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Visualization of Social Life Cycle Assessment and Ethics Audit Outcomes in the Context of a Circular Manufacturing Ecosystem

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Abstract: The identification and consideration of social and ethical aspects are key enablers to achieving sustainable production, including human-centrism. Existing social life cycle assessment and ethical audit methods identify relevant risks and their impacts on such complex systems. In the context of a business ecosystem, an integrated view of the assessments' outcomes is missing. Addressing this gap, we propose an extension of the V² value network notation. By combining economic and social sustainability aspects, the resulting holistic view creates a comprehensive visualization of the overall system. This view serves as the basis for the analysis and communication of complex socio-technical systems' aspects. The proposed extension of the notation is presented, and its application is demonstrated by means of a case study of a platform-based circular manufacturing ecosystem that enables the reuse of assembly lines.

Keywords: circular economy; ethical audit; social life cycle assessment; sustainable production; value network

1 INTRODUCTION

Ideally, a successful circular economy contributes to all three dimensions of sustainable development (economic, environmental and social) [1]. In practice and in particular, the social dimension is not always adequately considered, which impedes the uptake of circular strategies [1]. The social dimension lacks research, particularly concerning circularity in the manufacturing industry [2]. To ensure the oftentimes missing social pillar is properly embedded within circular economy strategies, social indicators need to be assessed to identify the positive and negative impacts that arise from the implementation of a circular economy model [3].

In addition, when new technologies are introduced, there is always a risk of unethical consequences. Especially nowadays, since legal compliance is not always keeping pace with digital developments, we require approaches that ensure ethical digital innovations [4].

Existing social and ethical assessment methods [5, 6] identify relevant risks and their impacts on such complex ecosystems. Value network models [7-11] provide a means of abstraction, visualization and analysis for business ecosystems such as the circular manufacturing ecosystem. However, an integrated view of the above-mentioned assessments' outcomes in value network models is missing. To address this gap, we propose an extension of the V² value network notation [7, 12-14] in order to combine economic and social sustainability aspects, thus resulting in a holistic view that creates a comprehensive visualization of the overall system. This extension serves as the basis for analysis and communication of the aspects of complex socio-technical systems, such as the Circular Manufacturing Ecosystem (CME) in the research project Assembly Lines in Circulation (ALICIA) [15], in order to better understand the relation of social and ethical risks to economic aspects. The application of the V² value network extension is demonstrated in the case of the ALICIA CME.

To foster sustainable production, ALICIA [15] aims to develop a CME platform. This platform will be a one-stop shop for second-hand equipment, enabling faster and easier selection, procurement, delivery, installation and commissioning of second-hand equipment while also decreasing factory owners' costs, as purchasing second-hand equipment is cheaper than purchasing new build equipment. Besides production performance, quality and economical aspects, social aspects, such as existing worker skills and environmental aspects, are also considered. In addition, the platform ecosystem will be open to various service providers, offering complementary services that are required for covering the entire life cycle of equipment. In order to enable all this, various digital services will be developed in the course of the ALICIA project. Their detailed functionalities, interrelation as well the additional services that must be offered via the platform have yet to be defined.

The remainder of this paper is structured as follows: Section 2 describes the social and ethical assessment methods applied in the ALICIA project. Section 3 describes our extension of the V² value network notation. Its application in a case study in the ALICIA project is demonstrated in section 4. The single case study method is based on [16]. Section 5 concludes the paper, discussing the results, contributions to research and practice, limitations and future research.

2 SOCIAL AND ETHICAL ASSESSMENT

This section describes the selected methods for the social and ethical assessment and how they were applied in the context of the ALICIA research project, including the elements that were used to describe the outcomes of the assessment.

2.1 Social Assessment

The ALICIA CME encompasses a diverse array of digital tools. A significant portion of these tools is deployed prior to the integration of second-hand equipment into customers' assembly lines. Most of these tools contain, apart from their technical processes, non-technical processes that affect the stakeholders (e.g., factory owners, workers, or other value chain actors) of ALICIA. To guarantee the socially responsible implementation of all tools and processes across the spectrum of ALICIA's stakeholders, it is imperative to assess their social impacts, along with the associated social risks.

ALICIA utilizes various digital and AI-based tools that potential users might view as risky or unsafe. As a result, they may show a lack of willingness to apply such technological innovations. This could pose barriers to the widespread implementation of ALICIA when compared to traditional second-hand marketplaces. To address both the social risks that the ALICIA platform may bring and the barriers users may have concerning the use of the platform, a Social Life Cycle Assessment (S-LCA) has been conducted.

S-LCA is becoming an increasingly important method for ensuring holistic sustainability assessments. It allows for the assessment of the social impacts of products, services, or organizations across their life cycles [5]. Potential social impacts are defined by the United Nations Environment Programme (UNEP) as "the likely presence of a social impact, resulting from the activities/behaviours of organizations linked to the life cycle of the product or service and from the use of the product itself" [5]. S-LCA is an iterative methodology, which means that the assessments' outcomes can be improved over time, going through several assessment loops and moving from more generic/potential results to more site- and case-specific ones.

A leading framework for conducting S-LCA has been developed by UNEP (latest version published in 2020) [5] and is in large part based on the ISO 14040 framework for Environmental LCA (E-LCA) [5, 17]. Still, S-LCA allows, which is different from the E-LCA, the quantification of social impact indicators which are largely not simple to determine [18] for complementing the results of E-LCA.

The S-LCA methodology by UNEP is considered a keystone of S-LCA approaches [19] due to numerous applications within case studies and research. Another existing approach is the ISO/DIS 14075 - Environmental management - principles and framework for social life cycle assessment [20]. However, at the beginning of the ALICIA project, the UNEP framework was in a more mature state than the ISO/DIS 14075. There is a very limited amount of research available regarding social impacts of CE in manufacturing and thus few opportunities for validating the results obtained with a new method. Therefore, the UNEP S-LCA framework [16] was chosen as a base method for analysing the social impacts of ALICIA.

The applied methodology comprises four main phases: 1) goal and scope definition, 2) social life cycle inventory analysis, 3) social life cycle impact assessment (impact pathway based on [21]) and 4) interpretation of the results.

The following descriptive elements (see also Tab. 1) are used to summarize the outcomes of the applied S-LCA approach according to [5]: The **life cycle stage** represents the life cycle of the product as defined in ISO 14040 [17] and 14044 [22]. The **stakeholder category,** according to the UNEP S-LCA guidelines, includes six total stakeholder categories (workers, local communities, value chain actors, consumers, children and society) to consider when performing an S-LCA. Stakeholder categories, which are the basis of every S-LCA, have to be linked to **impact categories** that represent socially meaningful attributes or themes. **Inventory indicators** are specific definitions derived from the collected data during the social life cycle inventory analysis and relate directly to each life cycle. Every inventory indicator belongs to a stakeholder and impact category. It is considered as the beginning of a cause-effect chain and thus the cause of midpoint and endpoint impacts. **Midpoint indicators** represent impacts on the middle of the cause-effect chain. **Endpoint indicators** refer to impacts that occur as a consequence, at the end of the chain. To define those indicators, social mechanisms and collected inventory indicators are required to assess these midpoint and endpoint indicators [5]. **Potential solutions** (or mitigation strategies) describe how this (negative) impact might be avoided.

2.2 Ethical Assessment

When new technologies are introduced, there is always a risk that this may unintentionally lead to unethical consequences and therefore requires approaches that ensure ethical digital innovations [4].

It is necessary to analyse which ethical issues the technology may cause and to assess potential impacts and to ensure the ethical implementation of the new technology. Doing this facilitates the design of the technological innovations in a more ethical and value-sensitive way [23]. Within the context of CE, digital technologies can enable services that are beneficial for CE implementation, such as the provision of technical support, evaluating a product's life cycle and maintaining or enhancing a product [24].

The digital technologies, which are developed in ALICIA, were the subject of analysis of the ethical assessment. The chosen approach for this ethical assessment was a digital ethics audit. The methodology from this auditing framework contains components of ISO 19011 (guidelines for auditing management systems) [25], ISO 31000 (risk management guidelines) [26] as well as literature and other sources from existing auditing approaches, including ethical auditing and other auditing fields (e.g., ESG auditing [6]). ISO 19011 especially represents a critical part of this auditing process and includes, among other aspects, a risk-based approach to the principles of auditing.

The aim of this audit was to identify and mitigate the risks of ALICIA's technologies, designing appropriate mitigation measures as feedback into the project design process, so that later, all affected stakeholders feel safe using those technologies [27].

The entire auditing process contains five auditing cycles, and every auditing cycle contains several sub-cycles that split the cycle's task into its actions or methods. The process was conducted with help of desk research, interviews and workshops.

- Cycle 1 - Scope setting: 1.1 audit objectives, 1.2 identifying stakeholders, and 1.3 establishing values and identifying risks
- Cycle 2 - Risk analysis: 2.1 aggregating risks, 2.2 risk prioritization
- Cycle 3 - Validation: 3.1 internal validation, 3.2 validation with involved partners
- Cycle 4 – Mitigation: 4.1 communicating design considerations, 4.2 designing of mitigations by all partners

- Cycle 5 - Evaluation and report: 5.1 finalizing audit report, 5.2 presenting audit results to all partners.

Within the project so far, Cycle 1 and Cycle 2 have been conducted. The following descriptive elements (see also Tab. 1) were used to summarize the outcomes of the applied ethical assessment approach: **technology** refers to the objects to be audited. In ALICIA, these are the digital tools of the platform and the **stakeholders** who are affected by the technology. When auditing the ethics of digital technologies, it is imperative to define and incorporate **values**, as defined by [28, 29], into the technology. These values help to shape the extent to which future users can utilize and potentially be influenced by the technology [30]. **Risk (affected stakeholders)**: Since values are always linked to certain risks (for each value, multiple risks can exist), it can often be challenging to define values without also considering the associated risks. Therefore, Cycle 1 also aims to identify preliminary potential risks related to those values and those that affect certain stakeholders. Cycle 2 deals with the risk analysis. It aims to identify further risks and to subsequently analyse the priority of all existing risks. To do so, the "risk prioritization" sub-cycle assesses each risk, based on [31], by its likelihood of occurrence (**risk likelihood**) and severity levels (**risk impact**). The remaining steps are validating the identified impacts and to start mitigating the negative impacts they may bring, which is described as **mitigation** in the outcome of the assessment. Finally, the outcomes are evaluated and reported.

3 EXTENSION OF THE V² VALUE NETWORK NOTATION

The V^2 value network notation [12] used in the presented work builds on the notation of Biem and Caswell [7], which synthesizes and extends concepts of e3 e-business modelling [6], the c3-value method [9] and Allee's [10, 11] concept of intangibles [5]. The V^2 notation is structured around dedicated layers which serve to visualize and analyse actors, their value exchanges, motivations, legal aspects and needs (see Fig. 1). These layers have been developed over the course of various research projects over the past decade [12, 13]. In the recent literature, value network models are still investigated in the context of business modelling [14]. As stated by [32], visualizations improve communication, support collaboration and foster human engagement by supporting cognitive processes and augmenting the capacity of the human mind and creating a common understanding.

In order to integrate the outcomes of a social and ethical assessment into a value network model, we, the authors, developed an extension of the V^2 value network notation. By combining economic and social sustainability aspects, the resulting holistic view creates a comprehensive visualization of the overall system. This view should serve as the basis for the analysis and communication of complex socio-technical systems' aspects.

In order to define a means of visualizing the outcomes of S-LCAs and ethics audits, we compared and consolidated their elements with elements used in the application of risk management to medical devices [33], which represents a state-of-the-art risk management standard (see Tab. 1). Based on that we defined the risk layer extension of the V^2 notation (see Tab. 2 and Fig. 2).

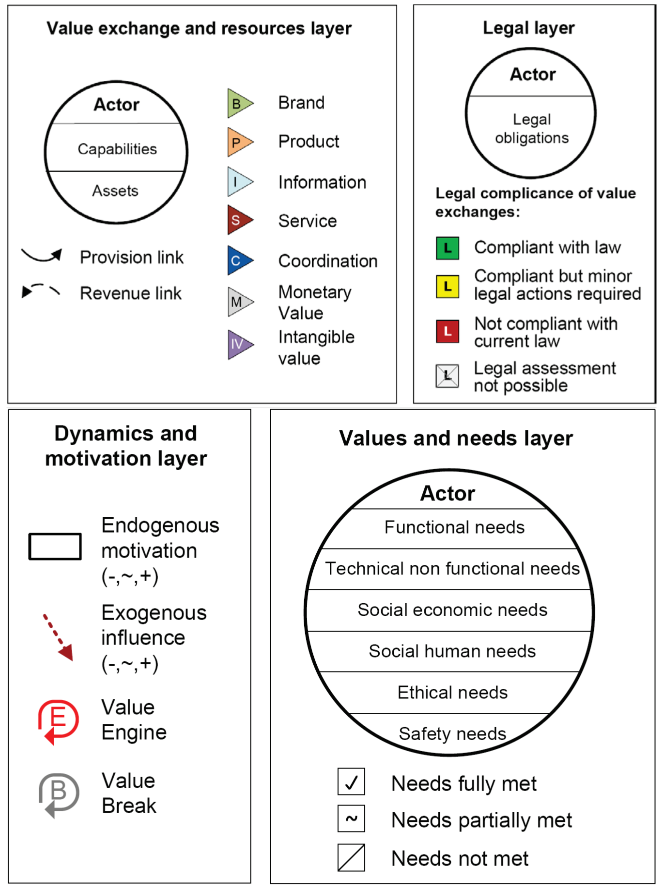

Figure 1 The analysis layers of the V² value network notation (figure from [12] based on [7, 13, 14])

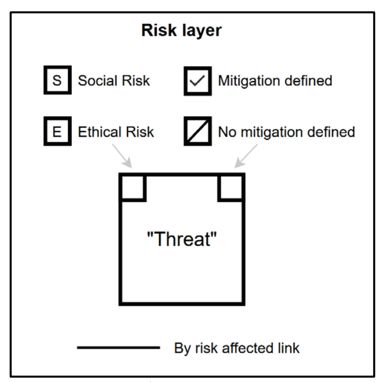

Figure 2 Representation of risks in the V² value network notation

The elements consolidated to a common risk layer, indicated by a merged column in Tab. 2, are described in the following. The elements "**impact category**" and "**value**" are represented by the element "**value category**", which describes either the social or ethical values the risk relates to. "**Inventory indicator**" and "**risk (affected stakeholders)**" are represented by the element "**threat**" of the risk layer. The newly added element "**description**" allows a further elaboration of the identified threat. The element "**source of information**" was also added to assist with keeping track of where the information about the threat was identified from e.g. data sources or references. "**Mitigation**" is used to commonly describe any potential solution for social as well as ethical risks. The "**stakeholder categories**" represent the affected stakeholders for both assessments. The remaining elements were considered as too specific for this type of assessment when defining a common element. Therefore, these elements were taken over to the new risk layer without modifications. The common grounding was finally validated with the social and ethical assessment expert from the ALICIA project.

Table 1 Comparison of elements of S-LCA, the ethical audit and risk analysis

S-LCA elements (based on UNEP [5])	Ethics audit elements (based on ISO-19011 [25] and ISO-31000 [26])	Risk analysis elements (based on ISO-14971 [33])
Life cycle	Technology	Life cycle stage
Impact category	Value	Category of hazard
-	-	Hazardous situation
Inventory indicator	Risk (affected stakeholders)	Event
Midpoint impact	-	Harm
Endpoint impact	-	
-	Risk likelihood	Probability of occurrence
-	Risk impact	Severity of impact
Potential solution	Mitigation	Mitigation
Stakeholder category	(already included in "Risk")	Groups of people affected by the harm

Table 2 Consolidated risk layer definition for the V^2 value network notation based on [5, 25, 26, 33]

Social risk elements	Ethical risk elements	Description of element
Life cycle stage	Technology	In which situation (activity, technology) the threat can occur
Value category		Defined categories that either describe social or ethical values.
Threat		The possible negative (harmful) event.
Description		Additional description clarifying the threat.
Source of information		Describes from which source the threat was identified.
Midpoint impact	-	Midpoint indicators represent impacts in the middle of the cause-effect chain.
Endpoint impact	-	Endpoint indicators refer to impacts that occur as a consequence, at the end of the chain.
-	Probability of occurrence	Probability of occurrence is a quantitative ranking defined by the assessor.
-	Severity of impact	Severity of impact is a quantitative ranking defined by the assessor.
Mitigation		This is a possible solution so that the threat does not occur
Stakeholder categories		Describes affected stakeholders and is used to identify affected actors in the value network.

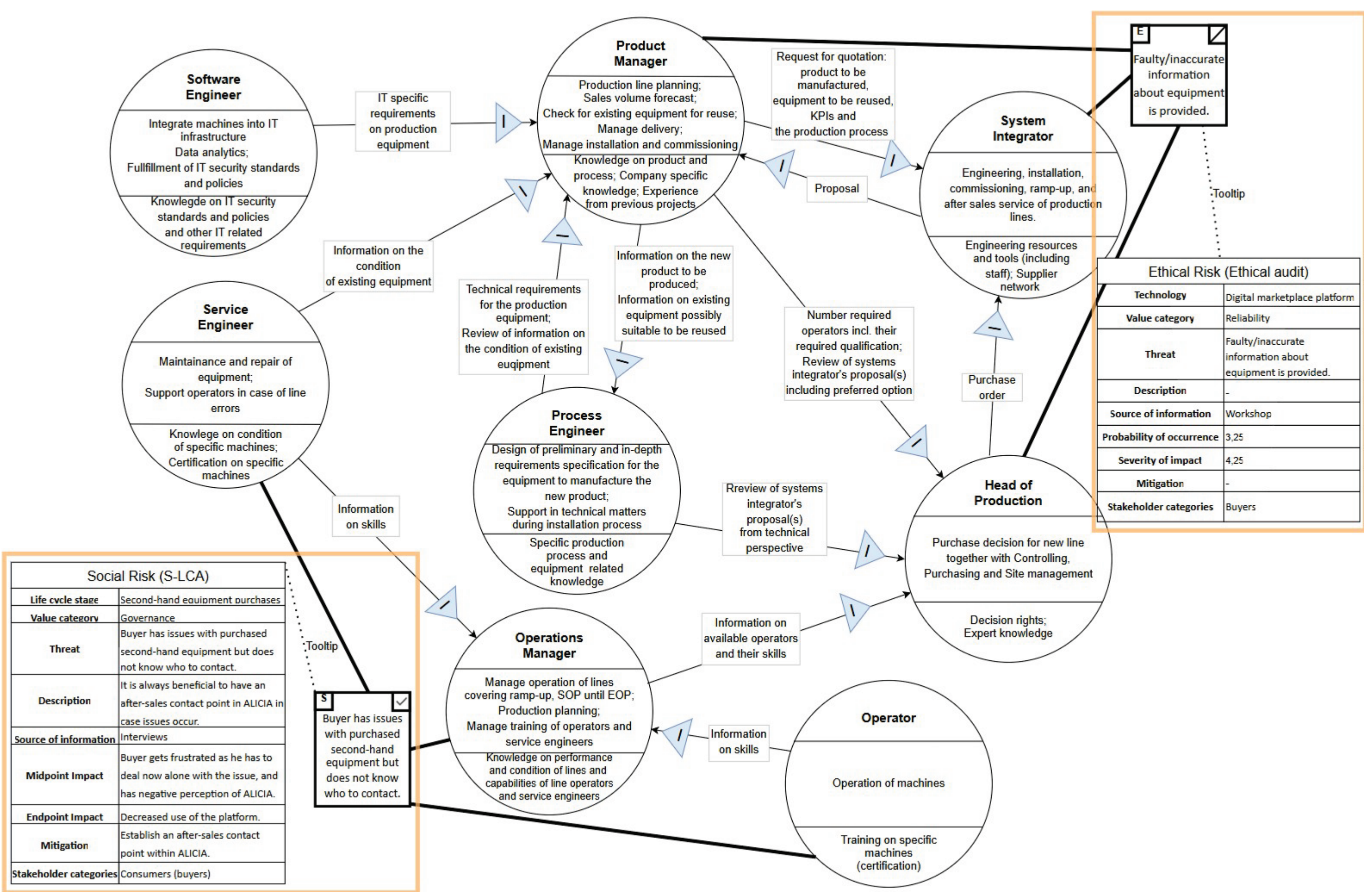

Figure 3 Example of visualizing social and ethical risks in a value network

To extend the existing V^2 value network notation, we defined the following symbols (see Fig. 2) to represent a risk in a value network. Each identified risk is represented by a square. Each square shows the information that has been documented as a "threat" in the assessment. The small upper left square indicates whether the risk was identified from the social (S) or the ethical (E) assessment. The small square in the upper right corner indicates if a mitigation has already been defined for the risk. This shall provide a quick overview in the overall value network, in which risks still need to be handled in terms of identification and documentation of an appropriate mitigation. With the help of a "tooltip" function, which is planned to be implemented in the EcoViz tool [34], the detailed information about the risk, as defined in Tab. 2, is displayed. This function is also illustrated in Fig. 3.

4 DEMONSTRATION OF THE RISK LAYER

In this section, we demonstrate the application of the V2 value network notation, including the risk layer with the case of ALICIA. The value network analysis, shown in Fig. 3, was conducted in the context of requirements engineering of the ALCIA CME platform. It includes typical actors at a factory owner, including their capabilities and assets, and shows the exchanges of information in a scenario in which a line for the assembly of a new product is bought. In addition to the value exchange and resources layer, which supports the visualization of economic value exchanges, the newly developed risk layer has been applied to visualize one social and one ethical risk, which were identified in the social and ethical assessment in the ALICIA project. Their visualizations are highlighted with an orange square in Fig. 3. Both risks describe "Buyers" as their stakeholder category. It is clearly shown in the context of this scenario that the two risks may affect very distinct types of actors at a factory owner. The "tooltip" function reveals all details documented as defined in Tab. 2 for each identified risk. With this risk layer it is now possible to additionally visualize results from a social and ethical assessment in the economic context of a value network. This enables an integrated view on the economic and social sustainability dimension of a complex system.

5 CONCLUSIONS

Our work provides further insights on how social and ethical assessments can be conducted in the context of a circular economy and how to visualize the assessment's outcome in a networked economic context. By combining economic and social sustainability aspects, the resulting holistic view creates a comprehensive visualization of the overall system. This view can serve as the basis for the analysis and communication of complex socio-technical systems, such as the ALICA circular manufacturing ecosystem.

The value network analysis with the risk layer sets the risk in a specific context and relates it to specific actors rather than purely generic stakeholder categories. Further insights on impact, beyond the specific actor, may be gained through this because of the visualization of relations between the actors in the system. Furthermore, the visualization in the value network may also support certain steps of the assessment itself, such as the validation cycle of the ethical audit.

Nevertheless, a validation of the visualization and its benefits is still required. So far, it has only been demonstrated in a single case. Additional applications in further cases are required. As a next step, we will also focus on the integration of the new risk layer in the existing EcoViz tool [34] to support practical applicability and foster validation. Additional features may be required to tackle the challenge of visualizing a large number of risks to prevent visual overload. These features may include the possibility to aggregate risks and to deep dive into specific groups of actors. Furthermore, we also plan to extend the notation by also integrating the visualization of environmental impacts in the value network and to include a comparison of other existing risk analysis frameworks in this context.

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