Chapter 2
The Complexity of Sustainable Innovation, Transitional Impacts of Industry 4.0 to 5.0 for Our Societies: Circular Society Exploring the Systemic Nexus of Socioeconomic Transitions

Manuel Morales, Susu Nousala, and Morteza Ghobakhloo

Abstract In this chapter, we explore and analyze the foundations of our societal relationships, in relation to the concept of industrial transitions. When trying to understand how humans, collectively and prospectively, adapt or react to socioeconomic disruptive changes like the one Industry 5.0 is enacting, two concepts emerge. The first concept is the scope at which humans can handle complex issues. The second is the speed at which they are able to reframe their mental models, based on exposure to high-speed information exchange, that may drive thinking towards unexpected and completely different outcomes. We argue that ecosystems and their innovation capabilities are the only available mechanism we collectively have to build creativity and address the prioritizing of societal values. Innovation ecosystems can supply the testbed pathways on which better societal functions may emerge. In summary, this chapter discusses ways in which socioeconomic transitions could be dynamically applied to relevant functional systems, with a time horizon that allows enough time for evaluation of the effects (positive or negative), so that elements could be changed and/or introduced into or for the system. The circular society described in this chapter would have both intended and unintended consequences, as does any social complex adaptive system. As such, changes to any social contract defining particular interactions and relevant issues, would in turn, contribute to the fabric of preconditions and definitions of the transition between Industry 4.0 and Industry 5.0.

M. Morales (✉)
ESC Clermont Business School, Clermont-Ferrand, France
e-mail: manuel.morales@esc-clermont.fr

S. Nousala
Kaunas University of Technology (KTU), Kaunas, Lithuania

M. Ghobakhloo
Industrial Engineering and Management, Uppsala University, Uppsala, Sweden

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2.1 Introduction

This chapter discusses some of the less obvious but important elements of the transition from Industry 4.0 to a loosely defined Industry 5.0 (Ghobakhloo et al. 2021, 2022). This particular transition has been and remains problematic because of complex and sometimes contradictory objectives set among different layers of the socioeconomic context. A rarely-acknowledged human-centricity nexus exists within the transition towards Industry 5.0, that needs to be analyzed and can no longer be ignored.

The complexities of any aspect of societal transition demand that integration be informed by a systemic approach. These unseen demands of the industrial transition of 4.0–5.0 must, by their very nature, encompass the notion of human-centricity across a board spectrum of interactions. It could be said that Industry 5.0 aims to simultaneously identify the interconnections and patterns that typify a human-centric approach between socioeconomic and environmental transitions.

The socially-constructed human-centric transition within Industry 5.0 (Ghobakhloo et al. 2021) can be described as Social Complex Adaptive System (SCAS) (Nousala et al., 2005; Nousala and Marlowe 2020). When it comes to emergent societal transitions, not all aspects can be controlled, at least not simultaneously. The many moving parts of the socioeconomic ecosystem, are multilayered complexities that constantly emerge and create new connections. A SCAS lens offers a means by which to better anticipate, adapt, and build resilience in a more participatory and balanced way.

2.2 Value Paradox and the Drive for Industry 5.0

The emergence of Industry 5.0, in the wake of Industry 4.0's rapid progress, is a testament to the sustainability and human centricity gaps of the evolving industrial landscape. Industry 4.0 initially took the industrial world by storm, driven by aggressive technological implementations that drastically improved productivity and waste reduction. However, it soon became apparent that Industry 4.0 had overlooked crucial sustainability and human-centric aspects in its design and technology. This void, marked by a lack of consideration for environmental impact, employment concerns, and ethical dilemmas, necessitated a political patch through the Industry 5.0.

Industry 4.0's primary focus on productivity often led to unintended environmental consequences, as some organizations prioritized output over sustainable practices. Increased automation, while boosting efficiency, could contribute to higher energy consumption and increased waste generation. Furthermore, the human element seemed marginalized, as the rapid automation of processes raised concerns about job displacement and the social implications of reduced human involvement. Scholars argue that Industry 4.0 has not adequately addressed the pressing need for creating new job opportunities or upskilling the workforce. Ethical considerations, particularly regarding data privacy, security, and the ethical use of AI and machine learning, have also been inadequately addressed. In line with these arguments, the controversial impacts of Industry 4.0 on social and environmental issues have indeed been extensively scrutinized and brought to the forefront through the comprehensive research efforts of the European project titled "Industry 4.0 Impact on Management Practices and Economics" (IN4ACT). This research initiative focused on assessing the multifaceted consequences of Industry 4.0 by delving into a substantial sample of 527 academic contributions. This research aimed to elucidate the nuanced interplay between Industry 4.0 and various aspects of environmental and social values across microscopic (firm level), mesoscopic (supply chain level), and macroscopic (regional level) analysis levels. As shown in Table 2.1, examining the effects of Industry 4.0 on multiple dimensions of social values provides critical insights into why the swift introduction of Industry 5.0 has become necessary.

Figure 2.1 illustrates that Industry 4.0 offers distinct societal advantages, such as enhancing workplace safety, facilitating product customization, and fostering digital literacy. However, it is also linked to adverse effects on various social values. At

Table 2.1 Four visions of circular economy, (adapted from Martin Calisto Friant et al. 2020)

		Approach to social, economic, environmental and political considerations	
		Holistic	Segmented
Technological innovation and ecological collapse	Optimistic	**Reformist Society** Capitalism mixed with behavioural and technological change, compatible with sustainability and socio-technical innovation, falls short of achieving absolute eco-economic decoupling to avert ecological collapse	**Technocentric Circular Economy** Capitalism, when aligned with sustainability and enabled by technological innovation, can facilitate eco-economic decoupling to prevent ecological collapse
	Skeptical	**Circular Society** Capitalism, in its current form, is incompatible with sustainability, and socio-technical innovation. Emergence of the Industry 5.0 as a paradigm integrating human centricity and seeking to prevent ecological collapse	**Fortress Circular Economy** While no alternative to capitalism is evident, relying solely on socio-technical innovation cannot achieve absolute eco-economic decoupling, risking ecological collapse

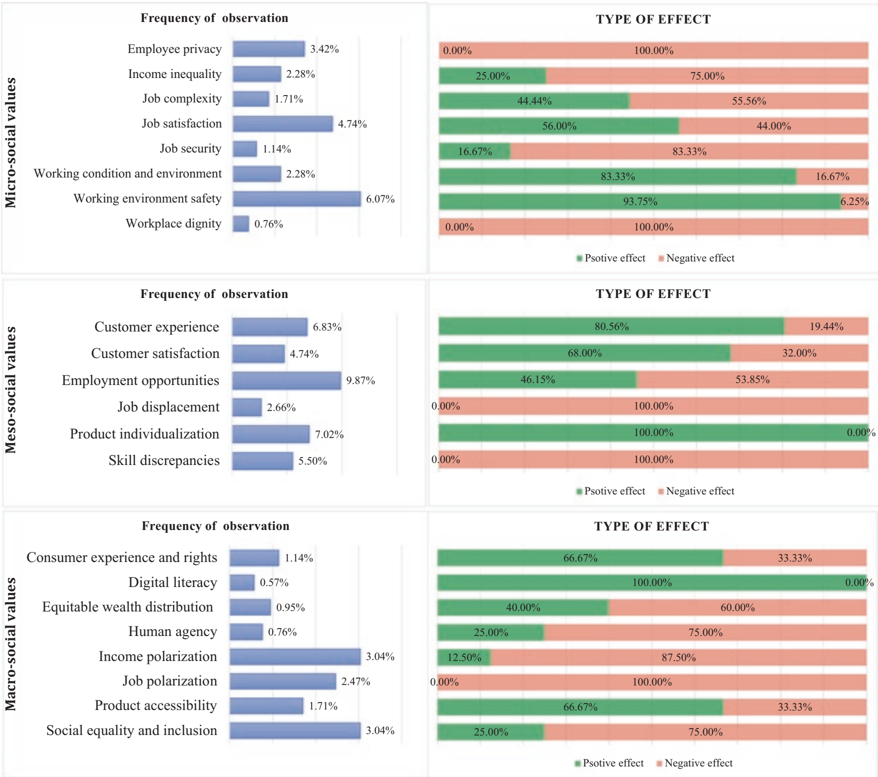

Fig. 2.1 Social implications of Industry 4.0 at various analysis levels (Adapted from Ghobakhloo et al. 2021)

the micro analysis level, the digital transformation associated with Industry 4.0 has been found to compromise employee privacy, exacerbate income inequality among workers, and erode workplace dignity. Moving to the meso analysis level, Industry 4.0 has been connected with substantial job displacement and the emergence of skill disparities within the workforce. These effects are particularly pronounced as companies adopt automation and other disruptive technologies, altering job requirements and workforce dynamics. Zooming out to the macro level, Industry 4.0 has stirred controversy due to its implications for broader societal values. Notably, it has a negative impact on social inclusion, as some groups may face barriers to access and participation in the digital economy. Additionally, there has been a risk of job polarization, where technology-driven job growth occurs primarily in high-skilled and low-skilled sectors, leading to a hollowing out of middle-skilled jobs. This phenomenon can further exacerbate income inequality. Furthermore, Industry 4.0 has posed challenges to human agency, as automated decision-making systems may limit individual control and autonomy in various aspects of life.

In response to these deficiencies, Industry 5.0 emerged as an evolutionary step that builds upon the technological foundation of Industry 4.0 while rectifying some of the problems. It places a renewed emphasis on the human element in the industrial ecosystem, fostering collaboration between humans and machines to create a more inclusive and sustainable working environment. Sustainability takes center stage in Industry 5.0, with a commitment to reducing environmental impact, optimizing resource utilization, and promoting circular economy practices. This includes the incorporation of eco-friendly technologies, energy conservation, and waste minimization. Additionally, Industry 5.0 addresses social issues by actively creating employment opportunities through technological advancements that enhance human skills and promote innovation. It champions ethical Artificial Intelligence (AI) and data usage, ensuring transparency and fairness in decision-making processes. In summary, Industry 5.0 has emerged as a response to Industry 4.0's fast-paced progress, filling the sustainability and human-centric gaps to pave the way for a more balanced and responsible industrial future.

2.3 The Iterations and Layers of Industry 4.0 to 5.0 Transition

The complex spectrum of elements within this industrial transition must also include the complexity of sustainable innovation within the socioeconomic realities. Viewed from a holistic perspective, the current industrial transition reveals a serious lack or missing gap, namely the social dimension (OECD 2013). Large corporations have had an unbalanced view regarding their behavior and have long been considered "net takers." Most firms have lacked an understanding or any real awareness of the industrial ecosystem, as evidenced and witnessed by the imbalance seen in open innovation (H. W. Chesbrough and Appleyard 2007; H. Chesbrough and Brunswicker 2013). Corporations in the USA and Europe have freely used intellectual assets developed by others without any immediate pecuniary compensation. It can also be said that these same USA and European corporations are three times more reluctant to share outbound innovation, referring to the external use of the internal knowledge, preferring to source, find, and develop new ideas from internal projects within the market (H. Chesbrough and Brunswicker 2013).

The transitional pushing actions of Industry 5.0's demand to absorb, must be reconciled with the impact of Industry 4.0 pulling actions at the micro, meso, and macro societal levels. In other words, the technological push should be shifted into a customized transitional pull exerted by the priority of societal needs. With this reconciliation-balancing act in play, the short and recent history of 5.0 emergent changes have been somewhat contradictory. To date, these transitions have grappled with the tensions of man and machine being fully integrated vs. the emergent technological engagement to enhance societal living. These explorations have embraced both ends of the spectrum, with inevitable tensions emerging, providing many more questions asked than answered.

Recent historical pathways have looked at transition from a societal change through the lens of living materials and ecological systems, as specific stages. This approach was reflected in discussions during 2020, suggesting an incremental approach of Industry 4.0 resulting in Industry 4.1, 4.2, etc. This approach and thinking seemed to suggest that the layered transition (the same layers found in systemic approaches and thinking) was not strictly linear and introduced the possibility for simultaneously creating multiple transitional approaches. From 2021, it could be suggested that 5.0 was not necessarily an Industrial Revolution but more of a policy “patch” that had specific goals across the supply chains and human-centric impacts.

Industry 5.0 has, to date, been a concept that describes the latest evolution of industrial ecosystems. It builds upon Industry 4.0, which is characterized by the implementation of advanced technologies like the Internet of Things (IoT), more general AI, machine learning, and robotics to automate innovation and production processes and increase efficiency using a socially constructed human-centric approach. Moreover, Industry 5.0 aims to combine advanced technologies with the unique abilities of human workers, such as creativity, empathy, and problem-solving skills. It emphasizes the importance of human interaction, collaboration, and innovation in the industrial context, aiming to create more sustainable, adaptive, and resilient systems.

It seems that a new theoretical framework is required for a structural transition where a deeper understanding of the drivers is able to define the transition patterns and how they could shape new industry paradigms (Ghisellini et al. 2016). According to the current scientific literature, the most relevant driver of digital transformation in supply chains is innovation, which focuses on a process approach (Marion and Fixson 2021). This process approach highlighted the systemic and dynamic aspect of self-tuning feedback (Del Giudice et al. 2021), even/or emphasizing the management limitations coming from limited resources (De Massis et al. 2018). To date, the scientific community has observed and agreed that innovation should be approached in a systemic manner (Nousala and Marlowe 2020; Iacovidou et al. 2021) because it is the best available way in which society can entail the comprehensive transformation of the entire industrial ecosystem (Kerdlap et al. 2019). These transformations encompass the integration and optimization of processes, products, and services across the value chain (Hofmann 2019; Morales and Lhuillery 2021).

These large integrations can be seen as “systemic innovation” and can comprehensively impact the industrial ecosystem, as they aim to create interconnected and intelligent systems that enable seamless information exchange, real-time data analysis, and adaptive decision-making, which implies continuous technological advancements and iterative improvements.

In turn, the combination of iterative improvements informs the self-tuning model at the macro level. It refers directly to the sectorial ability to rapidly adapt to market changes (organizational agility), learn through experimentation (organizational adaptability), and effectively balance knowledge, technological exploration, and exploitation (organizational ambidexterity). A self-tuning (Del Giudice et al. 2021) model is necessary for a sustainable transition from Industry 4.0 paradigm to 5.0. The transition pathways for a sustainable transition of the Industry 4.0 paradigm have raised the question of agility and adaptability of dynamic innovation approaches in response to rapidly evolving market demands, customer preferences, and competitive landscapes. The agility of these rapidly moving markets has entailed the development of modular methodologies, flexible production systems, and iterative design processes (De Massis et al. 2018) to foster continuous innovation and improvement through IoT devices and sensors that allow machines and systems to communicate and exchange data, facilitating real-time monitoring, predictive maintenance, and optimized resource allocation.

2.4 Adaptability and the Transition: A Deeper Dive into Meso and Macro Level Impacts

Organizational adaptability (Ivanov 2020) has been a worthy competence and outcome of the Industry 4.0 transition patterns, as it has involved the integration of systemic and dynamic innovation with technological changes. This adaptability applied to supply chains has required a holistic approach that considers the interdependencies and synergies (Mancini et al. 2021) among different technological components and innovation strategies. For instance, VINCI Digital has adopted IoT devices that were not sufficient on their own; they needed to be integrated with predictive maintenance and AI capabilities to unlock their full potential. Similarly, dynamic innovation processes should be aligned with systemic changes to ensure compatibility and coherence within the industrial ecosystem (Piezer et al. 2019).

Industry 4.0 has called for a theoretical framework that provides the required means to manage complexity in supply chains. To seek efficiency, profit, environmental sustainability, and social benefits through the interconnection of actors in the value chain, the transition must call for a diverse range of scales of analysis to be simultaneously integrated into the framework. Analyzing the supply chain at a macro level involves considering the overall structure, dynamics, and interconnections of various industries, sectors, and regions. This usually includes an assessment of the flow of goods, services, and information across the entire value chain, identifying dependencies, and understanding the broader economic and geopolitical factors that influence the supply chain.

The meso scale of analysis is crucial in understanding and optimizing value chains in Industry 4.0. The meso scale focuses on the intermediate level, examining the relationships, interactions, and dynamics between different entities within the value chain. Some key aspects of the meso scale analysis have been skill and competency upgrading, internationalization through standards and regulations, circularity added value in business models, inter-organizational relationships, risk management, data integration and interoperability, and performance measurement and metrics. By considering the meso scale of analysis, organizations gain insights into the value chain's interdependencies, collaboration opportunities, and risks. This understanding allows for identifying areas for optimization, fostering more robust partnerships, enhancing data interoperability, and engaging symbiotic relationships to improve overall performance and competitiveness (Bennich et al. 2021; de Oliveira et al. 2018).

Analyzing the industrial supply chains at a micro-level involves examining the operations, processes, and interactions of individual actors within the value chain. This includes assessing the efficiency and effectiveness of production processes, logistics operations, inventory management, and distribution channels. Micro-level analysis enables identifying bottlenecks, optimizing workflows, and improving resource allocation.

Overall, transition patterns in Industry 4.0 encompass the integration of systemic and dynamic innovations among production and organizational processes. These integrations enable industries to effectively leverage advanced technologies, transform operations, and adapt to changing market dynamics. By embracing these transition patterns (Hazen et al. 2021), industries can enhance their production and consumption behavior, leading to increased efficiency, sustainability, and competitiveness.

There has been a lack of research interest in the social dimension of the Industry 5.0 transition (Ghobakhloo et al. 2022). The few existing analyses on social indicators for Industry 4.0 take place at the national level; however, if society aims to build a socially constructed human-centered transition paradigm for Industry 5.0, the social dimension of this transition needs to be strategically prioritized. As the outcome of a preliminary literature review, we have identified three main drivers that influence the social dimension of the Industry 5.0 transition.

The first reason the social dimension of Industry 4.0 lags behind is the complexity of implementing a multidisciplinary approach that combines insights from engineering, computer science, economics, sociology, and other fields (Hannon 2020) needed to address complex social issues.

The second reason is that there is no agreement among the scientific community regarding estimations and measures of social impacts and outcomes (Ghobakhloo et al. 2021; Martinez-Hernandez et al. 2017). Nevertheless, some relevant, although partial, methods for assessing the progress of Industry 4.0 through 5.0 have been constructed, like the Comprehensive Evaluation Frameworks (CEF), systems thinking analysis, long-term integration, and a robust and transparent data analysis monitoring (Morales et al. 2021). Even when those assessing methods could be improved, they provide the first stage for a more comprehensive, sustainable, transparent, and accountable evaluation process, enabling informed decision-making and maximizing the overall positive impact of these technologies. For example, (Huppes et al. 2017) provided a systemic design for long-term climate policy implementation in the European Union using a CEF.

Third and last, the lack of funding and resources available for social research on the Industry 4.0 transition, particularly in comparison to technological or economic research, has been responsible for the lack of interest or awareness among policymakers, the business sector, and the general public (Abad-Segura et al. 2020). Overall, the lack of political interest in the social dimension of Industry 5.0 has been accentuated because of the reduced funds and resources dedicated to analyzing the social challenges that can make this paradigm transition possible. However, current and newly designed research efforts are underway to address this gap.

It has become clear that Industry 5.0 needs a systemic and comprehensive integration of the economic, technological, environmental, political, and social dimensions of the transition (Saidani et al. 2021). This imbalance in the information generated at different levels and dimensions is one reason that limits the implementation of a systemic and comprehensive framework, which would be capable of depicting the causal effects of the various drivers involved, thus providing access to the bigger picture to understand a broader socioeconomic and environmental transition.

The social transition problems involved in Industry 5.0 have a spin-off effect within the environmental crisis, which are largely attributed to social structural impacts like mass production, unsustainable production and consumption patterns, and an increase in material consumption per capita, particularly in developed countries leading to ecological destruction. While innovation (OECD 2013) is often associated with high-tech advancements, it also encompasses many other technological developments, including low-tech and eco-efficient solutions. To truly understand the influence of social structures in the socio-environmental crisis, we need to move beyond simplistic assumptions that equate economic growth with the creation of well-being (Dzhengiz et al. 2023). Instead, we should adopt a more nuanced and comprehensive approach that considers the broader socio-environmental impacts of technological advancements and embraces alternative models that promote sustainability and justice. The potential negative impacts of technological changes can be overlooked, even when they are meant to address environmental concerns, such as in the Circular Society or the United Nation's Sustainable Development Goals. For instance, eco-design has been recognized for extending the lifetime of materials, thereby reducing their overall environmental impact. However, in certain cases, such as the housing sector, products designed for longevity may become outdated faster due to the rapid pace of technological progress. As a result, eco-design may not always have a purely positive impact and can lead to unforeseen negative consequences.

While innovation (Dooley and Van De Ven 1999) is often viewed as a positive force, it would be a mistake to assume that all types of innovation are beneficial. Unfortunately, the current scientific literature struggles to differentiate between different types of innovation, let alone addressing their complexity. This is particularly problematic in the context of unforeseen disruptions, such as the COVID-19 pandemic or geopolitical conflicts, which can have significant impacts on socioeconomic and environmental transitions.

2.5 Transitions and Impact of Creative Systemic Preconditions Towards Necessary Human-centered Frameworks

Regarding the complexities of Industry 4.0 transitions, society needs to invest in systemic and long-term tools as a means to tackle the impact of the risk of unbalanced calculation and measurement between different scales of analysis. Indeed, some identified strategies to avoid biases in analyzing the transition processes are a comprehensive evaluation, multi-stakeholder engagement, long-term shift, robust data collection and analysis, and transparency and accountability.

The CEF needs to consider multiple dimensions of benefits, including economic, environmental, technological, and social aspects. This framework should incorporate relevant key performance indicators (KPIs) and metrics to assess the impact of disruptive technologies on various stakeholders and the overall value chain. By adopting a holistic approach, it is possible to avoid narrow or biased calculations and ensure more balanced benefits and assessment. Moreover, integrating multi-stakeholder engagement in the evaluation and decision-making processes is required if the assessments seek to gain a more comprehensive understanding of the potential benefits and risks associated with implementing disruptive technologies. The multi-stakeholder analysis needs to include representatives from different departments within the organization, suppliers, customers, industry associations, NGOs, and relevant experts. This engagement also assists in identifying and addressing any potential biases or blind spots in the benefit calculations.

To address the biases and blind spots of complex interconnected systems, models need to account for both short-term and long-term consequences when assessing the benefits. While disruptive technologies may offer significant long-term advantages, we cannot eliminate the short-term challenges because they are essential regarding the impact on implementation costs. The current time frame for economic and strategic decisions in private and public institutions is two years, according to the 2013 global survey of over 1000 board members and C-suite executives, conducted by McKinsey & Co., and the Canada Pension Plan Investment Board (CPPIB) (De Massis et al. 2018). By thoroughly analyzing both time horizons, calculation models can better evaluate the overall balance of benefits and make informed decisions.

To achieve a tangible improvement in the calculation, the data used for analysis and monitoring should be robust and transparent, and well-identified institutions or public actors should be accountable for their performance. The collection and analysis of reliable and relevant data may involve conducting surveys, interviews, and data collection from various sources among public and private actors as well as civil society. Robust data analysis techniques, such as statistical analysis, modeling, and simulation, can help quantify and compare the benefits across different scenarios, enabling a more balanced assessment. The data management process must implement a system for continuous monitoring and review of the benefits derived from the disruptive technologies. This includes regularly tracking the performance metrics, reassessing the benefits, and making necessary adjustments.

Participatory, open decision-making processes should clearly set the assumptions under which they run the analysis, methodologies, and limitations. Additionally, the rigor of the collected data and decisions helps build trust, allowing stakeholders to provide helpful feedback and contribute to refining the calculations. Establishing accountability mechanisms ensures that calculations will be periodically reviewed and validated to minimize unbalanced assessments.

The supply chains must also be analyzed from a social perspective, considering their impacts on workers, communities, and society. The social dimension includes assessing factors such as labor conditions, worker health and safety, diversity and inclusion, ethical sourcing, and community engagement. Supply chain analysis should incorporate social responsibility and strive for fair and ethical practices throughout the value chain. The social dimension in the supply chain also considers the interests of the stakeholders involved in the value chain. This includes collaborating with suppliers, customers, regulators, NGOs, and other relevant parties. Stakeholder engagement enables a comprehensive understanding of the challenges, opportunities, and trade-offs associated with seeking efficiency, profit, and sustainability in the supply chain.

With all the elements involved in the social dimension, it is important to allow the system's interconnection recognition. However, a systemic and creative approach can better support social transitions because it is better equipped to address complex and interconnected problems more systemically and innovatively (de Jesus et al. 2019). Social transitions, such as those caused by Industry 5.0, often involve multiple stakeholders and competing interests. A systemic approach can help to understand these challenges by analyzing the underlying systems and structures that contribute to them. This can help to identify key drivers where interventions can have the greatest expected and emergent impact, and to design interventions that are more effective and sustainable over the long term. Indeed, a systemic and creative approach can also be valuable in social transition studies because it can help to generate new ideas and solutions that may not have been considered. This can be especially important when traditional approaches have failed to produce meaningful change or have led to unintended consequences. A creative approach can help to challenge assumptions, break down silos, and promote collaboration and co-creation among stakeholders (Barreiro-Gen and Lozano 2020). Furthermore, a systemic and creative approach can help promote innovation and experimentation, which is essential for successful social transitions. It can help to put into action the environmental agenda, where public and private stakeholders feel empowered to try new approaches, learn from failures, and adapt strategies as needed. Overall, a systemic and creative approach can better support social transitions by helping to address complex and interconnected problems, generating new ideas and solutions, and promoting innovation.

The unseen systemic processes are by their nature, hidden within the socially constructed human-centric approach of Industry 5.0. Those systemic processes are more easily observed at the level of ecological communities (both non-human and human), serving as an analogy of what is currently happening in the Industry 5.0 socio-environmental structure. With regards to potential and future frameworks, Complex Adaptive Systems (CAS) (Martín-Gómez et al. 2019) as well as the Social Complex Adaptive Systems (SCAS) (Nousala et al. 2005; Nousala 2009) contribute to the human-centric approach for Industry 5.0. These approaches also impact evolutionary preconditions (Nousala et al. 2021), which underpin the well-being of our societies. It is important to emphasize the potential, acknowledge the preconditions, and explore what is happening before these processes begin, and why this is important. Both adaptive systems refer to the ever-evolving equilibrium that any ecological (biological) community unknowingly strives for, meaning that the balance between sustaining emergent processes and the consequences of its constraints are both positive and negative, internal and external. Herein lies the potential that can lead to the necessary.

From the point of view of sustainability, or the ability to sustain, ecological communities (human societies included), need to be flexible about the idea of reaching a point of sustained equilibrium when approached through complexity and a systemic lens, as socially constructed human-centric paradigms are by nature, dynamic. Therefore, the preposition of preconditions (Nousala et al. 2021) changing according to the time and place they are observed makes this difficult to embrace, yet needs acknowledgment. The *complex connections hidden within the system* should be viewed as a means of translating a representation for mutual understanding across multiple scales (Nousala and Hall 2008). For instance, this mirroring effect could be viewed as the actions between multiple layers, and resembles the motion between chess pieces within a 3D chessboard. These in-between, multilayered actions have unknowable or unintended consequences, with perhaps the exception of the direct actors, and usually neither of them because of an oversimplified understanding of the systems (Carayannis and Campbell 2012).

In the socially constructed human-centric paradigm, the *creative systemic process* (Freire 2020) emerges over the recognition of the system interrelations; therefore, the preconditions offer extended historical views towards descriptors that add multiple layers to the subjective creative process within any ecological (or biological) community. The development of sustainable energy systems is a clear example of an evolutionary societal upgrade relying systemically on the intentions that came before them. Over the past few decades, societies worldwide have recognized the need to shift from fossil fuel-based energy sources to cleaner and more sustainable alternatives. This evolutionary transition is rooted in mitigating climate change, reducing environmental impact, and ensuring long-term energy security. In this instance, the preconditions triggered a transition and increased awareness of the negative consequences of carbon emissions and the importance of preserving natural resources. Therefore, preconditions' role in developing and adopting renewable energy technologies were essential. Moreover, this evolutionary transition has led to the integration of smart grid systems, energy storage technologies, and decentralized energy generation, an example of the potential and the necessary.

By recognizing and acknowledging the role of preconditions (Nousala et al. 2021), societies have been able to transition towards more sustainable, resilient, and human-centered systems, as in the case of Industry 5.0. Societal evolution usually disregards the creative dynamics at play because they are backstage and are not usually a visible part of the current processes, meaning, that what we are focused on usually determines what we miss. That said, focusing on the dynamic processes and their societal preconditioned relationships are not mutually exclusive. Since these processes are cyclical and longitudinal by nature, the concept of never-ending creative cycles continues to emerge.

2.6 Rapid Changes in Industry 5.0 Trigger Even More Complexities Within Systems

In Industry 5.0, workers and machines are expected to be working together in a symbiotic relationship (Shi et al. 2010), through augmented skills, competencies, and performance (Raisch and Krakowski 2021). Machines can handle repetitive and dangerous tasks, while humans focus on tasks that require creativity, critical thinking, and emotional intelligence. Overall, Industry 5.0 represents a shift towards a more human-centric and environmentally-conscious approach to society while still harnessing the power of advanced technologies.

The rapid pace of technological change (Geels and Schot 2007) in Industry 5.0 means that businesses need to adapt and evolve their practices to remain constantly competitive. This can be challenging as new technologies and practices are continually being developed and refined. However, the benefits of Industry 5.0, such as increased efficiency, productivity, and customization, usually make the transitions worth pursuing. Businesses implementing Industry 5.0 technologies and practices can gain a competitive advantage, improve customer satisfaction, and reduce environmental impact. To navigate the transition to Industry 5.0, businesses must adopt a proactive approach, invest in new technologies, and prioritize collaboration and innovation. They also need to develop a clear vision and transition strategies seeking to adapt and change their production and consumption behavior as needed.

The current industrial revolution as a complex adaptive system, embedded in a rapidly evolving field, has some of the available means to deal with its complexity and fast-speed changes, as listed in the following four points:

1. Design thinking and systems thinking have involved a holistic and iterative problem-solving approach, considering the interdependencies between different drivers. By adopting these approaches, stakeholders can better understand the complexity of the socioeconomic and environmental transition and identify opportunities for innovation (Dooley and Van De Ven 1999).
2. Collaboration and partnerships among stakeholders can help build a shared understanding of the challenges and opportunities in Industry 5.0 and facilitate the development of innovative solutions that address these challenges.
3. Policy and regulation (Ayres and Ayres 2002) can be critical for promoting the human-centric and environmentally conscious Industry 5.0 transition, by setting targets and standards, creating incentives for innovative practices, and establishing frameworks for collaboration and coordination among stakeholders.

4. Education and awareness-raising initiatives can help build public support for Industry 5.0 ethical concerns and promote scientific decisions among consumers, businesses, and policymakers.

Overall, dealing with the SCAS exposed rapid changes requires a multidisciplinary and collaborative approach that leverages the four previously mentioned means and strategies. By adopting these means, stakeholders can better understand the challenges and opportunities that Industry 5.0 could deliver to society as it seeks to create a more sustainable and resilient systems transition. The main difference between Industry 5.0 and the previous industrial revolutions lies in their focus and objectives. The first three industrial revolutions (mechanization, mass production, and automation) aimed to increase efficiency and productivity using machines and new production methods (Ghobakhloo et al. 2021). Industry 5.0, as framed by the European Commission, acknowledges the negative impact of previous industrial revolutions on the environment and society, and strives to create more responsible and sustainable practices. It values ethical production methods and waste reduction and supports local communities.

2.7 Exploration of Transition Speed Through Value Chain Interconnections at Circular Economy

In addition to the economic dimension, Industry 5.0 needs to address environmental and social dimensions by developing decision-making frameworks that explicitly consider socio-environmental criteria alongside economic and technological factors. This involves incorporating environmental impact assessments, cost-benefit analyses, and sustainability indicators into decision-making. By integrating environmental considerations into the decision-making framework, organizations can ensure that Industry 5.0 initiatives can handle complexity and align with sustainability goals and environmentally conscious practices. The creativity process and the systemic approach allow organizations to learn from experiences, including the transition patterns to address unintended consequences and optimize sustainability outcomes over time.

The Industry 4.0 transition towards 5.0 has included the circularity principles into a more human-centric socioeconomic model. However, not all the assumptions on which the concept of circular economy has been built fit into the Industry 5.0 theory. A typology of discourses on circular economy presents four visions (Martin Calisto Friant et al. 2020). A matrix categorizes the visions along dimensions of (1) approaches to social, economic, environmental and political considerations, and (2) technological innovation and ecological collapse is shown in Table 2.1.

A holistic-optimistic discourse of *Reformist Society* envisions capitalism mixed with behavioural and technological change, compatible with sustainability and socio-technical innovation, falling short of achieving absolute eco-economic decoupling to avert ecological collapse.

A segmented-optimistic discourse of *Technocentric Circular Economy* envisions a capitalistic approach, aligned with sustainability and enabled by technological innovation, capable of facilitating eco-economic decoupling to prevent ecological collapse.

A segmented-holistic discourse of *Fortress Circular Economy* envisions no alternative to capitalism, then relying solely on socio-technical innovation that cannot achieve absolute eco-economic decoupling, risking ecological collapse.

Finally, a skeptical-wholistic discourse of *Circular Society* envisions capitalism in its current form as incompatible with sustainability, implying that socio-technical innovation alone cannot achieve absolute eco-economic decoupling to prevent ecological collapse.

Only the Circular Society (CS) vision integrates the circular economy principle of slowing, within a human-centric and sustainable paradigm of Industry 5.0. The CS vision aims to extend product lifecycles and reduce overconsumption patterns, thereby reducing the need for continuous growth and resource extraction. It aligns with the notion of prioritizing well-being over endless economic expansion, emphasizing the need for a steady-state economy within ecological limits.

Entailing the CS vision by the Industry 5.0 transition highlights the challenge of achieving stability through socioeconomic and environmental transitions, due to complexity and rapidity of changes. CS is a paradigm shift. It aims to keep resources in the economic system for as long as possible by closing, extending, intensifying, slowing, and making long-lasting products (Blomsma 2018), towards more sustainable, resilient, and human-centric production and consumption. The transition to a CS vision involves significant changes to traditional linear production models, which can be challenging to implement. The complexities of multiple, interconnected layers in the CS vision and Industry 5.0 are only visible through longitudinal data analysis. These interactions critically underpin collaboration and coordination between different stakeholders.

One of the unquestioned risks for coordination among stakeholders is the potential for over-concentration of power and resources in the hands of a few large players. Hindering competition and innovation approaches monopolistic behavior, where a small group of stakeholders controls key resources or technologies, and can set prices or dictate terms to other players in the market. Without transparency in coordination, there is a risk that some stakeholders may seek to gain an unfair advantage over others. For example, if a small group of stakeholders colludes to control a market of recycled materials, they may be able to set prices and terms that are disadvantageous for clients, consumers, and other players in the market.

Organizations can adopt a territorial approach with contextual analysis and comprehensive multidimensional decision-making frameworks. At the scale of local communities, organizational leaders have more credibility to claim effective actions and promote sustainable decisions fostering environmental stewardship through implementing Industry 5.0 principles.

CS and Industry 5.0 share a system of processes and framework with SCAS that continues to evolve. This nexus of creative behavioral patterns can underpin the environmental and socioeconomic dimensions of any human-centric, sustainable, and resilient system. In a practical sense, the design and innovation of the R&D activities, product industrialization, production, and supply chain management (Morana 2013) have usually improved through the lens of a systemic approach. Innovation, when understood as a SCAS, can influence understanding of the preconditions and resulting behavioral patterns (Nousala et al. 2021; Nousala and Marlowe 2020).

The speed of change required to implement a circular economy society can be challenging for businesses to manage. Adopting circular economy practices often involves significant investment in new technologies and infrastructure, as well as organizational changes in processes and supply chains. Rapid changes that might trigger imbalances and increase risks of monopolistic behavior and power concentration in the transition to a circular economy can be deterred through transparency, collaboration, and competition. This can be done by ensuring an open and inclusive coordination process, where all stakeholders have an equal voice and opportunity to participate (Palafox-Alcantar et al. 2020). It is also important to promote a level playing field by ensuring that all stakeholders have access to key resources, such as recycled materials or digital technologies, on fair and equitable terms. Society must play an important role in enforcing social and environmental values to engage in more equitable competition and prevent monopolistic behavior by enforcing anti-trust laws and promoting fair and sustainable competition as in non-profit organizations.

Overall, the complexity and speed of transitions required for Industry 5.0 to be embedded in a Circular Society has emerged as a complex and systemic challenge (Peponi and Morgado 2021). However, the benefits of a circular economy, such as reduced waste, increased resource efficiency, and improved environmental sustainability, propose a worthwhile and necessary transition. Businesses that adopt a transparent, findable, accessible, interoperable, and reusable (FAIR) data management system are able to facilitate collaboration and accelerate the circular economy transition, gaining competitive advantage for a more sustainable future. Circular society emerges as a promising socioeconomic and environmental collective innovation transition due to its potential to reduce resource consumption, waste generation, and environmental impact while also bringing economic benefits and stimulating innovation.

2.8 Two Test Bed Case Study Examples

To illustrate more dynamic approach, two case studies are discussed: (1) a French bio-refinery, and (2) an European digital traceability implementation.

The bio-based French economy case is a human-centric and systemic analysis (Ministry of Agriculture, Agrifood and Forestry 2016). The study is significant, representing 936,000 jobs with a total turnover of 78.4 billion euros (Ministry of Agriculture, Agrifood and Forestry 2016), with a national emphasis, scope and relevance to outcomes. The operation is the French biorefinery ecosystem located in the Pomacle-Bazancourt region. This biorefinery is an exemplar of an industrial symbiosis, with by-products exchanged across innovation ecosystem actors (Morales et al. 2022). Industrial symbiosis deals with the complexity of territorial governance through a more human-centric alternative to collectively making decisions, based on the functions that best respond to the needs of the whole. Industrial symbiosis reveals the impact of a circular society vision on Industry 5.0. The ecosystem is composed of ten actors, including Vivescia/Bletanol, Cristal Union, Cristanol, Chamtor, Givaudan Active Beauty, Wheatoleo, Air Liquide, European de biomasse, the Industrial research center (ARD), and the European Biotechnology and Bioeconomy academic research center (CEBB) (Domenech et al. 2019). Green sugar juice and syrups go across the production chain through crystallization or distillation in the biorefinery, resulting in sugar, alcohol, and bioethanol as the main products.

This agro-industrial innovation ecosystem emerged as a functional testbed of circular society, with SCAS linkages and causal interconnections. It is also an exemplar of a human-centric innovative ecosystem through the collective reappropriating of the social investment in research and innovation decisions. The systems transition was better understood, handling well the complexity of multiple stakeholders' interconnections.

The EU Digital Product Passport initiative implemented by Worldline, Ltd., is a second case for discussion. This initiative sought to exemplify how digital traceability could enable data collection throughout the value chain, and to support and trigger more human-centric and sustainable transitions to boost the circular society. As a testbed for circular society, the digital innovation ecosystems have raised implications of all the stakeholders involved in the value chains. Aims include the deterrence of illicit trades, unethical production practices, fragile supply chains, and environmental impacts, as well as non-human-centric decisions based on fast-track technological changes. The Digital Product Passport shows how traceability can cater to consumer transparency and quality assurance requirements. Innovation ecosystems can build an institutional architecture according to social and political preconditions, and potentially enabling the securing of the skills and competencies required for a systemic human-centric governance of Industry 5.0.

2.9 Innovation Ecosystems Emerging in the Circular Societies as a Testbed for Societal Functions

Current innovation approaches in value chains (VC) are based on linear thinking methodologies that cannot integrate the complexity of the iterative feedback effect, necessary for the circular economy (CE) paradigm to integrate. Therefore, overly-simplistic assumptions claiming that every innovation (OECD 2013) increase will trigger positive circularity is not sufficient to entail circular business models (Huerta Morales 2020; Lewandowski 2016) and industrial ecosystems settled within a circular society framework (Morales et al. 2021). A more integrated and nuanced approach is needed to fully address the challenges and opportunities of circular innovation.

Within the circular society paradigm, innovation (de Jesus et al. 2018) must be approached differently, shedding light on value chains and industrial ecosystems as the mechanisms that support necessary societal functions. This requires analyzing innovation to understand how resources, materials, and knowledge flows occur within a Circular Manufacturing System (CMS). To fully understand and harness the potential of industrial symbiosis, we must take into account the complex interactions and inter-dependencies within the CMS, and develop strategies that promote sustainability, circularity, and resilience (Holling 1973) across the entire value chain. Industrial symbiosis is defined here as a process of multi-stakeholder cooperation that seeks to enhance circularity in a territory (Diemer and Morales 2016). In the service of enhancing the circularity of a territory, most policy agendas are built on a mix of environmental efficiency and resilience to shocks. Efficiency affects the production and distribution of technologies (e.g., zero waste, minimum carbon footprint). Resilience involves the political, economic, and natural environments. Industrial symbiosis principles are: (1) The waste of one firm becomes the input of another; (2) There are economic and environmental benefits; and (3) There is interdependence between different partners.

Through definitions in the theoretical analysis of the circular economy (Kirchherr et al. 2017), the social side of the circular economy has been seen as left behind. Industrial symbiosis, herein considered as an innovation ecosystem example, emphasizes the extending loop principle of circularity, which includes substance cascading, waste to energy conversion, down-cycling, or symbiosis in the same or different value chains and through multiple lifecycles (Roci et al. 2022). The social dimension of circular economy is not only a question of collective organization but offers enormous governance possibilities in terms of skills and competencies upgrading, training of human resources, R&D methodologies and strategies adaptation, job creation, and justice in the consumption of raw materials. Industrial symbiosis appears to be at the heart of the transition to a circular society investing in skills upgrading.

When we talk about Circular Society in the Industry 5.0 transition, industrial symbiosis emerges as the ideal private-public arena to develop innovation ecosystems (Bennich et al. 2021) across the value chain scale where organizations, individuals, and resources come together to foster innovation and create new products, services, and processes. Industrial symbiosis is characterized by a high level of collaboration, knowledge sharing, and experimentation, and plays a critical role in driving sustainability, resilience, and competitiveness. Innovation ecosystems significantly impact the socioeconomic relationships that govern the speed of socioeconomic transitions. By fostering collaboration and knowledge sharing, these ecosystems help to break down silos of knowledge between industries and create new opportunities for cross-sectoral collaboration. This, in turn, helps to drive innovation and accelerate the pace of technological change. However, a fast pace of technological change has some inherent risks related to human adaptation and mismanagement of technologically pushed objectives.

Innovation ecosystems provide a collaborative and supportive environment for creativity (Tsujimoto et al. 2017). These ecosystems help to ensure that the benefits of technological change are widely shared, and that the transitions to new industrial paradigms and circular business models will be as smooth and inclusive as possible. For instance, the digital product passport plays a critical role in shaping socioeconomic relationships that seek to create the mechanisms and tools to respond to the fast-speed traceability needs imposed by industry. Rapid transitions in the industry need to be evaluated through real-time information, open innovation, collaboration, knowledge sharing, and even efficiency and performance information to show evidence of the pervasive effects of non-human-centered fast-speed transitions, which will be able to slow down or even cancel them. Therefore, these innovation ecosystems help to create a more inclusive and sustainable economy that benefits everyone.

The social implications of circularity (M Calisto Friant et al. 2021) on biophysical, monetary, human resources, and information flows are observed and empirically validated using the figure of innovation ecosystems. The social innovations recognized in the circular society are empirically observed in the skills upgrading and training of human resources, stakeholders' participatory decision processes, collaborative strategies like industrial symbiosis, and the R&D adaptation to fast-speed changes. Systemic circular society transitions in the industrial symbiosis face increased high-speed changes, bringing increased complexity to analyzing societal impacts.

Engaging in a participatory decision-making process involving society, the private sector, and the public requires a coherent systemic and dynamic approach. The scientific literature claims that collaborative platforms (Kerdlap et al. 2019; Robert et al. 2020) that bring together representatives from various sectors, including government agencies, businesses, civil society organizations, and academia, are required to provide spaces for dialogue, knowledge sharing, and co-creation of solutions. By fostering collaboration and active participation, diverse perspectives and expertise can be integrated into the decision-making process, claiming for shared vision and goals. Establishing a common understanding of the desired future makes it easier to align regulations, policies, and strategies toward achieving those goals.

Indeed, governance in industrial ecosystems is collectively constructed using systemic approaches to knowledge processes. Value is frequently extracted from innovation ecosystems like industrial symbiosis because the risks of research and innovation activities are socialized, but the rewards thereof are privately appropriated. Therefore, to regulate innovation ecosystems behavior towards achieving more sustainable, circular and resilient governance, the political and social narratives need to be included in the definition of fundamental values. The current scientific literature recognizes regulations, policies, and business strategies as the mechanisms required to shift the production and consumption process (Hosseini-Motlagh et al. 2020; Geldermans 2016). Adaptive governance (supported by SCAS), aims for policy integration and alignment to fulfill human-centric decisions, as evidenced by the environment-water-energy-food nexus described by (Laurens et al.

2017; Chen et al. 2020). Innovation ecosystems with a territorial approach are needed to break down silos and foster coordination among government agencies responsible for regulations and policies relevant to the topic at hand.

Finally, effective communication and transparency throughout the decision-making process must transparently engage stakeholders by providing accessible and understandable information. Innovation ecosystems should clearly communicate the rationale behind decisions, trade-offs, and expected outcomes. Transparency and accountability of the decision-making process and the collected data seek to foster an environment of trust by keeping stakeholders informed and engaged and actively addressing their concerns and feedback. Indeed, the implementation of the Industry 5.0 change should promote education and awareness among stakeholders about the systemic and dynamic nature of the challenges.

2.10 In Summary, the Intended and Unintended Consequences of SCAS Entail the Transitions Between Industry 4.0 and 5.0

It could be argued that sustainable supply at the regional macro level has not been successful. This is precisely where societal issues have failed in Industry 4.0, bringing about the policy patch discussions of 2021. Again, these tensions between levels and layers have brought about broader questions about relationships between various actors and their regions. To date, the less explored areas between Japan's Society 5.0 and the European Union's Industry 5.0 need better definitions that have yet to emerge. This lack of definition speaks directly to the human-centric question of what is really meant by this term, the human-centric definition, between different regions and their actors. This also leads to the next question of disruptive technologies, and 5.0's abilities to tackle and address societal impacts with the necessary awareness. It is simply not possible to know what we do not know, an obvious statement but one that, again, speaks to the human-centric definition question.

The speed at which the technological transitions demand societal structures poses yet another question of the cyclical and necessary feedback loops required for societal development and the emergence of their respective SCAS. Simply put, what are the significant developmental impacts on these systemic feedback loops within our societies? Given that the 5.0-definition boundary has yet to be clarified, the question of 5.0 being merely a policy patch seems have already been superseded by the speed of the technological development and impact of AI. The issue and tensions of how, why, what, and where a SCAS learns, develops, and evolves do not neatly follow linear transitional timelines, but instead evolve systemically, regardless of who, why or what actors may or may not be involved. This line of questioning again loops, follows, and leads back to what human-centric involvement is and what approaches support humans within our societal spheres. How will our governments and all the actors, that make up our societies strive for transparency whilst delivering sustainable governance for the long term? This is indeed a question to be grappled with and one that is complex, so it must be approached via systemic thinking. This said, if AI continues to develop algorithms within algorithms, the question of what is human-centric may become moot since algorithms, for the sake of its algorithms, are not something that is connected to humans any longer and do not necessarily serve or support the particular human-centric approach.

That said, the preconditions on all levels will continue to evolve, and acknowledgment of human creativity remains valid and necessary to analyze the complex circular society, paving the way toward the Industry 5.0 transition. This type of approach would improve the societal understanding of the human-driven condition, to source enhancement rather than remaining a hidden spring of potential without any clear background. Without acknowledging the source of the information, data, and knowledge can easily become fragmented and disconnected from societal values. Thus, even when in certain circles we recognize the prominence of the outcomes regardless of the means and processes that drive us there, this is a point worth mentioning when defining what human-centered foundations are.

For instance, the boundaries of human-centric decisions become fuzzy when data, information, and knowledge are considered interchangeable due to AI's entrance into the playground. It was debatable before, but an argument can be made that this is now the case. Whilst ChatGPT, for example, has the possibility to blur our previous definitions, it is worth considering that this is a precondition in the making. The preconditions set up the fundamental question of why, what, and how ontology and epistemology should remain in the human-centric process. This question is not new. Societies have been creating and supporting ways of maintaining knowledge bases for centuries, mostly paper-based, but other forms of data and records also exist. With the introduction of our machine-readable data and information, public institutions have struggled over many decades to maintain our public records. The loss of working devices meant the loss of data and information. How, for example, can ChatGPT address this? Can it be addressed, or will it not be seen as necessary?

These questions are part of the preconditions evolving now, and with it, there is the question of knowledge provenance and origins. Is it of value from a societal perspective or not? Do we still value or need to validate our threads of knowledge and providence for what is being communicated to each other and our societies as a whole?

Paraphrasing Albert Einstein: "The same level of thinking that created the problem, won't solve the problem." Questioning the validity of previous economic assumptions is crucial if society seeks to counter the production and consumption patterns that have contributed to the current social and environmental crisis. The current crisis highlights the limitations and negative consequences of certain economic paradigms and assumptions. Some of the assumptions that we have found to be important are:

1. Sustainability: The current social and environmental crisis is, to a significant extent, a result of unsustainable production and consumption patterns driven by

economic assumptions that prioritize endless growth, resource exploitation, and short-term profit. By questioning these assumptions, society can challenge the notion that economic growth should always take precedence over environmental sustainability and societal well-being.

2. Externalities and Systemic Issues: Many traditional economic assumptions fail to adequately account for externalities and socialize the rewards resulting from the socialized risks of research and innovation benefiting subventions that are rarely internalized by the market. These externalities include environmental degradation, social inequalities, disruptive innovations, and the depletion of natural resources, among others. By questioning previous economic assumptions, society can seek to address these systemic issues and develop economic models.
3. Alternative Metrics of Success: Conventional economic assumptions often prioritize GDP growth as the primary indicator of success, neglecting other important dimensions of well-being such as social equity, health, and environmental quality. By questioning these assumptions, society can explore alternative metrics of success that incorporate a broader range of factors, including measures of social progress, ecological footprint, and the well-being of future generations.
4. Collaborative and Participatory Decision-making: Society can foster more inclusive and participatory processes by questioning mainstream top-down decision-making methods. Holistic and participatory processes encourage the engagement of diverse stakeholders, including communities, civil society organizations, and marginalized groups, in shaping economic policies and strategies. This ensures that a wider range of perspectives and values are taken into account, leading to more equitable and sustainable outcomes.

Overall, questioning the validity of previous economic assumptions is essential for rethinking and turning into a Circular society that uses Industry 5.0 paradigms to tackle the current social and environmental crisis through human-centered decisions to fulfill fundamental human needs. Circular society aims to pave the way for more sustainable and inclusive economic models that prioritize the well-being of people and the planet.

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Manuel Morales is a Project Researcher with the IN4ACT project at Kauno Technologijos Universitetas (KTU) School of Economics and Business. He is also appointed as an Associate Professor at ESC Clermont Business School, at Auvergne-Rhône-Alpes, France.

Susu Nousala is a Project Researcher with the IN4ACT project at Kauno Technologijos Universitetas (KTU) School of Economics and Business. She is Founder and Research Director of the Creative Systemic Research Platform (CSRP) Institute centered in Ticino, Switzerland.

Morteza Ghobakhloo is a Project Researcher with the IN4ACT project at Kauno Technologijos Universitetas (KTU) School of Economics and Business. He is also appointed as an Associate Professors in the Department of Civil and Industrial Engineering at Uppsala University, Sweden.