data can have fatal consequences. P3 made an interesting statement by mentioning that a trade-off of both must be considered. Such a trade-off sounds like a possible solution, ensuring the selection of safe, operable equipment and not disclosing too much confidential data. This aspect is further within this section under "Data exchange within ALICIA" elaborated in more detail.

Additional human intervention into ALICIA's AI component besides the input data was proposed by P4, the AI expert, in terms of experts that steadily control the AI's estimations in case of errors (over/underestimations). P5 explained that a human in the loop could help improve the feedback from the AI matchmaker. Additionally, an interruption function was recommended by P4 to quickly intervene in the AI process, especially when generating the DS/DT, in case an unforeseen malfunction can lead to severe consequences.

Equipment interoperability

Many worthwhile insights could also be gained for the equipment interoperability required to connect all the different second-hand equipment and their parts. To first address the socio-ethical issues, P1 mentioned that the equipment should be designed in a worker-friendly way. Since these solutions for guaranteeing interoperability can be very costly (mentioned by P5 as well), it is necessary to make these costs affordable for every company type, also for small and medium-sized corporations. Another point related to the language aspect already discussed regarding the AI matchmaker is that, here as well, language should be considered while making the equipment interoperable and ensuring that the newly developed equipment syntax facilitates the required language output on the user interface. P2 expressed his concern that interoperability-facilitating parts have to originate and be produced from and in an ethically responsible way. Based on a vivid example of how lithium for electric cars stems from third-world countries where unethical conditions such as child labor and exploitation exist, P2 compared this to the case of reusing production equipment. Hence, this aspect is essential for the interoperability as also for the CE activities such as refurbishing or repairing equipment where only parts from an ethically responsible descent should be utilized. Another essential point mentioned by P7 is that these technological solutions that facilitate interoperability must run smoothly without disruptions. Otherwise, this can negatively influence the worker's acceptance of second-hand equipment. Furthermore, technological lock-ins must also be avoided. If the second-hand equipment still has a sufficient remaining lifetime and gets sold again, this interoperability technology should not create technological lock-ins that hamper the equipment's further circularity.

Legal issues mentioned throughout the interviewing process by multiple participants are related to IP right. While modifying new types of machinery (mechanically or software-wise) and making them interoperable, there is always a possibility of IP infringement on other companies that produce equipment as well. This aspect must be paid attention to at all times since P3 stated that this is always a possible scenario based on their experience in manufacturing production equipment. To avoid this potential risk, a solution around it must be designed.

Digital marketplace platform

Another decisive component of ALICIA is its digital marketplace platform since all operations that relate to the companies and users of the equipment take place on it. The desk research during *Anticipation* revealed that it is crucial to maintain a healthy and fair but simultaneously competitive environment. Nevertheless, the interviews conveyed a different standpoint. Four out of seven participants explicitly stated that a competitive environment must be ensured (P1, P2, P3, and P6). P6, responsible for designing ALICIA's marketplace, claimed that, by definition, a fair marketplace cannot exist and must be competitive to function. According to P1 and P2, competition creates a healthy market and determines the right quality and price. P7 added that a fair competition should take place. It must be mentioned that the four participants (P1, P2, P3, and P6) operate on a daily business with production equipment and, thus, are the end users of the ALICIA platform. So, it can be said that their opinion is relevant in this case.

Almost all asked participants (P1, P2, P4, P6, and P7) stated it would be a beneficial possibility if other stakeholders of ALICIA could contribute now and in the future during its operation on a broader scale in developing and designing the marketplace platform. Companies prefer such customization opportunities. Such an approach can be advantageous for the marketplace's innovational development. Additionally, everybody indicated a decentralized governance scheme of the marketplace. The participants' justification was that this governance type allows for more inclusiveness, flexibility, and ease, even though it might be more difficult to realize from a technical point of view. P5 suggested starting at the beginning of ALICIA's implementation with a centralized governance and then later switching to a decentralized one, which might avoid things getting out of control, especially at the beginning.

Moreover, all participants that were asked the question if an easy access in terms of registration to the platform should exist, they agreed. P1 proposed incorporating and applying a "certificate of good conduct" principle that verifies users first before they can straight away perform trading activities on the platform. This can prevent scam incidents since nobody can just easily register and interact with others as it is on digital platforms like eBay. Furthermore, everyone believed that an increasing number of platform users could lead to increased demand for second-hand equipment, making the marketplace a helpful tool for creating CE awareness.

CE activities

Concerning the CE activities of ALICIA (e.g., refurbishing, repairing, maintaining), it is worth recalling the previous finding from this section's category "Equipment interoperability". As already mentioned there, all parts, components, etc., used for these CE activities on the equipment have to originate from a socially and ethically responsible source. Assuring this is a crucial issue to label a CE as social-ethical responsible. Apart from this, the CE activities should happen in an environmental-friendly and sustainable way. Regarding these CE activities, P6 pointed out specifically the logistical processes when equipment gets transported from one location to another, while P3 named environmental aspects like energy consumption, fluids, air, and power that must be considered. This contributes, besides to sustainability, also to a good perception of the company/industry by the shareholders and the general public. Moreover, this counts for the ALICIA project and CE in general. Another significant aspect that P3 emphasized is to always ensure a contact party within ALICIA after purchasing in case any problems regarding the equipment appear (mostly of technical nature). This point of contact should feel responsible and assist if any problems emerge. If nobody feels responsible for the second-hand equipment after selling it, this can be a massive drawback for the establishment of ALICIA, moving companies away from acquiring second-hand equipment due to missing after-sales services. This contact point must be determined and can be either from the supplier side or within the ecosystem of ALICIA.

An additional crucial aspect is to provide affordable second-hand equipment that is still performing high operational quality. To elaborate more on this, P6 described that second-hand equipment is known to have a less good operational precision (e.g., tolerances) than new equipment. This quality gap between new and second-hand equipment can create a trend that only companies with substantial financial resources can buy new expensive equipment that produces in a precise way. This resulting trend can cause harm to ALICIA's CE concept since major companies then might continue to buy new equipment due to its better performance compared to second-hand ones. To counteract this trend and give smaller companies a chance to operate qualitatively high, it is important to modify second-hand equipment so that these smaller companies can create a high-quality output without spending much money on new equipment. A significant challenge to realize this constitutes solving it on a technical scale.

The legal issues that the interviews revealed in the context of CE activities are companies' corporate structures and policies that make it difficult to sell their utilized equipment due to the data they inherit. This data is sensitive information that many automotive corporations are reluctant to share. Clear policies must be defined on, according to P5, which historical equipment data needs to be shared, who owns it, and who has the right to use it (e.g., supplier or user). In the course of this section's category "Data exchange within ALICIA", this issue is emphasized further. Apart from this, the interoperability software developer (P7) claimed that insurance or guarantee-related issues must be taken into account since already minor technical modifications of equipment can immediately invalidate potentially existing guarantees from the supplier's side. Hence, it is necessary to establish an internal warranty policy within ALICIA.

<u>Second hand-equipment selection, purchase, and adoption</u>

Six out of seven participants deemed it necessary to include the production workers in selecting suitable production equipment based on the DT design before buying it on the marketplace. Still, they also all state that this should occur to a certain degree to not degenerate. P1 proposed a two-stage selection process that first, people with higher experience could make a preliminary selection resulting in three to four designs. Afterwards, in the second stage, the general workers can select one design based on these remaining options. The other participants also stated that not too many workers should be included in this process, only the ones with higher experience.

The workers' upskilling is crucial and was underlined by all participants. Since through ALICIA "new" purchased second-hand equipment that the workers might not be familiar with is operated, an unfamiliarity from the workers' side towards it can exist. Upskilling the workers can support alignment between the knowledge of the entire workforce and helps to avoid disadvantages among them (P1). Furthermore, it contributes to an increase in the workers' motivations which in turn can positively affect the production's efficiency (P2 and P7) and, of course, the working safety. Since all participants are familiar with such upskilling, they mentioned means to facilitate this, such as training or courses. Another aspect is to constantly increase people's awareness regarding CE and the purchased equipment. According to P7, people might be intimidated when they see incoming automated equipment because they might think it will replace them. Instead, this new second-hand equipment can be advantageous by assisting the worker. If this is the case, the workers should be educated concerning this to develop an optimistic assumption about the equipment that can benefit their work behavior. Finally, the fact that workers developed a particular habit to a specific equipment type should be, according to all asked participants, not considered since this can always exist, even for new equipment. Nevertheless, the production worker (P2) clarified to be open to using second-hand equipment as long as it meets the requirements and does what it was purchased for.

Data exchange within ALICIA

One of the most critical components is the data exchange within ALICIA, as it embraces the entire bounded CE system. Every in this section just described component of ALICIA is related to data. Because of this, the data exchange constitutes a crucial topic as it has been addressed throughout this interview synthesis and during the *Anticipation* step. In this sub-section, many components with their analyzed ELSA aspects that involve data exchange have already been outlined throughout the previous components. Their detailed issues are now re-addressed and carefully discussed here.

The issue most participants generally recognized is that a consensus must be found regarding equipment data. P1 expressed that the data incorporated in equipment is critical to disclose because the know-how of a company and how it operates can be deduced from it. A given example by the expert regarding this was that the equipment memory mostly inherits confidential information on production processes. P2 even claimed to delete all equipment data before selling by resetting it to factory settings. This option cannot be feasible from a technical point of view because historical equipment data is essential to perform CE activities (refurbishing, maintaining, reusing, etc.) on second-hand equipment since it includes information about the equipment's lifecycle. Multiple participants, including P4, also confirmed this. Another crucial data set required for ALICIA's operation is the factory owner requirements for the AI matchmaker. Here, P1 stated again that data about a corporation's production parameters, such as the production program with unit numbers, is complicated to share. ALICIA’s AI matchmaker responsible participant (P4) emphasized the significance of getting as much data as possible to ensure good estimations by the AI matchmaker, but he is as well aware that some companies might not want to share this since it can lead, as already mentioned, to a vast breach of privacy. Moreover, this opinion was shared by all participants. As a concluding remark, P6 stated that basically any data that can lead to reverse engineering is deemed sensitive.

Given that these data are crucial for ALICIA's CE and that there is no way around performing circularity without retrieving it, it is necessary to define a clear boundary. Clear boundaries in such a way as to make it possible that enough data is shared to get the best possible estimation/result while still disclosing the least sensitive corporational data possible. Such boundary can also be seen as a data standard policy that must be designed and implemented into ALICIA and agreed upon by all stakeholders. The task of the technical and industrial partners within ALICIA remains how this policy has to be conceptualized explicitly due to the technical and regulatory specifications that equipment and corporation data entail.

Closing remarks

Closing remarks that were given at the end of the interviews were vital to address the main view of the participants on ALICIA or circularity in the automotive sector in general. P1 and P2 noted their suggestion to utilize ALICIA for establishing networks. Even though competition in the automotive production sector exists, such networking can be of enormous benefit, considering that the EU automotive market must strengthen itself against other foreign markets. Moreover, circularity endeavors can be promoted by establishing a common product, different from what it has been with electric mobility. Similar was also emphasized by P6, who still sees the necessity to establish a more extensive ecosystem within ALICIA in the upcoming years after its design phase to ensure a successful implementation.

An opportunity for researching how AI and DT technologies can support CE on a broad scale was concluded by P3, who sees these technologies as a driver for the circularity of manufacturing equipment. P7 pointed out to constantly utilize open standards, which are crucial for the equipment’s interoperability and everything related to ALICIA’s data exchange. This is also a helpful means to prevent data silos. However, it was determined that this standard issue (mentioned by P7) relates to a larger scale environment beyond ALICIA's capabilities as it is an industrial matter and would affect all equipment manufacturers, even the ones who might not participate in circularity. Nevertheless, it is a well-thought suggestion.

As this step of the *Reflexivity* dimension is finished, the following sub-chapter deals with translating the gained insights into ELSA design points for ALICIA and categorizing them accordingly.

4.5 Step 4: Responsiveness

In this final step of the ALICIA case study and the conceptual framework, the translation and categorization of the analyzed findings from the previous dimensions and the interviews into ELSA design points happen.

4.5.1 ELSA categorization

In the following, Table 2 presents the ELSA categorization of the design points that ensure a socio-ethical responsible CE implementation of ALICIA according to the in the case study detected ELSA risks and impacts by demonstrating the conceptual framework. These ELSA design points originate from the findings of the framework's previous three steps with their dimensions, whose results are merged. They are structured according to the components of ALICIA with their functions, the potential risks/impacts and design points that need to be considered to remedy each risk, divided into ethical/social and legal categories. Since ethical and social aspects can overlap many times, no clear distinction was drawn between these two. Only the legal aspects are separately categorized. For the sake of not extending the table enormously, the consequences in the risks/impacts column (e.g., worker dissatisfaction that leads to lower production efficiency) are mostly left out, especially since they are extensively elaborated during the desk research in *Anticipation* and the dissemination of the interview results in *Reflexivity*.

Component	Potential ELSA risk/impact	Ethical/social design point	Legal design point
AI matchmaking algorithm engine	Unawareness by users can negatively influence their perception of ALICIA's AI technology	Educate all stakeholders on AI in general and how it is utilized for ALICIA (matchmaking and DS/DT)	-
	Bias that matchmaker might favor certain suppliers and neglects input data set (factory owner requirements)	Design AI matchmaker in a fair way that bias cannot occur, and AI focuses only on data input to be perceived as trustworthy. Ensure robust AI matchmaking	-

		process. Clearly communicate this to all stakeholders.	
	Lack of accountability concerning the AI's mechanisms and decisions	Constantly monitoring of the AI's black box mechanisms and estimations by an expert	-
	Lack of explainability of the AI's decisions	Being able to understand through traceability why the AI matchmaker made a particular decision	-
	Neglecting human-centricity in the factory owner requirements	Include workers' ergonomics (height, body stature, disabilities). Include workers' languages (native one where plant is located and always English)	-
	Generation of the DS/DT produces unforeseen malfunction	Implement interruption function e.g. "stop-button" into AI mechanism	-
Equipment interoperability	Equipment is designed in a non-worker-friendly way which frustrates workers	Design interoperability of equipment worker-friendly (e.g. operation and interface)	-
	Small-medium sized companies cannot afford second-hand equipment due to high costs of interoperability	Trying to hold costs for interoperability as low as possible to include as many companies as possible.	-
	Interoperability syntax is programmed in a way that user interface does not output preferred language (native one or English)	Modify syntax accordingly that native language of the operating country and English can be displayed on interface	-
	Technological components that ensure interoperability originate from non-ethical/sustainable circumstances (e.g. child labor, exploitation, environmental hazard)	-	Embed legal regulations into ALICIA that ensure ethical and sustainable origin of components (e.g. child labor prohibition law)
	Interoperability designs of equipment cause malfunctions: 1) disruptions, 2) technological lock-in that prevents further circularity	Design interoperability in a way that 1) a smooth operation is ensured, and worker is satisfied and 2) equipment can be sold multiple times until its end of life is reached	-
	Interoperability designs infringe IP	-	Modifying equipment in a way that IP of any corporation is not

			infringed and checking this constantly through auditing while making equipment interoperable
Digital marketplace platform	Unhealthy marketplace with no competition and realistic price creation exists	Establish a competitive marketplace environment that is healthy by being able to determine the right quality and price	-
	Participating stakeholders are not allowed to contribute to marketplace's development and thus might restrict innovation	Include stakeholders, especially companies that sell and purchase, to contribute to the marketplace's technical and strategical development	-
	Centralized governance scheme restricts marketplace's flexibility and inclusiveness	-	Establish a decentralized governance scheme for the marketplace
	Difficult access (registration) to platform restricts inclusiveness	Enable an easy access to ALICIA's marketplace platform to all industrial partners	-
	Fraudulent transactions occur on the marketplace	-	Establish "certificate of good conduct"-principle that demands verification of users before they can fulfill transactions on the marketplace
CE activities	Technological components that are used for CE activities originate from non-ethical/sustainable circumstances (e.g. child labor, exploitation, environmental hazard)	Ensure that CE activities' processes (e.g. logistical transport, refurbishing) happens in a sustainable way and constantly monitor this (e.g. emissions tracking)	Embed legal regulations into ALICIA that ensure ethical and sustainable origin of components (e.g. child labor prohibition law)
	Purchasing company has a defect equipment but no point of contact	Ensure point of contact within ALICIA that provides support for buyers (e.g. supplier or internal party within ALICIA ecosystem) in case of defects	Establish internal warranty policy within ALICIA that assures guarantee for purchased second-hand equipment
	Offered second-hand equipment is due to its technological requirements and performance only bought buy companies with less financial resources while major	Ensure that second-hand equipment can as well fulfill operations on a high-performance level	-

	companies still buy new equipment		
Second-hand equipment, selection purchase, and adoption	Second-hand equipment that workers are not satisfied with gets purchased	Include experienced workers or worker representation entity into equipment selection process that is based on DT design	-
	Workers lack skills/knowledge to operate "newly" purchased second-hand equipment and are discontent	Upskill workers and provide trainings, courses, etc. to align their knowledge according to purchased equipment	-
	Workers are intimidated by "newly" purchased automated equipment and fear job loss	Educate workers and communicate them that equipment is more assistance rather than replacement	-
Data exchange within ALICIA	AI matchmaker and DS/DT generator cannot operate successfully (calculating good estimations) due to insufficient factory owner requirements that company is reluctant to share because it includes sensitive data (e.g. process parameters)	-	Define clear data standard policy that determines which data must be shared within ALICIA to ensure a successful operation but at the same time does not jeopardize the confidentiality of companies. Through this, minimize the risk of disclosing sensitive data while still maximizing the success of ALICIA's data-dependent operations.
	Equipment cannot be sold/purchased because it still inherits confidential company data (e.g. historical data, process parameters)	-	

Table 2: Assessed ELSA design points of ALICIA's CE

4.5.2 Ensuring a responsible CE of ALICIA

Now, as the ELSA design points, which represent socio-ethical aspects that contribute to a responsible CE of ALICIA, have been assessed, this case study is regarded as completed. Implications, limitations, and other reflections regarding the case study, the framework, and the insights gained for socio-ethical assessment within CE and the general circularity for industrial automotive manufacturing equipment are elaborated in the upcoming Discussion and Conclusion chapters.

5 Discussion

This Discussion Chapter elaborates on the results and implications of the research. First, the main findings of the research and how they contribute to the detected knowledge gap are discussed. This also covers the responses to each sub-research question. Then, the main research question is answered. Subsequently, a critical evaluation of the research's limitations is given, while afterward, recommendations for future research follow.

5.1 Contributions

Since the identified knowledge gap comprises two domains (assessment of socio-ethical aspects in CE and circularity of automotive manufacturing equipment), this sub-chapter is divided into two sections that address each domain.

5.1.1 Relevance to the methodology of assessing ELSA aspects in CE

With respect to the first matter of the knowledge gap, the lack of assessing and incorporating socio-ethical considerations into the CE methodology, the main research question aims to determine how the RRI methodology can support the CE for assessing (socio-ethical) ELSA aspects. The carried-out literature review resulted in a lack of embedding such socio-ethical aspects into CE concerning the state-of-the-art methodology. It also provided recommendations for further research approaches to incorporate RRI and its four dimensions for facilitating such a socio-ethical assessment in CE. This represents a summarized answer to the first sub-research question, "*What is the current state-of-the-art methodology for assessing ethical and social aspects in CE in the context of RRI and CE activities for industrial manufacturing equipment in the automotive sector?*". The sub-question's second part regarding automotive equipment is stressed in the following section "Contributions to the circularity of industrial automotive manufacturing equipment through a case study".

Inigo & Blok (2019) and Purvis et al. (2023) significantly influenced this research. Both publications point out the lack of embedding socio-ethical considerations into CE. While the framework for a responsible CE by Purvis et al. (2023) constitutes a novel approach to incorporate the four dimensions of RRI (*Inclusion*, *Anticipation*, *Reflexivity*, and *Responsiveness*) (Stilgoe et al., 2013) into CE, the authors emphasize that their framework constitutes a sketchy starting point that demonstrates the relevance of these four dimensions and their beneficing for CE which requires future adjustment, rather than a completed approach that can be straight away applied to the CE methodology (Purvis et al., 2023). Moreover, besides this theoretical refinement, they proposed a practical application to a case study for testing if incorporating the RRI methodology into CE is feasible in practice (Purvis et al., 2023). This recommendation for the framework's theoretical adjustment was followed by establishing the conceptual framework, which provides the response to the second sub-question, "*How can the responsible innovation framework with its four dimensions by Stilgoe et al. (2013) be incorporated into the assessment of ethical and social aspects in CE?"*. The other recommendation concerning the framework's practical case study approach is addressed later in this section.

The conceptual framework established in this thesis represents an efficient approach to assess ELSA aspects in CE by executing a tool (technique) per RRI dimension. Most of the chosen tools of each dimension were proposed by Purvis et al. (2023) while slightly adjusting some to fit into the research with its given subject and time frame. The *Inclusion* dimension ensures that all relevant stakeholders are included, and their positions within the innovation project are accordingly considered. Therefore, a stakeholder mapping and analysis is chosen, as suggested by Purvis et al. (2023). In addition, it allows for gaining a comprehensive understanding of the project's environment. This sets the groundwork for a participatory approach. Potential (unforeseen) ELSA risks and impacts that could harm the innovation can be effectively anticipated by further analyzing the innovation in the dimension *Anticipation* through an elaborative desk research. The desk research builds on the fundamental understanding of the analyzed CE environment facilitated by the dimension of *Inclusion*. These anticipated issues can then be further examined through interviews with a CE system's internal and external stakeholders by the *Reflexivity* dimension. Doing this also provides insights into issues not identified during the *Anticipation's* desk research. Finally, *Responsiveness* allows to translate the findings from the previous dimensions into ELSA design points that contribute to RRI success that supports a socio-ethical responsible CE by mitigating the detected risks and impacts.

With regard to the second recommendation of Purvis et al. (2013) by applying such a framework to a case study, this was also followed up in this research. Applying the conceptual framework to a case study (ALICIA project) made it possible to comprehend the framework's applicability, including its benefits and drawbacks. Since the assessed ELSA design points for the ALICIA project are regarded as valuable input that contributes to guaranteeing a socio-ethical responsible CE, the framework's application and the case study were effective. The desk research (*Anticipation*) delivered insights from a more subjective point of view since a single researcher carried it out. In addition to this, expert interviews (*Reflexivity*) were consulted to receive, jointly merged and analyzed, in sum, an objective understanding. This combination of both subjective and objective viewpoints was instrumental. Particularly, for specific components of ALICIA (CE activities such as refurbishing and equipment interoperability) where a stand-alone desk research would not have delivered the same level of knowledge, these different understandings were crucial. Hence, integrating these two methods of desk research and expert interviews into the framework is something that created beneficial improvements relating to the results.

The framework's implementation also provided comprehension and an overview of ALICIA's bounded CE system by starting with the *Inclusion* dimension's stakeholder mapping and analysis. This allowed to receive an overview of the project environment and ALICIA's bounded CE system and to divide it into its several components, which was fundamental for the entire case study and, in the end, also the entire research. This approach guaranteed that no essential part of ALICIA was neglected, and its socio-ethical ELSA design points could be assessed on a holistic scale within its bounded CE system. Due to this, the conceptual framework's overall application was experienced positively which provides a scientific contribution to the current existing state-of-the-art methodology of such assessment in CE. It also shows that an incorporation of socio-ethical considerations in the form of such an assessment can be done in an effective way. Still, through the framework's application also limitations were disclosed, which Chapter 5.3 discusses. These just-described results answer the third sub-research question, "*To what extent is the designed framework applicable in the form of a case study within a real-life automotive industrial CE environment?".*

5.1.2 Contributions to the circularity of industrial automotive manufacturing equipment through a case study

Before beginning with discussing the research results' scientific contribution to the circularity of industrial automotive manufacturing equipment, the second part of the first sub-research question mentioned in the previous chapter, "*What is the current state-of-the-art methodology for assessing ethical and social aspects in CE in the context of RRI and CE activities for industrial manufacturing equipment in the automotive sector?"* revealed through the literature review lacking insights into the circularity for automotive manufacturing equipment. The research addresses this research gap by obtaining invaluable results that are now further outlined.

The conducted case study revealed that the circularity of manufacturing equipment in the automotive industry mainly depends on the prevailing competitional degree between the automotive industry's stakeholders. In principle, their willingness to utilize second-hand equipment is there to contribute to sustainability, provided that the equipment meets their requirements to avoid a deterioration in performance quality. What constitutes more of a challenge is the influence this competition has on crucial processes that are indispensable to make such circularity happen. These crucial processes are, first, the availability of the companies' equipment data to estimate its expected lifetime by sharing it. This must be guaranteed for refurbishing, maintaining, repairing, etc., the equipment for making it possible to offer it as second-hand equipment to companies. This might not be relevant for plain equipment such as conveyor belts or other non-automated equipment that runs without implemented soft and hardware. However, since the automotive industry has been increasingly relying on automated and/or digitalized production, it is quite certain that a CE for automotive manufacturing equipment will primarily affect equipment with integrated digital elements. The research revealed that corporations are reluctant to share such in the equipment inherited datasets because it also contains sensitive information on a company's know-how and other confidential process parameters.

Second, besides the equipment data, another sort of a company's internal data, that ensures they can acquire the best possible suitable production equipment tailor-made to their requirements, is essential. As well, companies are reluctant to share this data. This can be referred to ALICIA's AI equipment matchmaking technology of the case study that can only perform successfully by incorporating a complete factory owner requirements data set. Again, such data implies sensitive company data, such as process parameters like unit numbers, operational or strategical data, and many others that can facilitate reverse engineering and provide a competitor in the automotive sector with a clear view of a company's situation. Competing companies could use this informational data to strengthen their competitive advantage. But if the second-hand equipment is not precisely customized to the factory's requirements, which requires this alluded data, then companies will probably be hesitant to buy and utilize second-hand equipment because they do not want to downgrade their production efficiency due to inefficient equipment and lose their market position. This, in turn, affects the success of purchasing second-hand equipment. Consequently, clear data-sharing policies and arrangements must be defined that clarify which data is inevitable for making such circularity possible while at the same time ensuring that this data disclosure does not infringe on a company's privacy and success. Thus, to summarize, automotive companies generally want to participate in such a CE for industrial equipment but are seeing themselves impeded due to the major risk of data sharing that could harm them within their operating sector, which is a result of the existing competitional level.

In addition, other in the research detected challenges related to this kind of CE, comprise worker-related aspects and the integration of innovative ICT technologies or AI mechanisms. Such digitalized means were identified as supportive towards equipment circularity. However, these two obstacles occur regularly in the automotive sector, whether for new or second-hand equipment. Still, for ensuring a human-centric responsible CE, such barriers can be managed feasibly through the clearly defined ELSA design points and do not constitute a severe impediment. Another barrier linked to the competitional nature of the automotive industry is the lack of collaboration between the several competitors to ensure the equipment's standardization. To allow a smooth process of making equipment interoperable for all stakeholders contributing to such CE, all stakeholders must facilitate and ensure open standards that realize the interconnection of different equipment interfaces. This would make circularity easier to implement from a technological and organizational point of view. The development of a "common product" for CE, with specific regard, to equipment interoperability standardization, must be thus approached by the automotive sector. Besides this, while still referring to the interoperability, it must be ensured that second-hand equipment is also available for smaller companies with less financial resources since making equipment interoperable can be costly. Next to that, second-hand equipment should be technically able to perform on a high-quality level. Otherwise, as stated at the beginning of this section, companies that produce on a high-quality level and require such equipment do not want machinery that cannot fulfill their expected quality requirements (e.g., operating on low tolerances). Such an issue could lead to a rejection of circularity by companies.

The final vital insight of this case study is the necessity of guaranteeing an ethically responsible and sustainable origin of all parts (e.g., machinery parts) utilized for equipment circularity activities like reparation. Especially CE, which underlines sustainability, must also embed socio-ethical values into all its functions and operations from the start. Similarly, as it is within the automotive electric mobility field where many critics claim that the origin of these products, such as the lithium batteries, stems from an ethical irresponsible (e.g., child labor) and sustainable unaccountable (e.g., crop desiccation of South American fields) origin. Such conditions lead to a doubt about the sustainability of electric mobility. Hence, a similar scenario must be avoided in any case for a CE in the automotive sector. This also counts for the side effects caused by CE activities, such as emissions resulting from logistical processes (e.g., equipment transportation) or refurbishment concerning the equipment or its parts. Consequently, to prevent this flaw within a CE realization for automotive manufacturing equipment, such considerations must be embedded from the beginning into the concept of an automotive CE, as also CE in general, and constantly communicated and monitored. Otherwise, a dilemma, as in the electric mobility scheme, can arise that scrutinizes the sustainability and ethics of such a CE concept. This final finding can also be integrated into the entire automotive CE concept with its raw materials and consumables, and not only for manufacturing equipment.

Therefore, regarding the fourth sub-research question "*What value do these gained insights of the case study add to the circularity of industrial manufacturing equipment in the automotive* *sector?* ", it can be argued that the willingness to realize a CE for industrial automotive equipment is among all stakeholders in principle there but does not represent a sufficient factor. Rather, the main challenges which constitute decisive barriers to such a realization must be overcome and are mainly connected to the existing competition in the automotive industry that inhibits data sharing and collaboration, plus the significance of incorporating from the CE's beginning social and ethical responsibility. This ethical responsibility is related to the origin of CE parts and the CE activities with their resulting side effects so that the same mistake that has been taking place in the automotive's electric mobility agenda can be prevented. Trying to remedy such a dilemma later, when the concept is already implemented, always constitutes considerable difficulty. These discussed results provide a significant scientific contribution to the circularity of automotive manufacturing equipment.

5.2 Answering the main research question

The previously discussed results related to all four sub-research questions allowed to answer the main research question "***How can the RRI methodology complement the CE framework to assess ethical, legal, and social aspects (ELSA)?"***. It can be said that by incorporating the RRI methodology into CE, helpful outcomes were obtained by developing the framework and as well applying it to a case study. The way the RRI methodology, with its four dimensions, was utilized in the CE framework, and the continuation of given research recommendations in this field and building further upon that allowed to establish a conceptual framework for assessing ELSA aspects in CE. This research showed that utilizing the RRI methodology for assessing ELSA aspects in CE can be done and constitutes a supportive approach to gain insights into which ELSA aspects of CE are relevant to embed socio-ethical considerations that lead to a responsible CE. Moreover, this not only delivered a beneficial understanding of the circularity of manufacturing equipment in the automotive industry but also for the general assessment of ELSA aspects in CE. Answering the main research question contributes to advancing the CE framework more strongly and supporting its holistic development by incorporating socio-ethical considerations through RRI.

5.3 Limitations

Of course, this research also imposed limitations, now discussed in more detail. Starting with the methodology of the conceptual framework; fundamental research and future recommendations, in particular, provided by Purvis et al. (2023), served as guiding input to assess socio-ethical considerations in CE deeper by proposing multiple techniques (tools) per RRI dimension. Due to the intention of adhering to the given recommendation of advancing the theoretical framework and exploring its practical application through a case study, the time constraints imposed by the thesis research, which spanned approximately five months, necessitated the selection of only one tool per RRI dimension from the multiple suggested ones. For instance, in the case of *Reflexivity*, expert interviews were chosen as the preferred methodological tool, while other described techniques were precluded. This was also done to ensure that each determined tool could be applied as useful as possible during the research time frame. Prioritizing a thorough execution of one tool per dimension in the case study was, in this case, preferred to receive beneficial insights instead of applying multiple tools within a short period and receiving vague insights due to their poor execution. Another critical point of these executed tools is that they do not constitute any scientific novelty. Stakeholder mapping/analysis or expert interviews are methods that have been already existing for a long period. Thus, it is questionable if it is necessary to put them completely under the umbrella of RRI since they can rather be seen as generic tools of a project management approach.

Another limitation of the framework is the insufficient assessment of sustainable matters. Given that ELSA also relates in a way to sustainability because environmental performance can have an effect on social and ethical implications as well, it was during the case study detected that the framework covers this precise environmental assessment insufficiently. The outcomes of the framework's application with its categorization of ELSA design points cover namely environmental aspects, such as the monitoring of emissions during CE activities, but not in an extensive manner. To achieve complete coverage of these environmental factors, other frameworks, such as Life Cycle Assessment (LCA), must be employed. Such an LCA can be combined with the established conceptual framework and would allow to take additional environmental factors into account (e.g., generated scrap per equipment or used fluids).

Apart from the framework's methodological limitations, regarding the case study, some important points were also recognized on the circularity of automotive manufacturing equipment. The interviewing process included seven experts. To attain saturation, interviewing more participants would have been more helpful for gaining as much insights as possible. The current number of participants may have led to some ELSA design points being hidden. With reference to this, more external participants outside the ALICIA project and more people with less general understanding of CE could have been included. Because the analyzed bounded CE system of ALICIA is in its design phase, additional ELSA design points, besides the ones recognized, most probably can be assessed at a later stage of the project, even though the future scenario of ALICIA's operation was considered as well. Maybe even when, besides ALICIA, another similar CE for industrial automotive equipment is in operation or draws more use cases on a broader scale, more potential risks from the ELSA context will appear. This also counts for actually evaluating the assessed design points, which did not happen within this research since this will occur in several years during the project, where those factors serve as a benchmark for the project's use case.

Concerning the realization of the critical ELSA design points that impose a general solution to the identified challenges (exchange of data and creating technically and costly feasible equipment interoperability standards) for implementing an industrial automotive equipment CE, this thesis could not precisely define such as this requires expertise specifically for these areas. Thus, this research was only able to define the design points for these significant challenges on a broader scale which, still, constitutes a fundamental starting point towards the challenges of circularity for automotive manufacturing equipment.

Therefore, it requires further enhancement to the conceptual framework's methodology and, in addition, more than only this case study to first, test the framework and second, concretize the proposed solutions for the challenges existing in a CE for automotive manufacturing equipment. This is exemplified in the following sub-chapter.

5.4 Recommendations for future research

Thus, based on the explained limitations, recommendations for future research can be formulated. A required theoretical development of the conceptual framework's methodology is suggested. This includes incorporating more techniques per RRI dimension. Moreover, it must be investigated how LCA frameworks and other environmental impact assessment frameworks can be combined with the conceptual framework of this research since sustainable impacts relate, as described in the previous subchapter, to ELSA as well. Doing this could facilitate a more holistic social-ethical assessment of CE than the one obtained in this research.

Besides this, it is essential to apply the conceptual framework to more CE environments on a larger scale in the form of case studies or other similar approaches. Since this conceptual framework has been, so far, only applied to one case (ALICIA), it requires further applications to receive broader understandings and implications not only for the framework's methodological state but for the circularity of automotive manufacturing equipment as well.

The third and last recommendation is to continue research that analyzes the major challenges for realizing a CE for automotive production equipment. These in the research identified challenges are data exchange between the different stakeholders in the automotive industry, creating standardization of equipment interoperability, all embraced by the general existing competition in the automotive sector. It is essential to research how such a collaboration that works within or even counteracts this competitive structure can be reached to establish a "common product" in terms of a CE for automotive manufacturing equipment. Of course, this study revealed within the case study ELSA design points to overcome these challenges, still, they must be researched further in-depth for each specific area such as data governance and regulations, technological equipment interfaces and standardizations engineering, and the design of business models that promote such collaboration between competitors in the automotive industry in the context of circularity for production equipment and make such feasible.

Furthermore, it is necessary to explore how CE in the automotive sector can integrate from its beginning socio-ethical values, allowing it to operate ethically responsible. This must be done to avoid fatal mistakes which might be difficult to resolve later on when the CE is already in operation.

6 Conclusion

In order to address the lack of assessing socio-ethical aspects in CE, this research explored how the RRI methodology can be integrated into CE to provide a scientific contribution to this knowledge gap. Since several publications stressed that RRI could support this approach (Inigo & Blok, 2019; Kalioujny & Ermushko, 2017; Purvis et al., 2023), the main research question ***"How can the RRI methodology complement the CE framework to assess ethical, legal, and social aspects (ELSA)?"*** was defined. Based on the theoretical underpinnings of RRI, its four dimensions *Inclusion*, *Anticipation*, *Reflexivity*, and *Responsiveness* were integrated into the thesis' established conceptual framework to assess socio-ethical considerations within the realm of CE in relation to ELSA (aspects). The other part of the detected knowledge gap represents a lack of research on the circularity of manufacturing equipment in the automotive sector.

This conceptual framework was, after its creation, applied to a real-life use case in the form of a case study. The Horizon Europe granted ALICIA project that aims to establish a CE for industrial manufacturing equipment in the automotive sector represented the case. A demonstration and evaluation of the conceptual framework were thereby possible to recognize its strengths and limitations. Moreover, through the case study, the framework's application resulted in valuable findings concerning the methodology of socio-ethical assessment in CE and the circularity of automotive manufacturing equipment (definition of ELSA design points and challenges), which characterize the framework's demonstration as being helpful. To emphasize these findings in more detail, the four dimensions of RRI served as supportive means for assessing crucial ELSA aspects since the design points for a responsible CE of ALICIA could be defined. Within the framework, performing different tools (e.g., stakeholder mapping or expert interviews) per RRI dimension lead, in the end, to these ELSA design points. What is essential is that it starts from the beginning on with *Inclusion* in terms of including the stakeholders by mapping them, understanding their positions, and analyzing the entire project/CE environment before further actions are executed. During the *Anticipation* and *Reflexivity* dimensions, potential risks and impacts in the context of ELSA could be revealed from a subjective (desk research) and then a more objective point of view by active communication with multidisciplinary stakeholders within and outside the CE environment through expert interviews.

Concerning the results for the circularity of automotive manufacturing equipment, it can be argued that they constitute a fundamental starting point for further research in this field. In principle, automotive corporations are willing to utilize second-hand equipment. Still, major challenges were discovered that hinder realizing such CE. These challenges are mainly caused by the existing competition between companies in the automotive industry. Well-defined data exchange standards that allow the circularity of production equipment between companies must be defined in a way to not disclose sensitive data that could harm an organization's market position but simultaneously allows for obtaining sufficient data to enable equipment to be circular. Examples for this type of data are a company's production program-related data, which serve as input requirements to computationally allocate tailor-made production equipment, and historical equipment lifecycle data relevant for refurbishing activities. Next to this, another required standard that needs to be specifically designed is one for the interoperability between different (second-hand) equipment types that entail various interfaces and syntaxes. These two described crucial standardizations can only be established if the competing automotive companies cooperate with each other. The development of a common product for CE is a way to describe this necessary endeavor that must happen for making, as identified in this research, a CE for automotive equipment realizable. Furthermore, another considerable challenge that must be kept in mind while aiming to establish this type of automotive CE, is to pay attention to embedding socio-ethical values from the beginning on into its sustainable approach. This is significant to avoid mistakes that have been occurring in the automotive industry's sustainable agenda of electric mobility, where critics point out the unethical and non-sustainable origin of parts that are used to achieve sustainability. Such non-considerations might be later on, within a CE's operation, difficult to remedy.

Besides the research's emphasized benefits, of course also limitations were recognized. First, the conceptual framework established in this research only incorporates one tool per RRI dimension. This is due to the given time constraint of the thesis research, which led to the decision of using one tool properly in order to guarantee an effective operation during the case study and attain valuable ELSA aspects. A recommendation for future research regarding the framework's methodology is to develop it further by implementing more tools per RRI dimension as proposed by (Purvis et al., 2023), who presented a conceptual sketch for a framework towards a responsible CE based on the four RRI dimensions, or tools out of own understanding. Another critical point is that these tools of the conceptual framework do not constitute any scientific novelty as they rather refer to a generic project management approach. Still, under the umbrella of RRI in combination with CE, their combination can be viewed as such a "novel" approach. This is also due to the addition of ELSA to these tools. Besides this methodological refinement, also practical applications in form of case studies on other CE systems must be conducted to gain more outcomes that are beneficial for testing and evaluating the framework. This can also be helpful to receive, besides the framework's methodology, advanced insights into socio-ethical considerations of CE in general.

Second, even though the during the case study assessed ELSA design points help to tackle the major challenges of CE for industrial automotive equipment, this research could not delve deeper into examining how these design points could be technically and strategically made feasible in a specific way. Due to the researcher's lack of expertise in this area it requires concise experts e.g., data experts or software engineers that are able to realize such data exchange and equipment interoperability policies and standardizations. Because of this, it is suggested to further research on the specific feasibility of these assessed design points. Doing such further research can then contribute to overcoming these challenges for implementing an automotive industrial production equipment CE. This further research recommendation includes as well the investigation of potential business models that can support cooperation between automotive corporations within this competitive environment.

Generally, it can be concluded that this research yielded key insights concerning combining the RRI and CE methodologies for assessing ELSA aspects in CE. The main research question was answered as this was done by developing a conceptual framework that is capable of such an assessment. The framework was demonstrated by gaining relevant insights through the ALICIA case study that are beneficial for the framework's methodological part as also for its practical one. It is interesting how the junction of these two methodologies (CE and RRI) will evolve over time, especially since sustainability has been entrenching as a steadily growing subject within our society. Still, due to the insufficient research in this field, this thesis research needs to be further followed up as also scrutinized to gain more insights as it does not constitute a final conclusion within this subject. Regarding the circularity of automotive manufacturing equipment, this research established a fundamental starting point. Due to existing insufficient insights into embedding circularity for automotive equipment, this study only covered a small amount of a possibly larger pool of ELSA-related socio-ethical aspects. These unexplored issues will probably appear during the next years and need further addressing. To preventively avoid the serious mistakes that have already been occurring within the automotive's sustainability agenda of electric mobility, socio-ethical considerations must be from the start on firmly connected to the automotive's emerging sustainability initiative of a CE for manufacturing equipment. By not doing so, a sustainability agenda (CE) is established that misses vital socio-ethical pillars. This could lead to faults that might be later on hard to redress due to the CE's advanced implementation into automotive operations. Thus, 1) the established conceptual framework for analyzing ELSA aspects in the CE concept was capable to assess such but still has to be further investigated, and 2) the obtained fundamental insights regarding the circularity for automotive industrial manufacturing equipment constitute an elementary starting point but need to be further concretized. Both of the research's recapitulated major findings are crucial and their future research is highly recommended to achieve a bigger picture that contributes to establishing a holistically thriving and just CE. Not only for the automotive sector but also in general.

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Appendix

Appendix A Analyzed publications from the literature review

Title (authors, year)	Focused research field	Summary
Conceptualizing the circular economy: An analysis of 114 definitions (Kirchherr et al., 2017)	CE definition	Even though CE is gaining steady momentum, critics state that it does not have a consistent definition amongst people. Through analyzing multiple existing CE definitions the authors aim to contribute to the general understanding of CE and making it more consistent.
Circular economy performance assessment methods: A systematic literature review (Sassanelli et al., 2019)	State-of-the-art CE assessment	Examination of existing CE performance assessment methods through systematic literature review. Authors recommend further research for an assessment that covers all essential aspects of CE.
Toward sustainable circular economies: A computational framework for assessment and design (Thakker & Bakshi, 2021)	State-of-the-art CE assessment	Establishment and application of a computational framework to analyze existing CE systems. Methods like Life Cycle Assessment (LCA) are being implemented here.
Circular Economy Performance Measurement in Manufacturing Firms: A Systematic Literature Review with Insights for Small and Medium Enterprises and New Adopters (Negri et al., 2021)	State-of-the-art CE performance indicators	Literature review on existing frameworks to measure indicators of CE performance in manufacturing firms. Authors state the current limitations in doing this and recommend executing a more holistic approach.
A systematic review for measuring circular economy: The 61 indicators (Pascale et al., 2021)	State-of-the-art CE indicators	Systematic review on contributing to establish standardized indicators for measuring CE. Authors mention that social indicators should be also incorporated and recommend this for future research.
The DigiPrime KPIs' framework for a circular economy transition in the automotive industry (Kanellou et al., 2021)	State-of-the-art CE indicators	Framework for monitoring essential indicators that need to be ensured for the performance of a CE system. Focus here is on the automotive industry.
AI watch, evolution of the EU market share of robotics (Haarburger et al., 2021)	Robotics in production	Authors discuss the development and impact of robotics in the EU production sector over the years.
Approaches of Applying Human-Robot-Interaction-Technologies to Assist Workers with Musculoskeletal Disorders in Production (Reinhart et al., 2012)	Robotics in production	Emphasis with recommendations for the future concerning robotic use in production and how they can affect aspects like the economy or the production workers.
From Manual Operation to Collaborative Robot Assembly: An Integrated Model of Productivity and Ergonomic Performance (Zhang et al., 2021)	Robotics in production	Establishment of a model in which authors aim to evaluate the productivity and workers' ergonomic performance of production robots.
Management and Innovation of Robot in Automobile	Robotics in automotive production	Insights into how robotics influence the automotive production sector, what can be

Production Line (Chang et al., 2020)		still improved, and what challenges exist regarding reusing them again.
A Review on the Outlook of the Circular Economy in the Automotive Industry (Buruzs & Torma, 2018)	CE in automotive industry	Authors analyze how CE implementation in the automotive industry looks like. They do this based on published literature and data.
Circular production and maintenance of automotive parts: An Internet of Things (IoT) data framework and practice review (Turner et al., 2022)	CE in automotive industry	Authors propose a framework for analyzing the integration of digital technologies for assisting CE actions in the automotive industry.
Creating a Circular Economy in the Automotive Industry: The Contribution of Combining Crowdsourcing and Delphi Research (Wurster, 2021)	CE in automotive industry	A concept is presented that aims to support CE implementation for, specifically, tyres in the automotive sector.
Circular economy practices and industry 4.0 technologies: A strategic move of automobile industry (Yu et al., 2022)	CE in automotive industry	The authors provide through their research new guidelines that aim to support automotive firms to successfully implement CE into industry 4.0 production schemes.
Exploring Synergies Between Circular Economy and Asset Management (Acerbi et al., 2020)	CE for production equipment	The authors explore the connection between production equipment and CE which constitutes a huge research gap. They conclude that there is still the need for research in this field.
Circular Economy Strategies for Equipment Lifetime Extension (Fontana et al., 2021)	CE for production equipment	The authors aim to address the knowledge gap of CE and production equipment by proposing a framework that helps to build the ground for research in this field. Their focus is on lifecycle extension for production equipment.
The underrepresented key elements of Circular Economy: A critical review of assessment tools and a guide for action (Chrispim et al., 2023)	State-of-the-art CE assessment and actions; Ethical and/or social aspects in CE	Contributions and limitations of CE assessment tools are addressed. Emphasis on lack of considering, inter alia, social dimensions and stakeholders engagement in CE.
Strengthening the socio-ethical foundations of the circular economy: Lessons from responsible research and innovation (Inigo & Blok, 2019)	Ethical and/or social aspects in CE	Authors address the ongoing criticism of the CE concept of not sufficiently considering socio-ethical aspects. Furthermore, they examine how the RRI methodology can be used on CE to counteract this.
Is circular economy the key to transitioning towards sustainable development? Challenges from the perspective of care ethics (Pla-Julián & Guevara, 2019)	Ethical and/or social aspects in CE	Exploratory study of CE concept where authors conclude that, from an ethical point of view, CE needs to follow a more holistic approach as it constitutes of participants.
Mapping the social dimension of the circular economy (Mies & Gold, 2021)	Ethical and/or social aspects in CE	Authors emphasize lack of integrating social aspects into CE. This paper lays the groundwork for further analyzing the integration of social dimensions into CE.
The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context (Murray et al., 2017)	Ethical and/or social aspects in CE	Exploration of CE concept. Authors' findings are several limitations of the CE concept such as the lack of incorporating ethical and social dimensions which can hamper the sustainable development of CE.
COULD RRI APPROACH PLAY KEY ROLE IN ESTABLISHMENT OF CIRCULAR ECONOMY? (Kalioujny & Ermushko, 2017)	Ethical and/or social aspects in CE; ELSA & RRI	Authors utilize RRI approach to discuss the problems of CE integration into society. Their findings are that it requires further development strategies that include social aspects.
A framework for a responsible circular economy (Purvis et al., 2023)	Ethical and/or social aspects in CE; ELSA & RRI	In this paper, a first attempt to embed the RIF's four dimensions into CE to tackle the lack of incorporating socio-ethical aspects

		into CE is done. Their proposed framework lays the ground for conducting further research in this area.
Adapt or perish? Assessing the recent shift in the European research funding arena from 'ELSA' to 'RRI' (Zwart et al., 2014)	ELSA & RRI	Assessment of the development from ELSA to RRI. Moreover, the authors compare both embedded methodologies and state their similarities/differences and describe how both can complement each other.
Definitions and Conceptual Dimensions of Responsible Research and Innovation: A Literature Review (Burget et al., 2017)	ELSA & RRI	Literature review to discuss the definitions of the RRI concept. Authors claim that RRI consists of four dimensions (inclusion, anticipation, responsiveness, and reflexivity) and also of the concepts of sustainability and care.
The role of philosophy of science in Responsible Research and Innovation (RRI): the case of nanomedicine (Oftedal, 2014)	ELSA & RRI	Discussion of the ELSA & RRI concept and their integrations into science.
Developing a framework for responsible innovation (Stilgoe et al., 2013)	RRI	Authors emphasize how important a responsible governance for emerging science and innovation nowadays is. They create a framework based on the four RRI dimensions for addressing and applying responsible innovation.
Responsible Innovation and Responsible Research and Innovation (Owen & Pansera, 2019)	RRI	The evolution of RRI is explained here. Also, the four dimensions of the RIF and how they contribute to responsible innovation is illustrated by the authors.
Applying a Responsible Innovation Framework in Developing an Equitable Early Alert System: A Case Study (Patterson et al., 2023)	RRI	This paper described the application of the RIF (here called AIRR framework) in a data analytics project to gain more insights on how to enable responsible innovation in this field.
Modeling the effect of responsible research and innovation in quadruple helix innovation systems (Paredes-Frigolett, 2016)	RRI	The author presents a model for strategic decision-making in the context of responsible innovation for complex multi-actor systems by using as a starting point the RIF dimensions.
Governance of Responsible Research and Innovation: An Agent-Based Model Approach (Paredes-Frigolett et al., 2015)	RRI	Through the development of an agent-based model, the authors aim to assist actors in the decision-making within innovation endeavors to make better decisions for strategies concerning the governance of RRI.

Table 3: Overview of the selected and analyzed publications from literature review with associated information

Appendix B Field notes during the ALICIA case study

Observational field notes during ALICIA kick-off meeting in Munich - 15.02.2023: general discussions about the different and right now most relevant components of ALICIA and the tasks the industrial partners have concerning them

The Ecosystem Analysis Partner and Digital Marketplace Partner 2 presented their tasks and aims. As the Ecosystem Analysis Partner performs the ecosystem analysis, they aim to clarify the demands on the customers' side. Thus, the Ecosystem Analysis Partner presented the needs of Industrial Partner 1, who are participating in the use cases. Their main points are to counteract the premature waste of resources and underutilization of assembly lines. Through ALICIA they aim to, hence, operate carbon-neutral through fewer equipment purchases, less scrapping, and reaching a specific amount/period of the used material's service life(time) in the assembly line. What is necessary for them and currently does not exist is an overview that shows what production equipment currently exists in their assembly lines and when they reach their end-of-life.

What will be done by Ecosystem Partner 1 in the following months is to explore the state of the art (existing solutions of the technologies and marketplace) to better understand the current situation. This assists in identifying the requirements of the actors.

Concerning the task of Digital Marketplace Partners 1 &, Partner 2 noted that it is essential to obtain data in order to establish a smooth distribution of the equipment. As for now, Partner 1 acquires the machines with only few to no data. This is due to the fact, that Partner 1 buys the machines from organizations that are sometimes insolvent and there is no contact point anymore (e. g. engineers) that can provide Partner 1 with detailed information/data regarding the machine. For this issue, it requires a solution that, both, these two digital marketplace partners will work on. This is essential since automated and digital equipment is essential within automotive manufacturing.

AI Partner 2 must establish within their component task the Application Programming Interface (API) for the Digital Shadow (DS) and Digital Twin (DT). A significant point is to clarify what can be understood under the terms DS and DT. It occurred that many stakeholders have different understandings of the DS/DT. A lively discussion allowed everybody to share their definition and through this make a more uniform definition of these two terms, which are:

- DS: It contains data on a more abstract level and can be seen as a snapshot of the equipment’s state. It provides answers to the questions what the equipment is able to do and what it further needs.This allows the model to give an answer which machinery or parts are appropriate.
- DT: It contains more predicted data (sensorical) that can be described as a behavior model of a specific resource parametrized from the DS. Historical data on the equipment is therefore crucial.

In conclusion, the DS is a more abstract illustration while the DT is a more concrete one.

Besides these points, Partner 2 wants to figure out what can be expected from these simulations (DS & DT) and what the connection, testing, and validation of the DS with the plug & produce middleware (from Equipment Interoperability Partner) looks like. The further, more detailed specifications also regarding the DS & DT will be elaborated within this work package.

Equipment Interoperability Partner is responsible for the planning and development of the plug and produce middleware adaptors. This is necessary to align all the different machines that have their origin from different producers with different syntaxes and make them interoperable with each other. Currently, they has the framework to collect and work with all these kinds of different data. To imagine the concept of their work a comparison with Amazon can be drawn. Equipment Interoperability Partner produces these adaptors, delivers them to the customer who plugs them in and assists the customer within a 20-minute phone call on how to set it up. Moreover, they stated that it must be defined a ground definition of the machine’s historical data (e. g. using time, used tools, used materials, etc.) which is needed for creating a DT. Also, “must-haves” and “nice-to-haves” for this data should be determined so that Equipment Interoperability Partner and the AI model know where to focus on.

A very important point we figured out during this discussion was regarding the middleware adaptors. Equipment Interoperability Partner can easily read every information out of the machines (input). Rather, creating the output for every different kind of machine constitutes a huge challenge in case an assembly line has more than 25 machines in work, which is most likely the case. The exact issue lies in setting up this huge machinery network which many times constitutes of different machines and components. In addition, doing this for more than 25 machines, a huge amount of resources is required (money, staff, …). Thus, summarized the two main problems which must be addressed within this component are to ensure an “easy” and functioning plug-in connection to the middleware and a connection to the ALICIA framework to provide data for the actual execution part.

It was also mentioned that the user interfaces’ languages of the production equipment, should be, as most as possible, adjusted to the native language where the company is located and the majority of the workers speak. Like if for example if a German company purchases a second-hand machinery from France its user interface language should be changed to German. Furthermore, ergonomics in connection to the newly designed, refurbished, and composed equipment with the workers was mentioned.

Technological lock-in through the adaptors must be at any tme avoided. Technological lock-in means in this case that the adaptors might impede or even prevent second-hand equipment to get again further refurbished, re-assemblied, re-used, sold, purchased, etc.

Appendix C Informed consent opening statement form interview

Informed Consent Opening Statement for Interview – Marvin Ikedo (YAGHMA & TU DELFT)

You are being invited to participate in a research study titled "Developing a framework to assess ELSA design points that contribute towards a Circular Economy in the industrial automotive manufacturing sector: An exploratory research applied to the case of the circular economy project 'ALICIA' ". This study is being done by the MSc. student Marvin Ikedo from the TU Delft and YAGHMA.

The purpose of this research study is to get more insights into the circular manufacturing ecosystem with ALICIA and its impact KPIs (success factors) from the relevant actors' points of view and will take you approximately 60 minutes to complete. You will be asked questions regarding ALICIA and your position and expectations within the project.

The interview will be recorded by an audio device and an anonymous summary of the interview will be created. The data will be used for the Master thesis research with its related framework. The data will be used for research purposes and by YAGHMA for the activities within the ALICIA project.

The data (audio recording and transcript) will be securely stored at YAGHMA.

The final Master thesis that results from many parts, including this interview, will be published online and will publicly available on the TU Delft Educational repository. Thus, the thesis will only contain the anonymous summary of the interview and nobody outside of YAGHMA will get access to the raw .mp3 file in order to guarantee your privacy. The raw .mp3 file will be deleted at YAGHMA after the ALICIA project. The summary will contain your domain of activity and broad description of your activity in the domain.

Again, all personal data collected (audio + transcript and record of your participation) will be deleted at the end of the ALICIA project, and will remain in YAGHMA until deleted (approx. in the year 2027).

If you provide during the interviews any information that might be confidential or you do not want to be utilized and published within the Master thesis please explicitly state this before the interview takes place! In any case, we will send you the anonymous summary before publication. You can always contact of the below mentioned contact person if you have any concerns regarding the content of the summary that relate to your privacy or other internal private information. The summaries and the thesis will be published approx. August 2025.

As with any online activity, the risk of a breach is always possible. To the best of our ability, your answers in this study will remain confidential. We will minimize any risks by publishing the gained data anonymously without any names and, if wished, without the name of your organization. Before the summary will be published you will receive it after the interview to check if it is fine for to be published in this way. If not, you can always please clearly communicate it to the below mentioned contact person.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. If you wish certain data to be removed, please request this before 23.06.2023 as this date is the internal deadline for the thesis finalization.

In case of any questions or issues concerning this research, you can contact the following person:

Marvin Ikedo, M.O.Ikedo@student.tudelft.nl

Emad Yaghmaei, ey@yaghma.nl

Shiva Noori, sn@yaghma.nl

By taking part in this interview you agree to this informed consent opening statement with its above-described conditions.

Appendix D Interview protocol of expert interviews

- **Expert interview with production area manager of major European automotive components producer (P1)**
- **Participant exists within the ALICIA project consortium**
- **Interview performed on 13.06.2023**

Topic block 1: Introduction questions

1. Could you please briefly introduce yourself, who you are and what your profession is?
2. How would you define CE for industrial production?
   a. What would you consider as general main developments regarding CE in the automotive sector for industrial production equipment?
3. How do you and your organization work on Circular Economy within and outside the ALICIA project?
4. What is/are the biggest benefit/s you hope to gain through realizing ALICIA?
5. What is/are the biggest challenge/s you think that exist in realizing ALICIA?

Topic block 2: ALICIA's AI-matchmaking engine algorithm

1. Could you please define some of the general main challenges of AI you recognize and how they could relate to ALICIA's AI-matchmaking algorithm?
   a. Do you have any type of bias or concerns about letting an AI matchmaking technology select suitable production equipment for companies?
2. Do you think it is necessary to incorporate the workers' ergonomics, working safety, and other similar human-centric aspects into the factory-owner requirements which serve as an input for the AI matchmaking algorithm?
   a. Other data would be more sensitive information about employees, such as their height, preferred languages. Do you see a need for such data as well? And are there any other types that you would like to add?
3. I figured out that there might be a possible tension between security (e.g. the company acquires correct equipment that is secure to operate based on requirements) and privacy (e.g. not every single company data is shared through ALICIA and the matchmaking just requires/uses the least possible sensitive data). Which do you think is more important, security or privacy?
4. Concerning ALICIA's AI-matchmaking engine are the only current human interventions the entering of the factory owner requirements and equipment data into it. Would you recommend, besides this only existing human intervention, any other human intervention into this AI engine matchmaking process?

Topic block 3: Equipment interoperability

1. Do you have experience with making equipment from different manufacturers compatible with each other?
    a. Did you recognize any flaws not from the technical but social, ethical, or legal side?
    b. Do you deem it as important that the user interface or manuals of the equipment display all the same language (e.g. German)?

Topic block 4: ALICIA's digital marketplace platform

1. Do you value ensuring a healthy and fair but still competitive environment within ALICIA's marketplace?
    a. Which one of these two aspects is more important to you?
2. Do you think it is important that organizations, including you, are allowed to contribute to designing technically but also strategically the marketplace platform and hence further develop it?
3. Would you prefer a centralized or decentralized governance of the marketplace platform or even both?
4. Would you consider an easy access in terms of registering and signing up to the ALICIA marketplace platform as an important criterion?
5. Do you think that an increasing number of platform users can lead to increasing demand for second-hand equipment?

Topic block 5: Circular economy activities such (de-commissioning, refurbishing, and maintaining production equipment)

1. Have you ever made any experiences with Circular Economy activities like re-using, evaluating, de-commissioning, or refurbishing/maintaining production equipment?
    a. Do you see or have ever experienced any social/ethical issues arising while performing these Circular Economy activities?
    b. Do you see or have ever experienced any legal issues coming up while performing these Circular Economy activities?
2. Do you currently have or are aware of any competition regulations or rules that may restrict you from cooperating with other companies, especially in the automotive field, which could harm circular economy activities in ALICIA?

Topic block 6: Production equipment with its operational activities during and after second-hand purchase such as equipment selection, workers' adoption and operation of equipment, and worker requirements

1. Do you consider it as important to include the production workers in the decision-making process of selecting suitable production equipment based on the DT design?
    a. If yes, to which extent and why?
2. Do you think it is better to consider workers' aspects such as operation ergonomics or safety already before the selection and implementation of the equipment or afterward?

3. Do you think it is important to upskill the worker's knowledge and skills especially if they sometimes have to work with newly purchased second-hand commissioned equipment?
    a. Do you have experience in such upskilling activities as e.g. training, guidance, feedback, etc.?
4. Have you ever experienced any problems with workers in terms of them being used to a specific type or brand of equipment where they perhaps even claimed their dissatisfaction?

Topic block 7: Data exchange within ALICIA

1. Data exchange is an essential component of ALICIA. It is important to operate with data in the AI matchmaking engine which serves as a basis for the digital twin, but also for marketplace activities like selling and purchasing and further components of ALICIA. Thus, is there any data that you or your company might deem as very sensitive and would not like to share? Of course, you can state it abstractly without details.

Closing question:

1. Is there anything you consider relevant but has not been asked or mentioned in this interview yet?

- **ALICIA project expert interview with production worker from a major European automotive manufacturer (P2)**
- **Participant does not exists within the ALICIA project consortium**
- **Interview performed on 02.06.2023**

Topic block 1: Introduction questions

1. Could you please briefly introduce yourself, who you are and what your profession is?
2. How would you define CE for industrial production?
    a. What would you consider as general main developments regarding CE in the automotive sector for industrial production equipment?
    b. How do you and your organization work on Circular Economy?
3. What is/are the biggest benefit/s you hope to gain through realizing a CE for production equipment?
4. What is/are the biggest challenge/s you think that exist in realizing a CE for production equipment?

Topic block 2: ALICIA's AI-matchmaking engine algorithm

1. Do you have any type of bias or concerns about letting an AI matchmaking technology select suitable production equipment for your company?
2. Do you think it is necessary to incorporate the workers' ergonomics, working safety, and other similar human-centric aspects into the AI that selects the suitable equipment?
    a. Other data would be more sensitive information about employees, such as their height, preferred languages. Do you see a need for such data as well? And are there any other types that you would like to add?

Topic block 3: Equipment interoperability

1. Do you have experience with making equipment from different manufacturers compatible with each other?
    a. Did you recognize any flaws not from the technical but social, ethical, or legal side?
    b. Do you deem it as important that the user interface or manuals of the equipment display all the same language (e.g. German)?

Topic block 4: ALICIA's digital marketplace platform

1. Do you value ensuring a healthy and fair but still competitive environment within a CE equipment marketplace?
    a. Which one of these two aspects is more important to you?

2. Do you think it is important that organizations, including you, are allowed to contribute to designing technically but also strategically the marketplace platform and hence further develop it?

Topic block 5: Circular economy activities (de-commissioning, refurbishing, and maintaining production equipment)

1. Have you ever made any experiences with Circular Economy activities like re-using, evaluating, de-commissioning, or refurbishing/maintaining production equipment?
    a. Do you see or have ever experienced any social/ethical issues arising while performing these Circular Economy activities?
    b. Do you see or have ever experienced any legal issues coming up while performing these Circular Economy activities?
2. What are the second-hand equipment types/categories you might sell or buy through a CE platform?

Topic block 6: Production equipment with its operational activities during and after second-hand purchase such as equipment selection, workers' adoption and operation of equipment, and worker requirements

1. Do you consider it as important to include the production workers in the decision-making process of selecting suitable production equipment?
    a. If yes, to which extent and why?
2. Do you think it is better to consider workers' aspects such as operation ergonomics or safety already before the selection and implementation of the equipment or afterward?
3. Do you think it is important to upskill the worker's knowledge and skills especially if they sometimes have to work with newly purchased second-hand commissioned equipment?
    a. Do you have experience in such upskilling activities as e.g. training, guidance, feedback, etc.?
4. Have you ever experienced any problems in terms of being used to a specific type or brand of equipment where you or your colleagues perhaps even claimed their dissatisfaction?
5. Does it matter to you if the equipment you work with is new or from a second-hand origin?
    a. If yes, please specify the issues that matter to you concerning this difference.

Topic block 7: Data exchange within ALICIA

1. Data exchange is an essential component such a CE for production equipment. It is important to operate with data in the AI matchmaking engine which serves as a basis for the digital twin, but also for marketplace activities like selling and purchasing and further components. Thus, is there any data that you or your company might deem as very sensitive and would not like to share? Of course, you can state it abstractly without details.

Closing question:

1. Is there anything you consider relevant but has not been asked or mentioned in this interview yet?

- **ALICIA project expert interview with engineer for major European industrial equipment manufacturing company (P3)**
- **Participant exists within the ALICIA project consortium**
- **Interview performed on 12.06.2023**

Topic block 1: Introduction questions

1. Could you please briefly introduce yourself, who you are and what your profession is?
2. How would you define CE for industrial production?
    a. What would you consider as general main developments regarding CE in the automotive sector for industrial production equipment?
3. How do you and your organization work on Circular Economy within and outside the ALICIA project?
4. What is/are the biggest benefit/s you hope to gain through realizing ALICIA?
5. What is/are the biggest challenge/s you think that exist in realizing ALICIA?

Topic block 2: ALICIA's AI-matchmaking engine algorithm

1. Could you please define some of the general main challenges of AI you recognize and how they could relate to ALICIA's AI-matchmaking algorithm?
    a. Do you have any type of bias or concerns about letting an AI matchmaking technology select suitable production equipment for companies?
2. Do you think it is necessary to incorporate the workers' ergonomics, working safety, and other similar human-centric aspects into the factory-owner requirements which serve as an input for the AI matchmaking algorithm?
    a. Other data would be more sensitive information about employees, such as their height, preferred languages. Do you see a need for such data as well? And are there any other types that you would like to add?
3. I figured out that there might be a possible tension between security (e.g. the company acquires correct equipment that is secure to operate based on requirements) and privacy (e.g. not every single company data is shared through ALICIA and the matchmaking just requires/uses the least possible sensitive data). Which do you think is more important, security or privacy?
4. Concerning ALICIA's AI-matchmaking engine are the only current human interventions the entering of the factory owner requirements and equipment data into it. Would you recommend, besides this only existing human intervention, any other human intervention into this AI engine matchmaking process?

Topic block 3: Equipment interoperability

1. Do you have experience with making equipment from different manufacturers compatible with each other?
    a. Did you recognize any flaws not from the technical but social, ethical, or legal side?

b. Do you deem it as important that the user interface or manuals of the equipment display all the same language (e.g. German)?

Topic block 4: ALICIA's digital marketplace platform

1. Do you value ensuring a healthy and fair but still competitive environment within ALICIA's marketplace?
   a. Which one of these two aspects is more important to you?
2. Do you think it is important that organizations, including you, are allowed to contribute to designing technically but also strategically the marketplace platform and hence further develop it?
3. Would you prefer a centralized or decentralized governance of the marketplace platform or even both?
4. Would you consider an easy access in terms of registering and signing up to the ALICIA marketplace platform as an important criterion?
5. Do you think that an increasing number of platform users can lead to increasing demand for second-hand equipment?

Topic block 5: Circular economy activities (de-commissioning, refurbishing, and maintaining production equipment)

1. Have you ever made any experiences with Circular Economy activities like re-using, evaluating, de-commissioning, or refurbishing/maintaining production equipment?
   a. Do you see or have ever experienced any social/ethical issues arising while performing these Circular Economy activities?
   b. Do you see or have ever experienced any legal issues coming up while performing these Circular Economy activities?
2. Do you currently have or are aware of any competition regulations or rules that may restrict you from cooperating with other companies, especially in the automotive field, which could harm circular economy activities in ALICIA?

Topic block 6: Production equipment with its operational activities during and after second-hand purchase such as equipment selection, workers' adoption and operation of equipment, and worker requirements

1. Do you consider it as important to include the production workers in the decision-making process of selecting suitable production equipment based on the DT design?
   a. If yes, to which extent and why?
2. Do you think it is better to consider workers' aspects such as operation ergonomics or safety already before the selection and implementation of the equipment or afterward?
3. Do you think it is important to upskill the worker's knowledge and skills especially if they sometimes have to work with newly purchased second-hand commissioned equipment?
   a. Do you have experience in such upskilling activities as e.g. training, guidance, feedback, etc.?

4. Have you ever experienced any problems with workers in terms of them being used to a specific type or brand of equipment where they perhaps even claimed their dissatisfaction?

Topic block 7: Data exchange within ALICIA

1. Data exchange is an essential component of ALICIA. It is important to operate with data in the AI matchmaking engine which serves as a basis for the digital twin, but also for marketplace activities like selling and purchasing and further components of ALICIA. Thus, is there any data that you or your company might deem as very sensitive and would not like to share? Of course, you can state it abstractly without details.

Closing question:

1. Is there anything you consider relevant but has not been asked or mentioned in this interview yet?

- **ALICIA project expert interview with researcher that is focused on AI for European research institute (P4)**
- **Participant exists within the ALICIA project consortium**
- **Interview performed on 05.06.2023**

Topic block 1: Introduction questions

1. Could you please briefly introduce yourself, who you are and what your profession is?
2. How would you define CE for industrial production?
3. How do you and your organization work on Circular Economy within and outside the ALICIA project?
4. What is/are the biggest benefit/s you hope to gain through realizing ALICIA?
5. What is/are the biggest challenge/s you think that exist in realizing ALICIA?

Topic block 2: ALICIA's AI-matchmaking engine algorithm

1. Could you please define some of the general main challenges of AI you recognize and how they could relate to ALICIA's AI-matchmaking algorithm?
    a. Do you have any type of bias or concerns about letting an AI matchmaking technology select suitable production equipment for companies?
    b. I detected risks like bias that can harm the fairness of the matchmaking process, privacy and safety risks, and lack of accountability and trustworthiness. Do you have any disagreements with those or have further ones to add besides the ones already discussed?
    c. Is there a possibility that ALICIA's AI can develop itself by teaching itself and thus impair the trustworthiness?
2. Do you think it is necessary to incorporate the workers' ergonomics, working safety, and other similar human-centric aspects into the factory-owner requirements which serve as an input for the AI matchmaking algorithm?
    a. Other data would be more sensitive information about employees, such as their height, preferred languages. Do you see a need for such data as well? And are there any other types that you would like to add?
3. I figured out that there might be a possible tension between security (e.g. the company acquires correct equipment that is secure to operate based on requirements) and privacy (e.g. not every single company data is shared through ALICIA and the matchmaking just requires/uses the least possible sensitive data). Which do you think is more important, security or privacy?
    a. Do you think it is possible to design the AI algorithm in a way to reach both security and privacy?
4. Concerning ALICIA's AI-matchmaking engine are the only current human interventions the entering of the factory owner requirements and equipment data into it. Would you recommend, besides this only existing human intervention, any other human intervention into this AI engine matchmaking process?

   a. What do think of the idea to incorporate a "stop-button/function" that disrupts the AI's operation if there occur any unwanted/unforeseen circumstances that may cause harm?
   b. Did you ever implement such a function for past technologies?
5. Are you aware of any current regulations or policies for AI in general that ensure a social, ethical, and legal responsible/compliant AI process?

Topic block 3: Equipment interoperability

1. Do you have experience with making equipment from different manufacturers compatible with each other?
   a. Did you recognize any flaws not from the technical but social, ethical, or legal side?

Topic block 4: ALICIA's digital marketplace platform

1. Do you value ensuring a healthy and fair but still competitive environment within ALICIA's marketplace?
   a. Which one of these two aspects is more important to you?
2. Do you think it is important that organizations, including you, are allowed to contribute to designing technically but also strategically the marketplace platform and hence further develop it?
3. Would you prefer a centralized or decentralized governance of the marketplace platform or even both?

Topic block 5: Circular economy activities (de-commissioning, refurbishing, and maintaining production equipment)

1. Have you ever made any experiences with Circular Economy activities like re-using, evaluating, de-commissioning, or refurbishing/maintaining production equipment? It can be from the production or also IT/software sector.
   a. Do you see or have ever experienced any social/ethical issues arising while performing these Circular Economy activities?
   b. Do you see or have ever experienced any legal issues coming up while performing these Circular Economy activities?

Topic block 6: Production equipment with its operational activities during and after second-hand purchase such as equipment selection, workers' adoption and operation of equipment, and worker requirements

1. Do you consider it as important to include the production workers in the decision-making process of selecting suitable production equipment based on the DT design?
   a. If yes, to which extent and why?

Topic block 7: Data exchange within ALICIA

1. Data exchange is an essential component of ALICIA. It is important to operate with data in the AI matchmaking engine which serves as a basis for the digital twin, but also for marketplace activities like selling and purchasing and further components of ALICIA. Thus, is there any data that you or your company might deem as very sensitive and would not like to share? It can be also from solely from an AI-related perspective. Of course, you can state it abstractly without details.

Closing question:

Is there anything you consider relevant but has not been asked or mentioned in this interview yet?

- **ALICIA project expert interview with computer engineer focused on digital shadow/twin design and simulation for European research institute (P5)**
- **Participant exists within the ALICIA project consortium**
- **Interview performed on 02.06.2023**

Topic block 1: Introduction questions

1. Could you please briefly introduce yourself, who you are and what your profession is?
2. How would you define CE for industrial production?
3. How do you and your organization work on Circular Economy within and outside the ALICIA project?
4. What is/are the biggest benefit/s you hope to gain through realizing ALICIA?
5. What is/are the biggest challenge/s you think that exist in realizing ALICIA?

Topic block 2: ALICIA's AI-matchmaking engine algorithm

1. Could you please define some of the general main challenges of AI you recognize and how they could relate to ALICIA's AI-matchmaking algorithm?
    a. Do you have any type of bias or concerns about letting an AI matchmaking technology select suitable production equipment for companies?
    b. I detected risks like bias that can harm the fairness of the matchmaking process, privacy and safety risks, and lack of accountability and trustworthiness. Do you have any disagreements with those or have further ones to add besides the ones already discussed?
2. Do you think it is necessary to incorporate the workers' ergonomics, working safety, and other similar human-centric aspects into the factory-owner requirements which serve as an input for the AI matchmaking algorithm?
3. I figured out that there might be a possible tension between security (e.g. the company acquires correct equipment that is secure to operate based on requirements) and privacy (e.g. not every single company data is shared through ALICIA and the matchmaking just requires/uses the least possible sensitive data). Which do you think is more important, security or privacy?
4. Concerning ALICIA's AI-matchmaking engine are the only current human interventions the entering of the factory owner requirements and equipment data into it. Would you recommend, besides this only existing human intervention, any other human intervention into this AI engine matchmaking process?

Topic block 3: Equipment interoperability

1. Do you have experience with making equipment from different manufacturers compatible with each other?
    a. Did you recognize any flaws not from the technical but social, ethical, or legal side?

Topic block 4: ALICIA's digital marketplace platform

1. Do you value ensuring a healthy and fair but still competitive environment within ALICIA's marketplace?
    a. Which one of these two aspects is more important to you?
2. Do you think it is important that organizations, including you, are allowed to contribute to designing technically but also strategically the marketplace platform and hence further develop it?
3. Would you prefer a centralized or decentralized governance of the marketplace platform or even both?

Topic block 5: Circular economy activities (de-commissioning, refurbishing, and maintaining production equipment)

1. Have you ever made any experiences with Circular Economy activities like re-using, evaluating, de-commissioning, or refurbishing/maintaining production equipment? It can be from the production or also IT/software sector.
    a. Do you see or have ever experienced any social/ethical issues arising while performing these Circular Economy activities?
    b. Do you see or have ever experienced any legal issues coming up while performing these Circular Economy activities?

Topic block 6: Production equipment with its operational activities during and after second-hand purchase such as equipment selection, workers' adoption and operation of equipment, and worker requirements

1. Do you consider it as important to include the production workers in the process of selecting suitable production equipment based on the DT design?
    a. If yes, to which extent and why?

Topic block 7: Data exchange within ALICIA

1. Data exchange is an essential component of ALICIA. It is important to operate with data in the AI matchmaking engine which serves as a basis for the digital twin, but also for marketplace activities like selling and purchasing and further components of ALICIA. Thus, is there any data that you or your company might deem as very sensitive and would not like to share? Of course, you can state it abstractly without details.

Closing question:

1. Is there anything you consider relevant but has not been asked or mentioned in this interview yet?

- **ALICIA project expert interview with European Initiatives department leader for a major European online auction provider for industrial equipment that operate through a digital marketplace platform (P6)**
- **Participant exists within the ALICIA project consortium**
- **Interview performed on 13.06.2023**

Topic block 1: Introduction questions

1. Could you please briefly introduce yourself, who you are and what your profession is?
2. How would you define CE for industrial production?
3. How do you and your organization work on Circular Economy within and outside the ALICIA project?
4. What is/are the biggest benefit/s you hope to gain through realizing ALICIA?
5. What is/are the biggest challenge/s you think that exist in realizing ALICIA?

Topic block 2: ALICIA's AI-matchmaking engine algorithm

1. Could you please define some of the general main challenges of AI you recognize and how they could relate to ALICIA's AI-matchmaking algorithm?
   a. Do you have any type of bias or concerns about letting an AI matchmaking technology select suitable production equipment for companies?
2. Do you think it is necessary to incorporate the workers' ergonomics, working safety, and other similar human-centric aspects into the factory-owner requirements which serve as an input for the AI matchmaking algorithm?
3. I figured out that there might be a possible tension between security (e.g. the company acquires correct equipment that is secure to operate based on requirements) and privacy (e.g. not every single company data is shared through ALICIA and the matchmaking just requires/uses the least possible sensitive data). Which do you think is more important, security or privacy?

Topic block 3: Equipment interoperability

1. Do you have experience with making equipment from different manufacturers compatible with each other?
   a. Did you recognize any flaws not from the technical but social, ethical, or legal side?

Topic block 4: ALICIA's digital marketplace platform

1. Do you value ensuring a healthy and fair but still competitive environment within ALICIA's marketplace?
   a. Which one of these two aspects is more important to you?

2. Do you think it is important that organizations, besides you, are allowed to contribute to designing technically but also strategically the marketplace platform and hence further develop it?
3. Would you prefer a centralized or decentralized governance of the marketplace platform or even both?
4. Would you consider an easy access in terms of registering and signing up to the ALICIA marketplace platform as an important criterion?
5. Do you think that an increasing number of platform users can lead to increasing demand for second-hand equipment?

Topic block 5: Circular economy activities (de-commissioning, refurbishing, and maintaining production equipment)

1. Have you ever made any experiences with Circular Economy activities like re-using, evaluating, de-commissioning, or refurbishing/maintaining production equipment?
    a. Do you see or have ever experienced any social/ethical issues arising while performing these Circular Economy activities?
    b. Do you see or have ever experienced any legal issues coming up while performing these Circular Economy activities?
2. Are you aware of any competition regulations or rules that may restrict companies to cooperate with each other, especially in the automotive field, which could harm circular economy activities in ALICIA?

Topic block 6: Production equipment with its operational activities during and after second-hand purchase such as equipment selection, workers' adoption and operation of equipment, and worker requirements

1. Do you consider it as important to include the production workers in the process of selecting suitable production equipment based on the DT design?
    a. If yes, to which extent and why?

Topic block 7: Data exchange within ALICIA

1. Data exchange is an essential component of ALICIA. It is important to operate with data in the AI matchmaking engine which serves as a basis for the digital twin, but also for marketplace activities like selling and purchasing and further components of ALICIA. Thus, is there any data that you or your company might deem as very sensitive and would not like to share? Of course, you can state it abstractly without details.
2. Are you aware of any data and data access policies for digital marketplaces besides the GDPR and EU Data Act Compliance?

Closing question:

Is there anything you consider relevant but has not been asked or mentioned in this interview yet?

- **ALICIA project expert interview with software developer for industrial production equipment for a European company that offers digitalization solutions for industrial production equipment (P7)**
- **Participant exists within the ALICIA project consortium**
- **Interview performed on 25.05.2023**

Topic block 1: Introduction questions

1. Could you please briefly introduce yourself, who you are and what your profession is?
2. How would you define CE for industrial production?
3. How do you and your organization work on Circular Economy within and outside the ALICIA project?
4. What is/are the biggest benefit/s you hope to gain through realizing ALICIA?
5. What is/are the biggest challenge/s you think that exist in realizing ALICIA?

Topic block 2: ALICIA's AI-matchmaking engine algorithm

1. Could you please define some of the general main challenges of AI you recognize and how they could relate to ALICIA's AI-matchmaking algorithm?
    a. Do you have any type of bias or concerns about letting an AI matchmaking technology select suitable production equipment for companies?
2. Do you think it is necessary to incorporate the workers' ergonomics, working safety, and other similar human-centric aspects into the factory-owner requirements which serve as an input for the AI matchmaking algorithm?
    a. Other data would be more sensitive information about employees, such as their height, preferred languages. Do you see a need for such data as well? And are there any other types that you would like to add?

Topic block 3: Equipment interoperability

1. Based on your experience in facilitating equipment interoperability, have you experienced any flaws from the non-technical side but from social, ethical, or legal aspects?
    a. Did you recognize any other flaws related to IP rights or similar legal issues that might be a challenge for realizing such interoperability/compatibility?
    b. Do you deem it as important that the user interface or manuals of the equipment display all the same language (e.g. German)?
2. Is it important to you that the communication between different equipment occur quickly without any disruptions?
3. As back then addressed in one of our meetings, is there a possibility that the interoperability adaptors would create a kind of ''technological lock-in'' that makes it difficult to sell or reuse second-hand equipment again that was already before made interoperable through your adaptors?

Topic block 4: ALICIA's digital marketplace platform

1. Do you value ensuring a healthy and fair but still competitive environment within ALICIA's marketplace?
    a. Which one of these two aspects is more important to you?
2. Do you think it is important that organizations, including you, are allowed to contribute to designing technically but also strategically the marketplace platform and hence further develop it?
3. Would you prefer a centralized or decentralized governance of the marketplace platform or even both?

Topic block 5: Circular economy activities (de-commissioning, refurbishing, and maintaining production equipment)

1. Have you ever made any experiences with Circular Economy activities like re-using, evaluating, de-commissioning, or refurbishing/maintaining production equipment?
    a. Do you see or have ever experienced any social/ethical issues arising while performing these Circular Economy activities?
    b. Do you see or have ever experienced any legal issues coming up while performing these Circular Economy activities?
2. Are you aware of any competition regulations or rules that may restrict companies to cooperate with each other, especially in the automotive field, which could harm circular economy activities in ALICIA?

Topic block 6: Production equipment with its operational activities during and after second-hand purchase such as equipment selection, workers' adoption and operation of equipment, and worker requirements

1. Do you consider it as important to include the production workers in the decision-making process of selecting suitable production equipment based on the DT design?
    a. If yes, to which extent and why?
2. Do you think it is important to upskill the worker's knowledge and skills especially if they sometimes have to work with newly purchased second-hand commissioned equipment?
    a. Do you have experience in such upskilling activities as e.g. training, guidance, feedback, etc.?
3. Have you ever experienced any problems with workers in terms of them being used to a specific type or brand of equipment where they perhaps even claimed their dissatisfaction?

Topic block 7: Data exchange within ALICIA

1. Data exchange is an essential component of ALICIA. It is important to operate with data in the AI matchmaking engine which serves as a basis for the digital twin, but also for marketplace activities like selling and purchasing and further components of ALICIA. Thus, is

there any data that you or your company (or your clients) might deem as very sensitive and would not like to share? Of course, you can state it abstractly without details.

Closing question:

1. Is there anything you consider relevant but has not been asked or mentioned in this interview yet?

Appendix E Expert interviews summarized respondent list

Participant # / *Topic blocks & Categories*	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
CE in general							
Definition of CE for industrial production	Produce as economically as possible and considering sustainability.	Exchange of production equipment.	Crucial to tackle energy and resources crisis through reuse.	Optimization of economy and minimization of costs, maximization of profit.	Products and practices are adopted to contribute to reuse, remanufacture, recycling. Digital information is therefore crucial.	Keep production as closed as possible. Maximize life cycle of production assets, reuse and recycle.	Reduce waste of old machin ery. Reuse and improve enviro-nmental aspects
Main developments of CE in automotive sector for industrial equipment	Standardizatio n for machinery and development itself for guaranteeing reuse and fairly long usability.	Development is important to always ensure success of company.	Increasing awareness of reuse but still long way to go, compared to e.g. Japan.	-	-	-	-
Current CE operations in or/and outside ALICIA	General: Already trying to implement this standard in production to use lines with equipment for variably for different products	General: Internal CE for equipment but not external with other companies.	General: Specific sector of their company to refurbish, maintain equipment.	Outside of ALICIA: Supply chain and transportation management of used products. Inside: Develop second-hand tools, AI matchmaker.	Outside: Technologies to increase security and sustainable manufacturing, efficient re-/manufacturing / Inside: Making extension of equipment lifecycle possible by accurate simulation through digital twin.	General: Extend lifetime of machinery and use it to their maximum lifecycle. Provide means (marketplace) to facilitate this.	Outside: Make old machinery network capable to extend their lifetime / Inside: Ensure equipment interoperability of second-hand equipment.
Benefits through realizing ALICIA	Contribute to improve such standardizatio n (for software, interfaces, etc.) globally for enabling a CE.	Bring automotive concerns together to collaborate and boost CE.	Develop the IT solutions/tools that can help to overcome challenges to e.g. evaluating equipment system (lifetime, etc.)	Improve the use of AI systems in manufacturing to save time, maximize profit, and minimize costs.	Develop new technologies that allow to assess equipment condition through digital twin and advance it further.	Change trends. Make people aware that second-hand equipment is a valid solution. Establish standardizatio ns.	Learn more about CE technologies and realization.
Challenges in realizing ALICIA	Find solutions that older hardware can also operate with new/old software and be able to upgrade it and	Difficult for companies to sell equipment due to disclosure of sensitive information. Common	Customers often request new equipment with new features and performances. Difficult to fully	Unavailability of historic equipment data like lifetime (relevant for maintenance, etc.)	Define standards for different tools of stakeholders and connect them. This is not there yet.	Some companies are reluctant to enter CE. Ecosystem must be built. Currently only testing ALICIA	Generalize software to read out correct data of equipment from different manufacturers.

	use it for a long time.	consensus must be found.	monitor remaining lifetime of equipment and to have databases for it. Change awareness of people regarding second-hand equipment. Ensure safety of second-hand machinery		Create solution for all different kind of stakeholders.	on two use cases which is a limitation and cannot address this CE system fully.	
ALICIA's AI matchmaking algorithm engine							
General challenges of AI and relation to ALICIA's AI matchmaking algorithm	Unawareness of participants, thus educate them about AI.	No.	No.	Only data management must be handled correctly. Maybe other production companies/stakeholders have concerns.	Data management and classification of different existing equipment data that serve as AI input. Bias towards certain suppliers (favor them, etc.). Thus, Ensure trust and explainability of AI.	Developed bias based on input data set that can influence result. Explainability of decisions + accountability of AI's black box. This needs to be monitored, but if done correctly, huge opportunity.	Bias. Train data accordingly, so that AI does not develop bias. Make matchmaker robust (Robustness).
Necessity of incorporating worker-related aspects into AI dataset	Ergonomics can increase workers' comfort and thus efficiency. Spoken language as well.	Ergonomics can increase to workers' concentration and thus efficiency. Height, body stature, language yes. Language only native language and English.	Ergonomics, safety, disabilities, and language.	Yes, but more in relation to the DS/DT and not only for the AI.	Ergonomics, only maybe later throughout project due to limited timeframe.	Yes.	Yes. Additionally, Workers disability or health history. But critical due to privacy.
Tension security vs. privacy	Security. Still, it would be great to also respect privacy	-	Trade-off required. Still, emphasis here on privacy.	No clear answer, but possibility to ensure privacy is possible	Security. Because its human lives.	Both. Trade-off required.	-
Additional human intervention besides data input	No.	-	No answer yet. Maybe later in the project.	Yes. Human intervention as in experts that control the AI's estimations in certain cases to avoid wrong ones.	Maybe humans can further annotate fed in data set, e.g. preference for certain supplier. Human in the loop to improve feedback from	-	-

					AI matchmaker.		
Interruption (stop-button) function for AI	-	-	-	Yes, in connection with the DS/DT generation. In case, since AI works quick, and unforeseen malfunction happens.	-	-	-
Equipment interoperability							
Ethical/social issues	Design it in a way that worker can work with it and everybody should be able to afford such interoperable made equipment. Regardless of company size (right now very expensive and just doable for big companies). Languages, in same language according to country.	Ethical and social responsible origin (parts for interoperability but also refurbishment). Automotive electric mobility parts originate from non-ethical conditions, e.g. lithium third world country, child labor, exploitation. Language, native one where plant is located + English due to world language.	Language, native language, English (not everybody understands). This also impacts safety.	None	Expensive (equality),	None	Make people clear this automation or equipment in general is not mainly to replace them but to bring advantages to production. Language and accessibility: Make equipment adjustments in a way that also disabled can operate it (e.g. color-blind mode, speech output) No disruptions: to create acceptance. No techn. lock-in to allow to sell equipment again
Legal issues	IP	None	IP (make sure new designed and interoperable made equipment is no infringement of patent from competitors Guarantee: still maintain guarantee	Competition, maybe company would not be interested in using different equipment on their devices	IP because of data (confidential data, process-related data). Don't exploit human knowledge data	Maintain security, don't expose confidential data within equipment.	Protect IP, some manufacturers don't want to share information.
Digital marketplace platform							
Healthy & fair vs. competitive environment	Both. But more competition, because this creates a healthy market and determines the	Competitive environment, demand determines the price. "Whether that's fair or nor	Both. But more competitive	Healthy, based on experience. But not involved in terms of actually using platform for	Both. But competitive more regarding other platforms that ALICIA marketplaces	Competitive, it is by definition impossible to make a marketplace fair, especially in this field.	Healthy and fair. But fair competition. So both?

	right quality and price. Legal: Not everybody should be allowed to sell.	remains to be seen"		purchase since participant designs AI matchmaker	is successful. So, basically Healthy and fair.	Because if everybody can post and buy stuff equally that would finish fairness. .	
Contribution of others to design and develop platform	Yes, would be great.	Yes. Because Companies are the ones that make use of platform end of day.	Cannot answer it.	Yes, customization is preferred by companies.	-	Yes	Yes, to a certain degree. It's good for innovation, but not everybody can contribute as they please. Always in interest of the project's goals.
Type of governance (centralized or decentralized)	Decentralized. Makes it more flexible and faster	-	Decentralized	Centralized.	Decentralized, to make it more fair & inclusive. But maybe more difficult to achieve	At beginning, centralized then decentralized, that it does not get out of control at beginning.	Decentralized, technically more difficult but more advantages then.
Easy access (e.g. registration)	Yes, but must be professional. Verification of participating parties (e.g. through certificate of good conduct) to avoid scams.	-	Yes, absolutely. Easy access important so people will make use of it.	-	-	Yes. But important to guarantee it for all type of clients (clients who want to operate with platform to make CE better through data input and other client who just buys equipment with no other intentions)	-
Increasing number of platform users lead to increasing demand of second hand equipment	Yes, has potential, but standardization issue must be solved	-	Yes, because platform could be helpful tool to support second-hand use. And create thus awareness to not always buy new equipment.	-	-	Yes, ALICIA can potentially enhance this awareness to use more second-hand equipment.	-
Circular Economy activities							
Ethical/social issues	None	None	Always make sure to have contact point in ALICIA after purchasing in terms problems show up (e.g. supplier, refurbisher, maintenance party, etc.).	None	None	Make logistics of machinery for CE activities efficient (e.g. sustainable regarding pollution, easy accessible etc). Try to also offer precise machinery	None

			Activities should happen in env. Friendly way (energy consumption, fluids, air power etc.). This also gives good impression of other shareholders as well as general public regarding company and ALICIA CE system			even when it is second hand. Try to give everybody the chance to buy best possible equipment even it is second hand. Only must be solved from technical point of view because reused equipment often has less precision.	
Legal issues	Corporate structure makes it very difficult. IP (missing data model to assess everything) & Competition regulations, often contracts required to do such activities.	None	None yet, but in future maybe more will emerge, since ALICIA is a quite novel approach.		Who owns data? Historian data of machinery (company, supplier?). Who has right to use this data?	Outside of EU is critical. But since ALICIA aims for EU implementation this is fine. Maybe refer here to Schengen description by Jordi before.	Insurance and guarantee might vanish due to changing the equipment's technological structure. Establish internal guarantee policy for ALICIA
Second hand equipment selection, purchasing, adoption							
Include workers in selecting equipment based on DT design	To a certain degree of experience. Multi stage process: worker with higher experience chooses 3-4 designs and then general workers can choose out of these the most optimal one.	To a certain degree. Only workers that are really involved with machinery and have higher responsibility. Otherwise would expand unnecessarily	Yes. Select right people. Workers that are representative and choose out of 3-4 possible solutions because workers always see things what maybe managers don't see.	No. maybe before AI matchmaking but not afterwards anymore.	Yes, because end of the day they are the users, they can give crucial feedback. But they are not expert in data mgmt. Thus, communicate it in comprehensive way to them. Proposal of augmented reality.	Yes, but not too many workers.	Yes, important. As much as possible.
Upskill workers	Crucial. To maintain alignment between all workers' knowledge	Crucial.	Crucial.	-	-	-	Essential. Increases motivation of workers and then in turn productivity.
Workers' habits to certain equipment	Yes, but will always exist	Yes, but will always exist. But open to use second-hand equipment if it meets the requirements	Yes, but not typically.	-	-	-	Rarely.

		and does what it should do.					
Data exchange within ALICIA	Process parameters (e.g. unit numbers) in factory owner requirements or equipment data (e.g. memory) are critical to share because a lot can be deduced from it (how company works etc.)	All sensitive equipment data must be deleted before selling equipment.	Equipment data (maintenance, expected lifetime data). Usually this data is not disclosed.	It is best to get as most as possible data for good estimations. Some companies reluctant to share equipment data, must be solved.	Equipment data is sensitive (historical data, CAD data, etc.). People are reluctant to share this. Also regarding security and privacy.	Any data that can lead to reverse engineering is sensitive. Not always easy to know what can be shared and what not. At end: Define clear standards and minimum data that must be shared to get best possible estimation/result and least disclosure of sensitive company data.	Equipment and production data is sensitive since conclusions about possible company secrets can be drawn from it.
Closing remarks	Maybe use ALICIA to establish networks. Even competition exists to boost CE and strengthen automotive EU market again.	Automotive companies work together, establish common product and boost circularity.	Looking forward to future and use of AI and DT in CE on a big scale.	None.	None.	Good start to address such a CE system but still it is necessary for involvement of much more stakeholders to create entire CE ecosystem.	Open standards for data exchange is very crucial and makes such CE easier and not again create data silos or lock-ins.

Table 4: Respondent list of the interviews' summarized answers per participant