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Article

A Systems Thinking Perspective on the Obstacles Faced by Industrial Organizations to Transition towards Sustainability

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Abstract The climate crisis threatens the sustainable development of our planet. Mitigating the complexity of the sustainable challenge needs a holistic and systematic perspective. Systems solutions, such as systems thinking and systems engineering, can help to mitigate such challenges. Systems engineering in particular has to assist in transdisciplinary development and cooperation. Methods, tools, and methodologies in systems engineering can be key enablers to align the present world condition towards sustainable trajectories. To align with the sustainable transition, industrial organizations need to integrate sustainability at their core: the system's development. Realizing socio-technical systems that are sustainable is not a triviality. Based on industry interviews and a literature study, this article discusses these challenges and presents how systems thinking and systems engineering disciplines may support industries to mitigate the same. To realize sustainable systems this work suggests i) identifying sustainability as a quality of the system; ii) collecting environmentally sustainable (big) data; and iii) establishing a collaborative environment among stakeholders where to discuss challenges related to the system's lifecycle.

Keywords sustainability; socio-technical systems; systems thinking; systems engineering

1. Introduction

Global warming and climate change pose unprecedented threats to humanity. To mitigate these threats the United Nations released the Paris Agreement. The Paris Agreement sets its goal "*to limit global warming to well below 2 °C above pre-industrial levels*" [1]. In support of the Paris Agreement, several international policies such as *The Agenda 2030* and *A European Green Deal* have been developed [2,3]. Both policies have the vision, among other aspects, to limit the rising global temperature by reducing Greenhouse Gasses (GHG) emissions and finally transform the present world condition into a more sustainable one. This transition is referred to as sustainable transition or transformation [4,5].

The Agenda 2030 presents a roadmap to develop a sustainable world for future generations focused on People, Planet, Prosperity, Peace, and Partnership [2]. Following the *Agenda 2030*, *A European Green Deal* aims to make Europe the first carbon-neutral continent by 2050, enhancing sustainable economic growth, and ensuring equal social opportunities [3]. To support these objectives, a taxonomy has been developed, namely the EU Taxonomy, that aims to identify the "*economic activities that can be considered environmentally sustainable*" [6]. This classification system makes it possible for organizations, such as industrial organizations, to quantify transparently their environmentally sustainable impact and, at the same time, support investors while making decisions in line with the *European Green Deal*. However, both the Agenda 2030 and the European Green Deal policies demand to reduce the GHG emissions. The GHG Protocol supports the management of GHG emissions and relatively responsible organization [7]. This is done through the use of three Scopes: Scope 1—direct emissions from the reporting organization; Scope 2—indirect emissions from the reporting organization; and Scope 3—indirect emissions from organizations over the supply chain [7,8].

"*Sustainability challenges are systematic in nature and require systematic responses*" [9]. In essence, these challenges need to be dealt with on one hand a holistic view and on the other a system perspective [10,11]. Among the existing disciplines dealing with systems complexity, there are *systems thinking* and *systems engineering*. These two disciplines through holistic and interdisciplinary approaches may support sustainable transformation [9,12–26].

Industrial organizations are required to align with the sustainable transition. The business-driven nature of these organizations stresses the same to be highly productive in order to remain

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healthy and competitive in the market. Transforming their traditional practices into more sustainable ones means integrating sustainability at the heart of their activities: their socio-technical systems. Socio-technical systems are engineered systems that include human and technical aspects [27]. In the present article, the term system refers to a collection of products each of which is composed of constituents that are assembled together with the purpose of satisfying one or more desired functions while interacting with humans [27–29]. For simplicity, in this work, the term system refers to any component above mentioned and related to the system. Also, industrial services are referred to as systems.

Realizing industrial systems that are sustainable through their lifecycle is not a triviality. The aim of the study case is to overview the challenges that organizations are facing towards sustainable transformation. This work investigates these challenges by means of a literature study and a case study. By means of semi-structured interviews, Norwegian organizations working in different sectors have been interviewed. The following three research questions drove the present work:

1. How industrial organizations can implement sustainability in the development of their systems?
2. What are the challenges that industrial organizations face to develop systems that are sustainable?
3. How systems thinking and systems engineering can support industrial organizations to realize systems that are sustainable?

Finally, the authors provide possible future research directions. The authors wish to keep vivid the discussion on the deployment of systems thinking and systems engineering approaches to better align the current industrial practices with the roadmap envisioned by the sustainable transformation.

2. Literature Study

This section presents a comprehensive literature study. The section begins by presenting the concepts of sustainability and sustainable development. Then it focuses on system disciplines, and finally industrial systems and the integration of sustainability.

2.1. Sustainability and Sustainable Development

Although significant attention in the last decades, the origin of the sustainability concept is yet unclear and open to discussion [30]. A recent review presents the concept of sustainability as composed of the relation of three perspectives, or pillars, *social, environmental, and economic* [30]. According to the same, the first definition of sustainability as a function of these three pillars appears in [31]. However, Purvis et al. [30] describe how the academic debate around sustainability is either based on the three pillars or as a systems approach. Yet the same stresses the importance of the contextual dependency of sustainability. In contrast, the concept of sustainable development appears to be widely recognized from the report of Brudtland [10]. The same presents sustainable development as a development that "*meets the needs of the present without compromising the ability of future generations to meet their own needs*". In addition, the latter concept entangles at its core the three pillars [10]. These pillars are essential components of the 17 SDGs suggested in the UN Agenda 2030. Each of the SDGs comprehends multiple object-driven targets [17,32–34]). Indicators have been developed and associated with the SDGs targets to assess how well each goal and target is performing towards the sustainable transition [17,35].

The significant attention given to sustainability leads organizations to assess their contribution towards the sustainable transition with the use of the *triple bottom line*. The triple bottom line is a framework based on the three pillars able to assess the impact of the organization related to economies, people, planet [36]. There are different methodologies that can support this framework. An example is the Life Cycle Assessment (LCA). The LCA is a practice to quantify the environmental impact of systems by depicting the environmental impact of any process and activity related from minor constituents to the final system [28]. Through LCA and similar tools, organizations can understand how their systems, or their constituents, can be repaired, re-used, and re-cycled without exploiting new resources. The economy based on reusing, recycling, and repairing is referred to as a circular economy [37]. This way of thinking favors the design of product systems and/or processes in a way to reduce the environmental impact and improve the healthiness of the surrounding ecosystem [38].

2.2. Systems Solutions: Science, Thinking, and Engineering

The word *system* (in ancient Greek *systema*) refers to a set of interacting elements [27,39,40]. Systems can be *abstract* if including conceptual elements, or *concrete* if comprehending real elements. Both cases can be *closed systems*, where all elements are comprehended and interact inside the system, or *open systems*, where part of elements are included or interact inside the system [27]. The field of science dealing with the understanding of systems is called systems science [27,41]. Systems science is an interdisciplinary field grounded on principles and concepts related to the system [12]. The understanding of systems science facilitates the related systems practices [27,40]. Any related thinking activities capable of conveying holistic systems to engineering matters are referred to as *system praxis framework* and the related thinking activities as *systems thinking* [27]. Systems thinking helps to understand a system of given interest, its constituents, dynamics, and patterns with a holistic view [27,42]. Systems thinking can be also defined as a perspective capable of investigating the systems' constituents, and its inter-relationships with an appropriate language and by means of appropriate tools and methods [43,44]. In their review, Salado & Nilchiani [45] describe the Soft Systems Methodology (SSM) [46] as one of the most known methods. The SSM is able to tackle problematic real-world conditions using a structured framework composed of seven phases. These phases bring the problem-solution domain from *concrete* real world to *abstract* system thinking and back in a clearly structured way [45–47].

The tools comprehended within the SSM provide a clear connection between assumptions and implications from different perspectives [48]. Among these tools, there is the Customer Actor Transformation Weltanschauung, Owner Environmental (CATWOE) tool. CATWOE is adopted due to its capabilities of effectively capturing at its core the multiple perspectives involved in a system of interest [48]. Similarly, the Strength Weakness Opportunities and Threats (SWOT) analysis is a tool capable of providing an understanding of the intrinsic systems components and how the relation between them [49]. Another tool is the PESTEL which consists of a multiple perspective from Political, Economic, Social, Technical, Environmental, and Legal [50]. Another conceptual tool is the Systemigram. Systemigram is adopted to draw the complexity of the system and visualize potential conflicts between components of the same system and/or between different systems.

System thinking comprehends other systems approaches such as system-oriented design. The latter is able to treat multiple complex systems in a way that each complex system does not harm other systems within the interested framework [51,52]. One of the tools adopted from systems-oriented design is the Gigamapping. Gigamapping is a "*multi purpose, multi layered device with multiple uses and intentionalities*" [53]. The same author underpins as major benefits of this tool, among others, the ability to grip complexity and related complex situations.

The International Council on Systems Engineering (INCOSE), defined Systems Engineering as *"a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods"* [54]. Fet & Haskins [12] presented Systems Engineering as a discipline and a process. The former refers to the capability of Systems Engineering to provide a holistic lifecycle landscape capable of dynamically adapting in a way to include interested characteristics of other disciplines. The latter is in line with the mentioned definition from [54]. Fet & Haskins [12] also pointed out the importance of approaching Systems Engineering problems with a systematic, organized, and structured approach. That is with a systemic perspective and a holistic understanding of the problem. Despite System Engineering being a rather new scientific discipline, there is a wide experience from professionals, documented in the Systems Engineering Body of Knowledge [27,55,56].

The discipline of Systems Engineering balances the technical, economic, and societal needs of the stakeholders involved in the system, according to the INCOSE [16]. Its aim is to provide a system that is fit for purpose in practice. The industry envisions Systems Engineering as a tool to tie together different kinds of competency within the same company. Indeed, "*Systems Engineering provides facilitation, guidance, and leadership to integrate the relevant disciplines and experts/specialty groups into cohesive effort, forming an appropriately structured development process"* [54].

2.3. Industrial Systems

The development of an industrial system involves multiple stakeholders such as customers, developers, and supplier organizations. Customer organizations commit the realization of the system to developing the organization. Supplier organizations assist the developing organization in the realization of systems. Industrial organizations are the main developing organizations.

The system to be realized needs to provide the customer(s) organization with a business-oriented solution that satisfies their needs [57]. These needs are defined as key drivers. These drivers are associated with the system's requirements to be complied from the intended system during its lifetime [58]. Muller [58] presents how to map from key drivers to the realization of system requirements. Figure 1 resumes the system development.

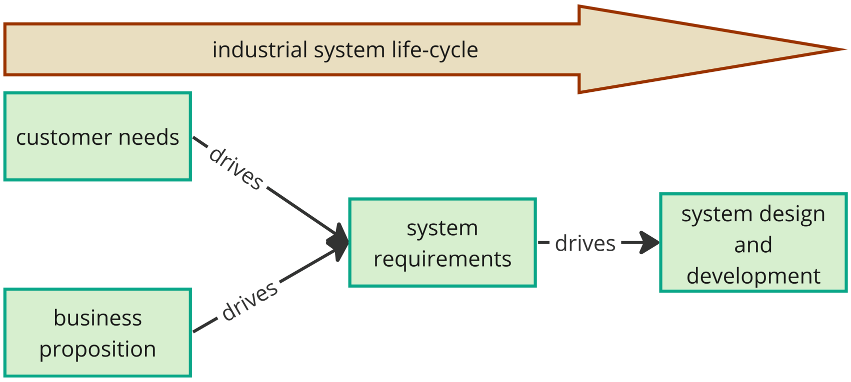

Figure 1. Scheme of system realization modified from Muller [59].

A list of qualities, also defined as *non-functional requirements*, are associated with the system. These qualities are a function of the entire system rather than the system's constituents [27]. These qualities are interdependent in a way that facilitating a given quality might significantly impact others [27]. Table 1 shows the most typical system qualities according to the SEBoK.

Table 1. Qualities of systems (modified from [27]).

System's Qualities	Description
Safety	Limiting the possibility of hazard risks
Reliability	Ability to perform the desired function
Maintainability	Easy maintenance of the system and/or the system's constituents
Effective	Ability to be goal-oriented using low resources
Changeable	Ability to exchange information between the system's interphases
Resilience	Ability to remain functioning in the same manner over the system's lifetime
Suitability for Humans	Easiness to be handled by humans
Manufacturability and Producibility	Ability to manufacture and produce a system and/or system's constituents

Sustainability can be included in the list of the system's qualities [16]. Several engineering fields already include sustainability as a quality, or property, of an intended system as software engineering [60], software requirements engineering [61,62], process systems engineering [63] and systems engineering applied in construction engineering [64].

Bakshi & Fiksel [63] adopted process systems engineering techniques to compare and select industrial processes as the most environmentally sustainable ones. In the same line, Matar et al. [64] developed a systems engineering model to quantify the sustainability performance of civil infrastructure projects. However, as in Bakshi & Fiksel [63], the approach of Matar et al. [64] may support the project stakeholders to depict activities and processes harmful to the environment and replace them with more environmentally sustainable ones. In their work, Pearson et al. [65] present how the complexity of sustainability depends on the involved stakeholders and the sustainability's value is often not fully grasped due to irrationality. To overcome such challenges, the same presents a systems engineering method, Halstar. Cabot et al. [66] investigated the integration of sustainability in the early phase of projects to assess and compare the environmentally sustainable impact of different alternatives supporting decision-makers to select the most sustainable one.

The presented review describes how sustainability can be integrated as a quality of the industrial system's life cycle. Based on its three pillars, considerations related to the social, environmental, and economic perspectives need to be assessed and evaluated. This applies from the extraction of raw materials to the end of life. Let us take as an example the raw material selection, extraction, and process stage. In this stage, industrial organizations need to be aware of the geo-political importance (and implications) of the selected materials. The extraction and processing of this material have to be investigated and traced from social, economic, and environmental aspects. The social aspect may consider for instance human rights, working conditions, inclusivity, ethics, equal opportunities, impact on communities, and life-work balance at local and global levels. Economic aspects may consider the investigations related to job opportunities, benefits, and concerns at local and global levels for society and for any involved organization. The environmental aspect may consider material selection, availability (re-use and re-cycle), waste generation, the related impact on environmental-related industrial processing, and implications for the surrounding ecosystem during the entire system's life cycle. This applies to all the stages of the systems' life cycle.

The literature review described how industrial organizations may implement sustainability by means of systems approaches inside their system life cycle. However, the obstacles faced towards the sustainable transition appear to be less persistent.

3. Case Study

The research approach performed in this work follows the approach suggested by Yin [67]. A mixed method composed of a case study research and industry-as-laboratory [68] research approaches has been adopted. The former portrays an exhaustive understanding of the complexity of a specific case keeping a holistic and contextual perspective [67,69]. The latter adopts industrial real-world situations to research [68]. The research is performed through an iterative process. Preliminary work and planning, in combination, lead to a design phase and later to the preparation and data collection phase. During the data collection, the design and/or preparation phase were modified according to the depicted need. After being collected, data were iteratively analyzed. Finally, the results were shared.

Researchers performed an iterative literature review. The purpose of the literature studies was to explore industrial practices related to the implementation of sustainability inside systems.

The researchers performed unstructured interviews and discussions. The preliminary work made us understand the need for explanatory research. There is a limited amount of experience in the field. Thus, structured interviews were planned, applying the case study methodology.

The interviews were planned and prepared in four consecutive steps: establish research questions and propositions; identify the case study; define the correlation between collected data and propositions; and interpret findings.

To prepare this study case, there are five steps: *i*) interviewer's self-preparation; *ii)* training; *iii)* preparation of a protocol; *iv)* screening of participants; *v)* pilot case study. *i)* To be prepared for the interviews, the researcher performed several internal meetings to discuss the *topic of interest*, the *questions to be asked,* and the *attitude* of the interviewer during the interview. *ii)* The researcher was trained to protect participant's sensitive information and to inform the same regarding the purpose of the interview. *iii)* A draft case study protocol was developed. The draft starts with the motivation of the study and information regarding data confidentiality and disclosure. The protocol did not store any identification of participants. Instead, the name of the company, the role of the participant in the company, and years of experience in the company were collected. A total of ten research questions have been elaborated: seven in the form of "*how and why*" questions; and three in the form of "*what/which*" questions. To answer a how and why, Question 6, a Likert scale was made available from one to five where one means no impact, and five very high impact. *iv)* Participants belonging to organizations were invited for the interviews. For each company, a single participant was involved in the interview to represent the company. *v)* A pilot case study has been performed to verify and validate the *drafted protocol*. After the pilot case study, modifications to some questions have been performed. The interview protocol was ready to be used.

In Spring 2023, the researchers interviewed six participants belonging to six different organizations. The form was semi-structured interviews lasting for one hour, digitally or physically.

Initially, the interviewer read out loud the purpose of the interview and how sensitive information would be treated. Once the participant agreed to these conditions, the interview started.

The interview contained ten open-ended questions, a few of which also were based on the Likert-hood scale. The questions were in categories as shown in Table 2.

Table 2. Survey's categories and questions.

Category	Questions
Policies	Q1, Q2
Engineering decisions	Q3, Q4, Q5, Q6, Q7
Use of complex data and human-centered technologies	Q8, Q9
Feedback from participants	Q10

The researcher took handwritten notes during the interview. After the interview, the notes were converted into a digital form, and stored in a digital database. During the analysis, the researchers read the retrieved information multiple times to get acquainted with the data set. After that, the researchers identify common information and observations belonging to the various categories in Table 2.

Six participants from six organizations were interviewed in this work. This section presents the obtained results for each category of questions. Tables 3 and 4 show the profile of the interviewed organization, with the relevant participant.

Table 3. Organizations involved in the case study.

Size	Maturity [years]
Medium	20–30
Small	20–30
Medium	5–10
Large	5–10
Large	>100
Large	>100

Table 4. Interviewed participants from each organization.

Participant role	Years of Experience in the Organization
Sustainability Expert	1–3
Sustainability Expert	1–3
Sustainability Expert	1–3
Technical Expert	10–15
Technical Expert	4–9
Director of Innovation	10–15

For confidentiality, the organizations were anonymized. In this work, the organizations were addressed with the following code: Organization A, Organization B, Organization C, Organization D, Organization E, and Organization F.

A limitation of this work is that there are only six interviewees. Research in industrial settings has limitations due to the limited availability of interviews. Another related issue is that there is limited information in the academic literature on this topic.

Results

The questions and results from the interviews were divided into the following categories.

i) *Policies*; Q1 and Q2 related primarily to the recently enforced EU taxonomy. During the interviews, focus was given to sustainable policies and how the organization approaches them.
ii) *Engineering decisions*; Q3, Q4, Q5, Q6, and Q7 relate to the engineering practices and decisions related to sustainability in the organization.
iii) *Use of complex data and human-centered technologies*; Q8 and Q9 aim to understand how complex data and human-centered technologies can be deployed to develop sustainable products.
iv) *Final feedback question*; The participant had the opportunity to give feedback regarding the interview and within the sustainability topic in Q10.

This section gives results from the interviews.

- Policies

Each organization has its sustainability strategy. Regarding the EU Taxonomy, among the six participants, one is implementing the EU taxonomy (Organization A), two are at the early stages of implementation (Organization B and Organization C) and for the remaining three organizations the EU taxonomy is not applicable (Organization D, Organization E and Organization F).

Organization A is currently implementing the EU taxonomy on a voluntary base over the last two years. The organization reports processes and key categories relative to the systems intended to develop for their customers. Considerable resources have been spent for training, internally and externally, to reach the current level of understanding and adoption of the taxonomy. Organization B and Organization C are in the early stages of implementing the EU taxonomy. Organization B reports its sustainable practices through international standard practices. Organization C developed a system to collect operational environmental data and follow the SDGs indicators to support their sustainability strategies. In other cases of this work, the SDGs are qualitatively assessed without using the SDGs indicators. Although in the early stages, these organizations spend considerable resources to integrate the EU taxonomy into their activities. Both organizations express the need for data-driven awareness to comply with the legislation and monitor their performance with regard to sustainability. The EU taxonomy is not directly applicable to Organization D, Organization E, and Organization F. Nevertheless, the sustainability strategy of the same targets to reduce the environmental impact of their systems. During the interviews, the participants of Organizations D and E expressed the importance of organizations complying with the taxonomy. Organization D is exposed to the challenges of its customers observing that the EU taxonomy significantly accelerates the sustainable transition due to its strict methodologies if compared to the SDGs, targets, and indicators.

- Engineering Decisions

Each company is involved in different phases of the lifecycle of systems/services and performs sustainability assessments accordingly.

Organization A focuses on early-phase innovation assessing the sustainability impact in systems development, material selection, testing, operation, and end-of-life. The assessments are based on a service developed internally in Organization A. Based on the EU taxonomy and other sustainable regulations this service is a checklist of LCA information related to the desired system. Organization A is also dedicated to circular economy and specifically to the reusing of test equipment, materials, and energy.

Organization B is involved in the operation (including maintenance and rehabilitation), end-of-life, and logistics. Sustainability assessments are made while selecting material, operating the systems/services, logistics, and increasing the re-using of recycled equipment. Sustainability assessments are based on the experience. The organization is preparing for sustainable requirements and expressed the need for data-driven information to perform more sustainable decisions.

Organization C deals with the early phase, product development, material selection production, and logistics. According to the participant, more sustainability assessments should be done in product development, material selection, production, and logistics possibly including LCA at each of these stages. To perform sustainability assessments, Organization C has developed an internal product capable of collecting operational information such as the use of resources, waste production, and others. The participant of Organization C highlighted how the sustainability assessments should focus, together with the environmental aspect, also to the social aspect.

Organization D deals with the design of systems and supports their customers in optimizing resources and processes making the systems sustainable through their lifecycle. A major challenge for its customers is the environmental assessments demanded by the EU taxonomy and GHG Scope 3. According to the participant of Organization D, assessing the environmental emissions requires IT systems, structure of data and metadata, and final reporting.

Organization E deals with the whole lifecycle, from design to end of life, of their systems. The company has a strong focus on social and governmental perspectives and attention is given to the environmental perspective. The organization aims to bring the environmental perspective in the design phase of its systems by quantifying the use of materials, resources, and carbon footprint produced for each system through the use of LCA. Organization E is focusing on Scope 3 and has strict environmental requirements. Regarding the sustainability impact, organization E developed an internal product to share such information with its partners. This product assesses and evaluates the potential risks related to the system aimed to develop.

Organization F deals with planning, developing, upgrading, and activities related to the management of their services. The organization works in collaboration with its suppliers. Sustainability assessments are performed by deploying low-emission technologies that guarantee a satisfactory system.

The competitive impact of sustainable-engineering decisions on systems is the object of Question 6. The answers from the participants were: three, five, four, five, difficult to answer, difficult to answer. The two latter organizations found it difficult to answer due to their working field: consultancy and dependence on the public sector. Interestingly, the latter discussed the practical importance of the *sustainability tradeoff* from the public sector that needs constantly to balance social, environmental, and economic perspectives of sustainability. The picture depicted from Q6 shows the importance of complying with sustainable legislation. An interviewed participant described how in its organization engineering departments request support from the sustainability department while developing new systems.

Question 7 investigates how organizations integrate sustainability inside the system development. Four answers described the fundamental importance of mapping any practice related to the system lifecycle. Mapping the practices related system lifecycle in turn leads to full traceability of energy, emissions, and material usage. Recycling and reusability of the system constituents are also observed to be part of the mapping process. Two of the remaining organizations interviewed are not involved in system development. However, one of them provides useful information due to its experience with customers. Specifically, traceability of sustainability in system development is a significant concern for customers. It is required to obtain sustainability data from the extraction and collection of raw materials in foreign countries to the final termination of the system and related processing. Among the answers, four participants described the usefulness of the LCA tool to manage sustainable (big) data. Question 7 portrays that five of the interviewed organizations need to improve the mapping of sustainability in the whole lifecycle. This extensive collection of sustainability data in turn gives each organization a comprehensive awareness of its activities and practices related to sustainability. Here it is observed that to achieve a satisfactory sustainable awareness there is a need to overcome challenges by transparently trace in a continuous way information related to sustainability.

- Complex Data and Human-centered Technologies

All the participants expressed the important role that complex data has in integrating sustainability inside technologies, in Question 8. In the present context, complex data refers to the collection of extensive heterogeneous information. These complex data are fundamental to quantifying and tracing the environmentally sustainable impact of any process related to the system. Tracing such complex data gives the possibility to: use this data to perform LCA, make sustainable engineering decisions in the system's lifecycle, and share this environmentally sustainable information with organizations over the supply chain.

During the operational phase, the human-technology interaction plays an important role. Indeed, humans are the end-users of technological systems. Question 9 aims to understand the role of humans in technological systems. The overall picture depicted from the answers is that technological systems should be developed in a way to make it as easy as possible to operate the systems from the end-users' perspective. This is reflected in an effective operation of the systems by optimizing the costs of the system and improving the socially sustainable impact from the end-user in the system's operation (easy operability, better balance of workload, others).

- Feedback from Participants

The interviewees were expressing their opinions on the subject matter and the interview in as a part of the last question, Question 10. Among the answers, an interesting observation was made by an interviewee claiming that the sustainable transformation of an industrial organization could be achieved by changing the organizations' people, culture, and strategy.

Common aspects were observed from the interviews in the different categories of questions. Significant resources are spent to be updated with the recent advancement of sustainable regulations. These regulations have to be complied by developers and engineers while realizing industrial systems. Any information related to sustainability (especially the environmental pillar) needs to be traced. This can be done by means of (big) data and data-driven technologies. However, the required traceability relies not only on the developing organization but also on its suppliers to share the expected environmentally sustainable data in a transparent manner for the whole life-cycle of the system. Yet a commonality is within the challenge related to the customer-supplier exchange of environmental data related to their practices.

4. Analysis

The UN sets the policies and drives the sustainability vision. Figure 2 illustrates the journey from the vision to the practice of sustainability.

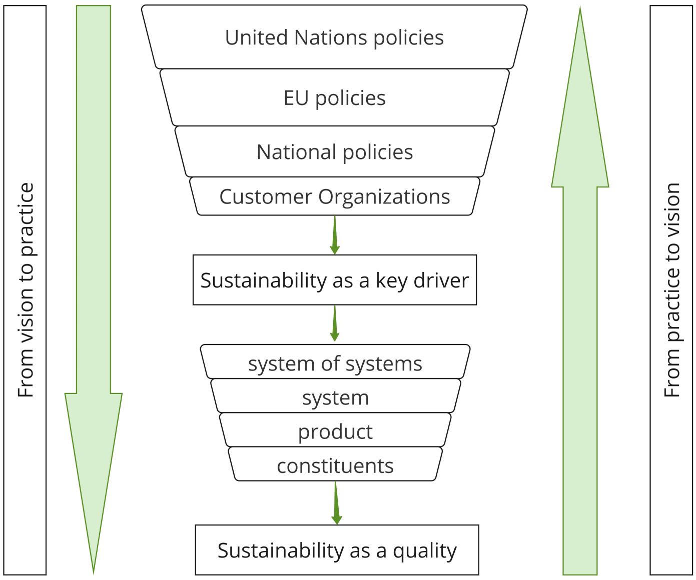

Figure 2. Path from policies' vision of sustainability to the practice in industry.

In line with the sustainable transformation, each country has to declare their contribution. The enforcement of sustainable policies demands compliance from organizations belonging to each country. Therefore, customer organizations request industrial organizations to develop systems that are sustainable. Sustainability may be included as a key driver in the system development.

Applying sustainability as a key driver, it is natural to associate sustainable requirements and qualities. A sub-set of such qualities would include directly sustainability as a quality. Hence, each of the system and subsystem components needs to fulfill the quality of sustainability. This includes any activity and practice related to the system components in its lifecycle through the supply chain. As a quality, sustainability comprehends the economic, environmental, and social perspectives. Such quality has to act as a center of gravity among its perspectives. Each of these perspectives is characterized by multiple aspects.

Figure 3 resumes the most relevant sustainability aspects collected from the UN framework, EU framework, and this case study. These aspects need to reflect the prerogative needs of sustainability as a quality. Sustainability as a quality and its subsequent perspectives and aspects bring into practice the sustainability vision enforced by international policymakers.

Each of the sustainability as a quality's perspectives is composed of multiple aspects. For each aspect, there is the need to identify and assess its impact on each system's component throughout its lifecycle and over the supply chain. International policies may support the mentioned need. Specifically, it can be deployed the UN framework of SDGs targets and indicators, the EU Taxonomy and the GHG Protocol.

Once identified and assessed the desired sustainability aspects and related perspectives, sustainability as a quality can be assessed. Finally, the sustainability quality can be included in the list of the other qualities during the system development. Section 2.3 shows the traditional scheme for the industrial system development suggested by Muller [59]. Sustainability can be included among the needs of the customer(s) becoming therefore a key driver for the realization of the system, as shown in Figure 4. Subsequently, sustainability as a key driver is associated with the system's requirements.

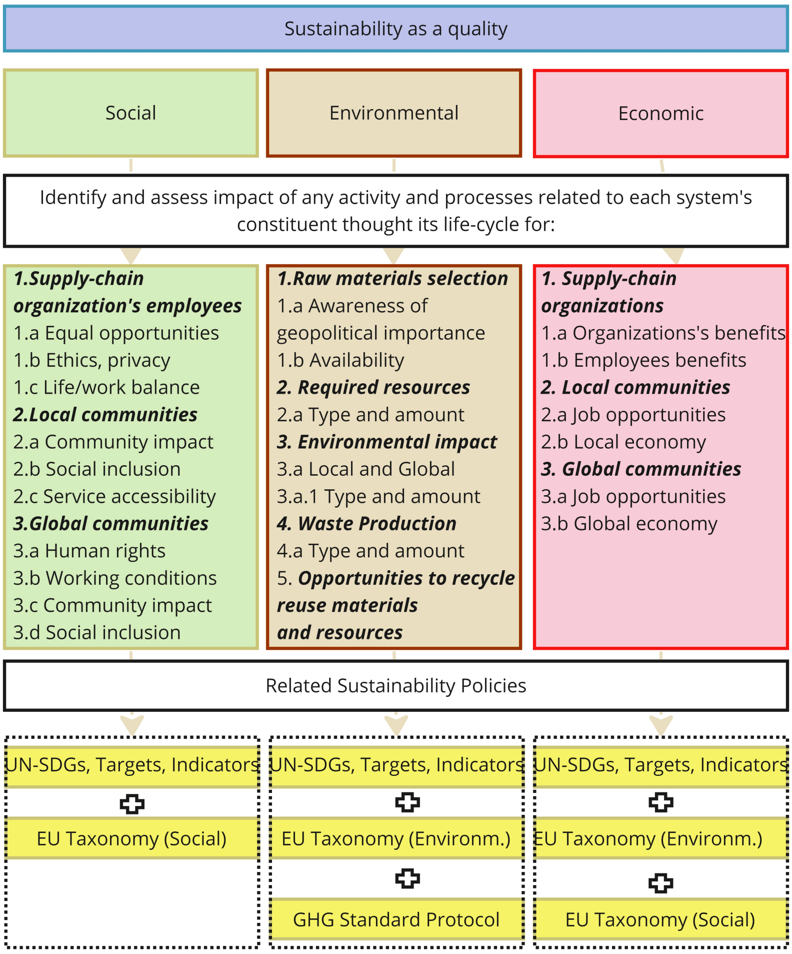

Figure 3. Sustainability aspects from UN-SDGs, targets, EU-Taxonomies, and case study.

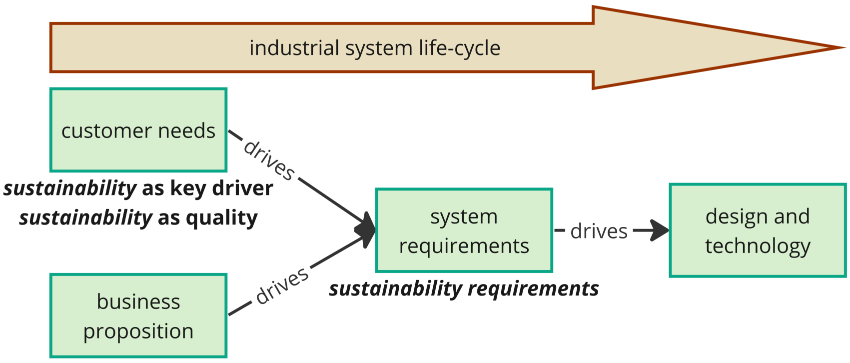

Figure 4. Integration of sustainability as a quality and key driver in the system's architecture modified from [59].

Model-based Systems Engineering (MBSE) may support the integration of the sustainability-as-a-quality together with the other desired system's qualities. The INCOSE defines the MBSE as the "*formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases*" [70].

5. Concluding Remarks

This article explored the obstacles that industrial organizations are facing toward the sustainable transition. The present article does so by means of a literature study and a survey work. The commonalities between the literature review and the presented survey can be resumed as *i) identify the sustainability as a quality of the intended system to be realized*; *ii) collect environmentally sustainable (big) data*; *iii) communicate environmentally sustainable (big) data over the supply chain*.

Identify sustainability as a quality of the intended system to be realized. The reviewed literature presents how sustainability can be integrated into the list of traditional system's qualities. Establishing sustainability as a quality in turn requires identifying, assessing, and evaluating the aspects belonging to each perspective of sustainability. UN-SDG targets and indicators, EU taxonomy, and GHG Standard Protocol may support the management of interested sustainability aspects.

Collect environmentally sustainable (big) data. To trace the environmental practices related to the system's life cycle, (big) data need to be collected and assessed. This environmental (big) data can be further adopted to evaluate data-driven decisions to reduce the environmental impact of the industrial system. However, converting the retrieved (big) data into useful sustainable engineering decisions requires human competence. This study observes that often organizations lack the required competence to perform sustainable engineering decisions. This competence should entail knowledge and experience regarding sustainability and, at the same time, holistic and perspective views on the intended system to be realized.

Communicate environmentally sustainable (big) data over the supply chain. To report environmentally sustainable emissions in line with sustainable regulations, organizations need to transparently share their environmentally sustainable data over the supply chain. However, the present case study observed that the inter-organizational communication of environmentally sustainable data can be a challenge. Indeed, different organizations may have different levels of preparedness regarding environmental sustainability practices and traceability. Poor preparedness may negatively impact not only the organization itself but all the involved stakeholders. A way to overcome such challenges is to establish a collaborative environment, where involved stakeholders may discuss sustainability drivers, indicators, and methodologies to be complied and shared through the supply chain [26]. This is particularly important in the early strategic phase of projects. During this phase, strategic decisions are taken having significant consequences, including sustainability, with respect to the system's lifecycle [66,71]. Any concern regarding sustainability should be considered in the early phase to facilitate the sustainable development of the intended system. In the strategic early phase, stakeholders envision the expectations and the feasibility of the system through a set of preliminary discussions. The discussion group is typically composed of a heterogeneous group of experts who communicate expectations and the technical feasibility of the system.

Strategic early phases comprehend two parts: a co-creative and a structured session.

Co-creation session starts by identifying customer(s) expectations. The expectations are converted into key drivers. Thus, the desired non-functional requirements, including sustainability, can be expressed. The desired system is identified. Here system thinking tools such as the Gigamapping can support the session by depicting potential tension(s) between the system's components and any involved activity and processes. Alternative to traditional systems engineering methods, Kjørstad et al [72] present the *co-creative problem-solving toolbox* as a new methodology to support stakeholders in collaboratively creating together innovation.

The structured session comprises the assessment and evaluation of the technical feasibility of the desired system. Technical experts from different organizations and fields of expertise meet together in this session. As a consequence, the attendee's opinions and approaches are limited to the silo where they belong. The communication between these silo-thinkers may be facilitated by means of systems thinking and systems engineering approaches. Wettre et al. [52] propose a framework to overcome silo-thinking during the design thinking session. An example of how systems engineering tools may support the technical feasibility can be found in Engen et al. [73]. Similarly, sustainability may be included as the other technical qualities. SWOT, CATWOE, PESTEL, LCA, and Life Cycle Engineering (LCE) support the experts in assess and evaluate the system's technicalities and related challenges to the quality of sustainability.

6. Limitations

This work presents limitations. The use of action research leads to possible bias from the researcher. To minimize this limitation, data have been retrieved from multiple sources. Another limitation is that this study case involves a limited amount of organizations each of which was represented by one participant. The participants answered the interview based on the field of competence and their personal driven interest. Further work should overcome the limitations of the present work by increasing the number of involved organizations. For each involved organization, a suggestion regarding the relative amount of participants may be to have at least three employees having different roles inside the organization.

7. Future Research Directions

Finally, this work concludes with possible future research directions to better align the current industrial practices with the roadmap envisioned by the sustainable transformation.

7.1. A Sustainability Framework to Monitor Performances of Organizations

The SDGs and their targets are entangled in a complex way making it difficult to consider one goal at a time, but instead, they should be addressed at the same time [74] centered on the whole vision of sustainability [32]. To quantify how well these organizations are aligned with the sustainable 2030 trajectory, the United Nations suggests using the framework composed of SDG targets and SDG indicators. There are a total of 169 targets and 258 indicators [2,17,35]. Also, the EU Taxonomy tackles the sustainability challenges. The methodologies envisioned by the EU taxonomy advance significantly the sustainable transformation for industrial organizations. To comply with the methodologies suggested by the EU taxonomy, industrial organizations are required to follow stringent standard requirements.

The use of SDG targets, SDG indicators, and EU taxonomy enhance a robust and trustworthy framework for the assessment and evaluation of organizations' sustainability performances. The use of SDGs and EU taxonomy brings transparency and traceability to activities and processes involved in the system development. Because of their different nature, SDGs and EU taxonomy should be adopted together in a way to simplify their usage by organizations. Here the authors suggest that a possible research question in this regard can be formulated as:

How can SDG targets, SDG indicators, and EU taxonomy be framed in a way to facilitate sustainable transformation, and its relative monitoring, while developing industrial systems?

7.2. Regenerative Sustainability to Overcome the Sustainability Challenges

Although sustainable transformation is a significant concern in itself, there is a tendency to look at the sustainability challenge as an opportunity to rethink current practices. This is the case, for instance, of the recent research from Gibbons [38]. In the work, the author describes how regenerative sustainability is an opportunity to improve continuously the healthiness of the current practices from a social and environmental perspective. Also, other research activity is performed in the same line through the use of the real world as a laboratory [75]. To some extent, regenerative sustainability can be applied also to organizations. For instance, within the context of the lifecycle of a system, organizations can adopt regenerative sustainability to identify opportunities for the improvement of the ecosystem and society during the system lifecycle usage. The approach of industry-as-laboratory should be coupled in combination with the real-world as a laboratory. A possible research question in line with the regenerative sustainability can be:

How can organizations implement regenerative sustainability for the environment and society that are involved in the industrial system during its lifecycle?

7.3. Sustainability in Systems of Systems

Each of the SDGs is composed of interconnected systems: *social, environmental,* and *economic* [76]. In the case of multiple SDGs, the complexity increases. If attention is given to one specific system it might have unwanted repercussions to the others [76]. Tackling more than one SDG at the same time enforces "*clear tradeoffs*" among the interconnected systems belonging to each SDG [76]. Thus, if a single SDG is a system of systems, multiple SDGs raise the overall complexity of the system of systems and its related subsystems *tradeoffs* [77]. Systems thinking and systems engineering tools have the potential to support the understanding of the system of systems. The use of these tools can simplify the understanding of the system sustainable systems of systems mapping each of its components to the sustainable systems foundation *social, environmental, and economic*. Mapping these routes implies understanding the tension of system of system's components and where the *sustainable tradeoff* requires major attention. Such an approach could reflect more conscious and holistic decisions from organizations related to the system of systems.

How can systems thinking and systems engineering simplify the sustainability tradeoff in the realization of industrial systems throughout their lifecycle?

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Data Availability

Data supporting this study are not available due to confidentiality and privacy concerns.

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Author Contributions

Conceptualization: H.G.; Data curation: H.G., K.F., D.E.H., E.D.; Formal analysis: H.G.; Funding acquisition: K.F.; Methodology: H.G., & K.F.; Writing – original draft: H.G.; Writing – review & editing: H.G., K.F., & G.M.

Conflicts of Interest

The authors have no conflict of interest to declare.

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