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REVIEW ARTICLE

Exploring the transition from techno centric industry 4.0 towards value centric industry 5.0: a systematic literature review

Etieno Enang [a], Mahdi Bashiri [b] and David Jarvis [b]

[a]Strategy, International Business and Entrepreneurship Subject Group, University of Liverpool Management School, Liverpool, UK; [b]Centre for Business in Society, Coventry University, Coventry, UK

ABSTRACT
This systematic literature review synthesises the literature on human centric IN 4.0 and IN 5.0 while exploring driving forces behind the transition from technocentric IN 4.0 to value centric IN 5.0 using the principles of the multiple level perspective (MLP). Works that discuss contextual, regime and niche level factors which impact on the transition were explored. The Covid- 19 pandemic and Climate change are identified as key contextual, 'Landscape', factors impacting the transition while Trust, Mass personalisation and Autonomy are highlighted as key Regime factors. In terms of Niche innovations, Advanced Extended reality technologies, Cobots/ Advanced Robotics, and Advanced AI are often connected with landscape or regime issues. Drawing on MLP theory, the study demonstrates that the transition from IN 4.0 towards IN 5.0 is occurring through a reconfiguration pattern. The paper further emphasises aspects that both practitioners and academics need to be cognisant of in order to affect a transition from IN 4.0 to IN 5.0.

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Human centric IN 4.0; value centric IN 5.0; MLP transition theory; contextual factors; emerging technologies

1. Introduction

IN 4.0, or the fourth industrial revolution, is considered a technology-driven (or technocentric) and high-tech strategy (Demir, Döven, and Sezen 2019; Müller 2020; Xu et al. 2021) that employs emerging technologies such as cyber physical systems (CPS), Artificial Intelligence, Big Data analytics and the Internet of Things (IoT) to create *Smart factories* with extreme automation (Ozdemir and Hekim 2018) and minimum human intervention (Demir, Döven, and Sezen 2019). However, IN 4.0 has recently come under attack by critiques who argue that extreme automation where 'everything is connected to everything else' creates vulnerabilities and systemic risks (Ozdemir and Hekim 2018). Critiques also argue that the centring of IN 4.0 around technology driven productivity aligns with maligned neoliberal models of capitalism that emphasise profitability and shareholder primacy (Ghobakhloo et al. 2022; Müller 2020; Neumann et al. 2021; Sgarbossa et al. 2020; Sindhwani et al. 2022), at the expense of other socio-environmental concerns such as regional inequality and environmental degradation (Renda et al. 2022). This has given rise to proposals for a shift towards a new paradigm that safely harnesses the potential of IN 4.0 (Ozdemir and Hekim 2018) but which also places emphasis not just on profit maximisation but also on humans, society and the environment (Breque, Nul, and Petridis 2021; Ghobakhloo et al. 2022; Müller 2020; Renda et al. 2022).

More recently, the concept of IN 5.0 has emerged as such a value centric paradigm and a means of refocusing IN 4.0 principles, creating a notion of industry that looks beyond economic or shareholder profit towards becoming a resilient provider of prosperity, respecting both environmental limits to growth and the wellbeing of industry workers (Fraga-Lamas, Varela-Barbeito, and Fernández-Caramés 2021; Gladden 2019; Nahavandi 2019). In this way, IN 5.0 is expected to complement and extend the hallmark features of IN 4.0 (Müller 2020); to support a better fit and 'win-win' interaction between industry and society, thereby shifting the focus from shareholder to stakeholder value (Breque, Nul, and Petridis 2021; Müller 2020). IN 5.0 is linked to 'society 5.0′ which was first presented by the Japanese government in 2016 (Huang et al. 2022). Both concepts propose a fundamental shift towards a new paradigm that aims to balance economic development with the resolution of societal and environmental problems (Huang et al. 2022; Maddikunta et al. 2022). For an in depth comparison of the two concepts, see Huang et al. (2022).

As such, although businesses have only just begun to embrace the fourth industrial revolution, the fifth industrial revolution is now happening simultaneously

CONTACT Mahdi Bashiri mahdi.bashiri@coventry.ac.uk Centre for Business in Society, Coventry University, CV1 5FB, Coventry, UK

(Xu et al. 2021). The disruptive impact of technological revolutions was initially captured by the concept of technological waves (Kondratieff and Stolper 1935), which suggests that radical innovations emerge over time driven by scientific discoveries, and that they cumulate and trigger technological change only when old technologies exhaust their potential (De Propris and Bailey 2021). However, this understanding is at odds with what is currently being experienced by the advent of IN 4.0 and IN 5.0, which seem to be occurring in tandem. There is wide agreement among researchers that there are overlaps between technological innovations in both IN 4.0 and 5.0 (Maddikunta et al. 2022). However, there is insufficient understanding of how and why there is a change from one revolution to another when existing IN 4.0 technologies have not exhausted their potential.

In short, there is a lack of understanding about how extant studies explain the broader contextual developments that influence the transition from IN 4.0 towards IN 5.0, and whether or how the new innovations or emerging technologies have shaped the transition. Additionally, although related concepts such as human centric IN 4.0, operator 4.0 seem to overlap with some key ideas of IN 5.0 in previous studies, to date no attempt has been made to synthesise the different streams of literature to provide a holistic account of the transition from IN 4.0 towards IN 5.0.

To address these gap(s), this study examines and critiques existing studies to identify themes, patterns, relationships and gaps in understanding of the transition from technocentric IN 4.0 and value centric IN 5.0. The contribution of this paper is two-fold: First, through a systematic review, we synthesise the literature on human centric IN4.0 and IN 5.0 to understand differences and overlaps between the two streams of research. Second, we examine the driving forces behind the transition from a technocentric towards a value centric regime by exploring exogenous factors and technological developments that have contributed to changes in policy, stakeholder expectations and stakeholder perceptions.

Despite being relatively new, the literature on human centric IN 4.0 is increasing rapidly. However, the literature results are fragmented and inconsistent on the issue especially regarding societal transformation (Grybauskas, Stefanini, and Ghobakhloo 2022). This situation is further exacerbated with the emerging concept of IN 5.0, where there are few relevant studies available for reference, especially in terms of high-quality journal papers (Leng et al. 2022). Although papers on human centric IN 4.0 and IN 5.0 seem to overlap in some areas, it is not entirely clear how exactly these concepts differ from one another or how IN 4.0 and IN 5.0 research and revolutions seem to be occurring simultaneously. Therefore, the objective of this paper is to provide researchers, policy makers and practitioners with a holistic overview of the state of research on the factors influencing the transition from technocentric IN 4.0 towards value centric IN 5.0. To accomplish these objectives, the paper will answer the following questions according to previous literature:

(1) What are the human and societal challenges in the era of IN 4.0 and what are the technological innovations within human centric IN 4.0 and IN 5.0 to address them?
(2) What are the policy and stakeholder perceptions or preferences that influence the transition?
(3) How do broader contextual developments influence the transition from technocentric IN 4.0 towards value centric IN 5.0?

The remainder of this paper is organised as follows. Section 2 provides a brief overview of transition theories, highlighting the usefulness of the multilevel perspective (MLP) as a lens through which to address our research questions. The section also provides an overview of our initial scoping review, highlighting the identified gaps that led to our study. Section 3 introduces the methodology by setting out the systematic literature review method and the fundamental review principles. Sections 4 illustrates and discusses the obtained results from both the basic data analysis of included papers (providing a general overview of the topic) and the specific data analysis corresponding to each research sub-question. Section 5 discusses the key implications of transitioning from technocentric IN 4.0 to value centric IN 5.0 for practitioners. Section 6 concludes the paper by highlighting the issues that remain unaddressed in existing studies on human centric IN 4.0 and IN 5.0, posing directions for future research.

2. Theoretical framework

2.1. An overview of transition theories

Although we are at the beginning of the fifth industrial revolution, there is still insufficient uptake of previous revolutions (Agnusdei, Elia, and Gnoni 2021; Baroroh and Chu 2022). A number of theories have been used to explain how and why technological transitions occur as well as how to manage or promote them. The extant literature identifies the multilevel perspective (MLP), Strategic Niche Management (SNM), Transition Management (TM) and Technological Innovation Systems (TIS) as four main strands of theory that explain technological transitions (Lachman 2013; Panetti et al. 2018). The first three theories posit that transitions are the outcome of

Table 1. Identifying the appropriate transition theory for the study.

Transition theory	Main aim	Level of considera-tion	Underpinning theories and main focus	Development Hierarchy: Bottom up	Development Hierarchy: Top down	Popularity*	References	Complexity	Systemicity
Multilevel perspective (MLP)	Alignment between relevant levels	Macro, meso and micro	Evolutionary theory, science & technology studies (STS) focus on regime changes driven by bottom up & top down factors	√	√	5840	Geels (2004), Geels (2005); Geels and Schot (2007) Coenen, Benneworth, and Truffer (2012), Kern (2012) Di Lucia and Ericsson (2014)	High	Fairly low
SNM (Strategic Niche management)	Alignment between relevant levels	Macro, meso and micro	Evolutionary theory, focus on the niche, bottom up	√		2549	Schot, Hoogma, and Elzen (1994), Kemp, Schot, and Hoogma (1998), Seyfang and Haxeltine (2012), Berry, Davidson, and Saman (2013), Slayton and Spinardi (2016)	Low	High
Transition Management (TM)	Alignment between relevant levels	Macro, meso and micro	Long term transformation, inclusivity, involving multiple stakeholders, top down		√	2998	Rotmans, Kemp, and van Asselt (2001), Smith, Stirling, and Berkhout (2005), Loorbach (2010), Kueffer et al. (2012), Voß (2014), Bettini et al. (2015)	Very High	Very Low
Technological Innovation Systems (TIS)	Explores the interplay between actors within an institution	Micro	Explaining success or failure by seven key indicators, bottom up	√		3938	Jacobsson and Johnson (2000), Jacobsson and Lauber (2006), Hekkert et al. (2007), Bergek et al. (2008), Alkemade and Suurs (2012), Huttunen, Pirttilä, and Uusitalo (2013)	Very Low	Very High

*adapted from Panetti et al. (2018)

coevolution and alignment of processes at multiple levels whereas TIS focuses on the interplay between actors in a particular institutional infrastructure and the key functions that underpin the success or failure of technology.

2.1.1. Identifying the appropriate transition theory for the study

As seen in Table 1, MLP was identified as a useful framing device for the current research by comparing and contrasting the four prominent theories based on a number of factors including level of consideration, main focus, development hierarchy, popularity, complexity (diversity of concepts) and systemicity (Panetti et al. 2018). Human centric IN 4.0 and IN 5.0 research are very much in their early stages, and therefore there is limited data from actors or organisations that have implemented the technologies involved. Hence, it may be advantageous to use a theory which enables a holistic approach to allow for deeper exploration. Compared to other transition theories which consider either bottom up developments only, i.e. from micro to macro level or top down developments only, i.e. from macro to micro level, the MLP considers both bottom-up and top-down developments, which makes it more suitable for the current study.

Although the complexity of MLP is not high compared to the TM or other combined theories; it is identified as the most popular transition theory which other transition theories draw on (Lachman 2013; Panetti et al. 2018). Additionally, since the movement from IN 4.0 towards IN 5.0 involves socio-technical development that enables a paradigm shift, MLP is a suitable tool to analyse the transition because it is concerned with the long-term dynamics of shifts from one socio-technical system to another, and the co-evolution of technology and society (Geels 2004). Hence, MLP allows us to unpack key characteristics of the value centric regime as well as the broader contextual developments at a landscape level that have triggered instability within the technocentric regime and thus enabled a shift towards the value centric regime. Furthermore, it allows us to understand and explore technological innovations within IN 4.0 and IN 5.0 that are emerging in the era of the value centric regime. Below we explore the MLP theory in more depth.

2.1.2. Theoretical framework- A MLP explanation of the transition from technocentric IN 4.0 towards value centric IN 5.0

The MLP is arguably the most prominent of the transition frameworks (El Bilali 2019). The MLP literature posits that technological transitions occur as a result interactions between three nested levels within socio-technical systems: Socio-technical landscape (macro level), socio-technical regime (at meso level) and technological niche (at the micro level). These form a nested hierarchy with niches embedded within regimes, which are in turn embedded in the landscape (Geels 2002; Geels 2005;

Geels and Schot 2007). There is no single cause or driver of change at work (Geels 2011), but rather, there is 'circular causality' in which processes at different levels interact with each other (De Propris and Bailey 2021).

Niche level

Niches, occur at the micro level and are the space where actors experiment with radical innovations that have the potential to challenge or break into the prevailing regime. In this way, niches can be thought of as locations where it is possible to deviate from the rules in the existing regime (Geels et al. 2017). Applying this idea to the transition from IN 4.0 and IN 5.0 is useful because it helps to describe the potential for the impact of emerging technologies that might transform business and society in a number of ways (Mourtzis, Angelopoulos, and Panopoulos 2022; Xu, Xu, and Li 2018). For example, by redesigning the organisation of production inside firms, emerging technologies may impact on employment (De Propris and Bailey 2021). They could also impact on value chains both in terms of value creation functions and geographical presence; introduce new value creation parameters in firms' business models; create new sectors and markets; and usher in new demand and consumer expectations (De Propris and Bailey 2021). Moreover, it can be said that through value co-creation processes, new insights and ideas are exchanged between firms and society in new and more rapid ways, creating a virtuous circle between innovation in firms and better conditions of life in society, where the real engine of this virtuous mechanism are the individuals supported by the enabling technologies of IN 4.0 (Aquilani et al. 2020).

Regime level

The regime level, which is the core level, can be defined as a set of historically established and institutionalised rules and beliefs that guide thoughts and behaviours of actors in a certain societal system (Geels 2002). The socio-technical regime refers to the incumbent socio technical system including the network of actors and groups, and informal and formal rules that maintain the dominant system as well as its technical and material elements (Geels 2002). These informal and formal rules include cognitive, normative, and regulative rules that inform user expectations, orient perceptions of the future and steer actions in the present. For example, if actors expect that problems can be solved within the paradigm of IN 4.0, they will not invest in radical innovations or improvements that lead to IN 5.0, and as long as firms believe that they meet their user preferences well, they will continue to produce same products (c.f. Geels 2004). Similarly, social and organisational networks are stabilised by mutual role perceptions of proper behaviour, such as technical standards, or rules for government subsidies which favour existing technologies (Geels and Schot 2007).

Landscape level

The landscape is the macro level and consists of slow changing socio-technical structures that exist in the wider or exogenous environment where transitions occur (e.g. material, environmental and economic conditions, the broader Socio-Cultural context, and political imperatives and actions), which are beyond the influence of individual human actors (Geels 2002; 2004; 2006; 2018). The literature on the MLP posits that the socio-technical landscape has two main functions in sustainability transition processes. One, exerting pressure on dominant regimes to change, and two, creating windows of opportunity for new technologies to emerge at the niche level (El Bilali 2019; Geels 2002). The intensity of landscape pressure on the incumbent regime can be low (regular change), moderate (disruptive change), high (specific shock) or very high (avalanche) (Kanger 2021).

2.1.3. Summary of related previous review papers

During our initial scoping review, we discovered a total of 38 related review/survey papers published between 2019 and 2022 that we categorised into two broad groups. The first group focused on human centric or human centred IN 4.0 without discussing IN 5.0. The second group focused mainly on IN 5.0 or the transition from IN 4.0 to IN 5.0. These studies provide some useful insights into technological innovations (niche), contextual factors (landscape) and stakeholder practices or perceptions that shape human centric IN 4.0 or IN 5.0 (regime). However, the findings are somewhat fragmented across different studies (See Table 2).

Among the review/survey papers discussing human centric IN 4.0, we identified four camps of studies. The first explore how research practices are shaping IN 4.0 or user attitudes and perception towards IN 4.0 technologies, associated challenges or user perceptions, and how IN 4.0 technologies are changing the role and performance of operators or the future of work (e.g. Boada, Maestre, and Genís 2021; Cotrino, Sebastian, and Gonzalez-Gaya 2020; Di Pasquale et al. 2021; Kadir, Broberg, and Conceição 2019; Mukhuty, Upadhyay, and Rothwell 2022). The second camp of studies under this group explore technological advancements within IN4.0 that provide human and societal advantages (Agnusdei, Elia, and Gnoni 2021; Baroroh and Chu 2022; Glock et al. 2021; Mark, Rauch, and Matt 2021; Miqueo, Torralba, and Yagüe-Fabra 2020; Nikitas et al. 2020; Zheng et al. 2021). A third camps explores stakeholder expectations or perceptions or policy and regulations involving IN 4.0 as well as technological advancements that can

Table 2. Summary and gaps of previous reviews and key contribution of current study.

AUTHOR NAME	YEAR	Industry 4.0	Industry 5.0	Industry Both	LANDSCAPE	REGIME	NICHE	CONCEPT DEVELOPMENT
Can, Arnrich, and Ersoy	2019	√			√		√	
Kadir et al.	2019	√				√		
Aquilani	2020			√			√	
Machado et al.	2021	√				√		
Nikitas et al.	2020	√					√	
Rauch et al.	2020	√				√		
Shahbakhsh, Emad, and Cahoon	2022			√		√		
Winkelhause and Grosse	2020	√				√	√	
Agnusdei	2021	√					√	
Aquilani et al.	2020			√			√	
Baroroh, Chu, and Wang	2021	√					√	
Bavaresco	2021	√				√	√	
Bittencourt	2021					√	√	
Boada et al.	2021	√				√		
Di Pasquale et al.	2021	√				√		
Glock et al.	2021	√					√	
Gualtieri, Rauch, and Vidoni	2021	√				√		
Mark et al.	2021	√					√	
Miqueo, Torralba, and Yagüe-Fabra	2020	√					√	
Miqueo, Torralba, and Yagüe-Fabra	2020			√		√		
Mylonas et al.	2021			√			√	
Reiman et al.	2021	√				√		
Sgarbossa et al.	2020	√				√		
Vijaykumar et al.	2022	√		√				
Brunetti et al.	2022			√			√	
Coronado et al.	2022			√		√		
Fatima et al.	2022			√			√	
Grabowska et al.	2022			√				√
Grybauskas et al.	2022			√		√		
Ivanov	2022			√				√
Kumar & Lee	2022	√				√		
Leng et al.	2022		√					√
Madhavan et al.	2022			√	√			
Mourtzis et al.	2022			√	√	√	√	
Mukhuty et al.	2022	√				√		
Nguyen et al.	2022	√				√		
Zizic et al.	2022			√	√			
Zheng et al.	2022	√					√	
Current research	20xx			√	√	√	√	√

help to realise these (Bavaresco et al. 2021; Bittencourt, Alves, and Leão 2021; Nikitas et al. 2020; Winkelhaus and Grosse 2020). Finally, the fourth camp discusses factors, or societal drivers, that pave the way for IN 4.0 technologies. For example, Can, Arnrich, and Ersoy (2019) identify stress as the second most severe work-related contextual factor that affects Europe and USA, and explore how work-related stress can be mitigated through smartphones and wearable sensors.

Among the review/survey papers discussing IN 5.0, we also identified four camps of studies. The first explore human or social implications of IN 4.0 technologies from individual or regional levels (Coronado et al. 2022; Grybauskas et al. 2022; Kumar and Lee 2022; Shahbakhsh, Emad, and Cahoon 2022) and how these create a need for IN 5.0 technologies. The second camp links the concepts of IN 4.0 and 5.0 by exploring challenges and opportunities associated with the application of certain IN 4.0 technologies such as IoT (Fatima et al. 2022), Digital Twins (Mylonas et al. 2021) or AI (Brunetti, Gena, and Vernero 2022) in the era of IN 5.0 or society 5. The third camp discuss contextual factors that act as drivers for the transition from IN 4.0 towards IN 5.0 (Madhavan et al. 2022). Finally, a fourth camp have sought to develop the concept of IN 5.0. For example, citing a lack of understanding of IN 5.0, due to the infancy of the concept, the key features of resilience, human centricity and sustainability have been applied to define and propose architectures for IN 5.0 implementation drawing on multiple perspectives (Leng et al. 2022) and from the perspective of specific domains, such as operations and supply chain management (Ivanov 2022). Similarly, Grabowska, Saniuk, and Gajdzik (2022) attempt to link IN 4.0 and IN 5.0 by studying areas related to humanisation and sustainability in the IN4.0 literature. Their study highlights that humanisation of the built technological environment for IN 4.0 and the role of operators was one of the first factors in the evolution of IN 4.0 towards IN 5.0.

We identified only two papers under the fourth camp (Mourtzis, Angelopoulos, and Panopoulos 2022; Zizic, Mladineo, Gjeldum, and Celent 2022) that explore the transition from IN 4.0 towards IN 5.0 by discussing stakeholder perceptions/expectations, contextual factors and technological innovations. However, Mourtzis, Angelopoulos, and Panopoulos's (2022) is not focused on providing a holistic understanding of the transition from IN 4.0 towards IN 5.0 by exploring multiple levels. Moreover, Zizic et al's (2022) study relied mainly on keywords analysis leaving open a scope for more in-depth exploration of the subject. These gaps and inconsistencies highlight again the value of a systematic review of the literature on human centric IN 4.0 and IN 5.0 in order better understand how and why the transition is occurring.

2.1.4. Explaining the interaction across MLP levels

Since MLP theory assumes that there is no single cause or driver of change, it is important to identify how the different levels interact with one another to enact different types of change. Geels and Schot (2007) identified five patterns that define sustainability transitions. The *reproduction pattern* leads to incremental change and occurs when there are no landscape pressures, hence the regime remains stable and reproduces itself. The *transformation pattern* occurs when there is moderate landscape pressure and underdeveloped niches, causing the regimes to react by modifying the direction of development paths and innovation activities. The *dealignment and realignment pattern* occurs when there are large, sudden, and divergent landscape changes that increase regime problems leading to regime destabilisation and de-alignment. If niches are not well developed, there will be competition of emerging niches leading to one niche becoming dominant and forming the core for the re-aligning of a new regime. The *technological substitution pattern* occurs when there is significant landscape pressure and sufficiently developed niches which lead to the dethroning of the current regime by niches. Lastly, the *reconfiguration pattern* occurs when symbiotic innovations developed in niches are used in the regime to solve local problems, resulting in further adjustments in the basic structure of the regime. In this study, we will assess existing literature against the three MLP levels to identify the pattern that defines the transition from technocentric IN 4.0 towards value centric IN 5.0.

3. Research methodology

3.1. SLR principles and methods

Following the MLP theory outlined in the earlier section, (Geels 2002; 2004; 2005; 2006; 2007; 2011; 2018), papers were reviewed according to the relevant MLP layers. For example, papers are categorised as *niche level* studies if they discussed technologies or technological improvements intended to resolve economic, social or environmental challenges. Papers are categorised as *regime level* studies if they explore policies and regulation, stakeholder perceptions and expectations around IN 4.0 or IN 5.0 technologies. Lastly, papers that discuss or explore exogenous environmental, Socio-Cultural and economic factors that may influence on IN 4.0 or IN 5.0 are categorised as *landscape level* studies. To ensure that all papers were assessed consistently, two fundamental review principles were defined:

- *Explicit inclusion and exclusion criteria*. The criteria for including or excluding papers were clearly outlined according to the MLP theoretical framework and covers all the layers including niche, regime and landscape. The papers that did not cover at least one of these three MLP layers were excluded. As can be seen in Figure 1, six main inclusion and exclusion criteria, together with their subsets have been outlined.
- *Objective review process*. The collected papers were reviewed by two of the authors and the findings were then cross examined. In rare instances where two authors could not reach an agreement on any categorisation, the third author stepped in to make the final decision.

3.2. Systematic literature review method

In order to provide a neutral basis for data collection and analysis (Tranfield, Denyer, and Smart 2003) this study applies the systematic literature review method using a mixed-methods approach, following the structure outlined in the Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) Statement (Moher et al. 2009). The PRISMA flow chart that reports the different phases of this systematic literature review is shown in Figure 2.

3.2.1. Paper collection

Drawing on the MLP theoretical framework, the search string was constructed through the combination of the operators 'or' or 'and' in between two or more of the following terms in order to obtain a comprehensive set of papers as indicated as follows:

MLP Categories	Relevant Keywords
Niche Innovation	'the fourth industrial revolution', 'IN 4.0∗', 'Operator 4∗', 'Operator 5∗ 'society 5.0'
Regime	'human factors', 'human centred∗'
Landscape	'reason', 'trigger', 'driver', 'condition
General	'emergence', 'transition'

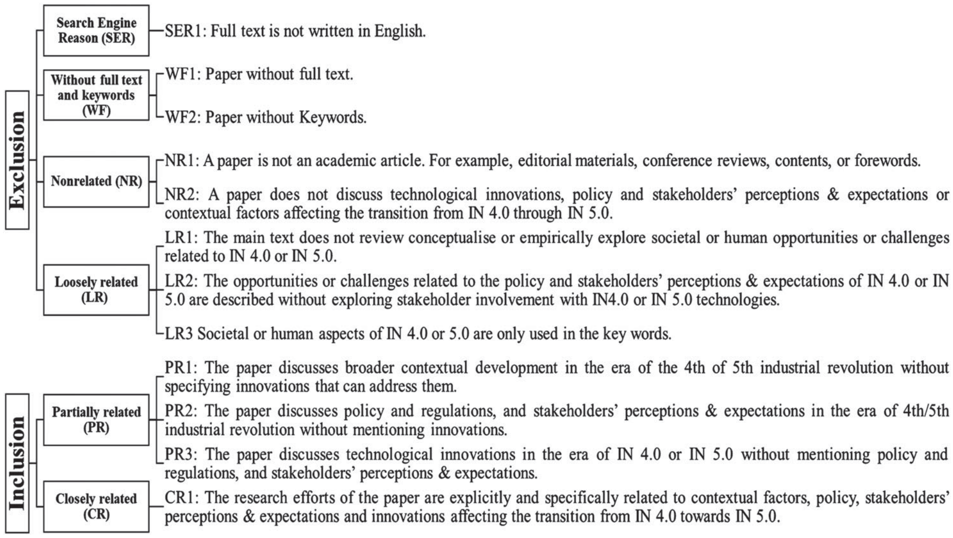

Figure 1. Inclusion and Exclusion Criteria and their explanations.

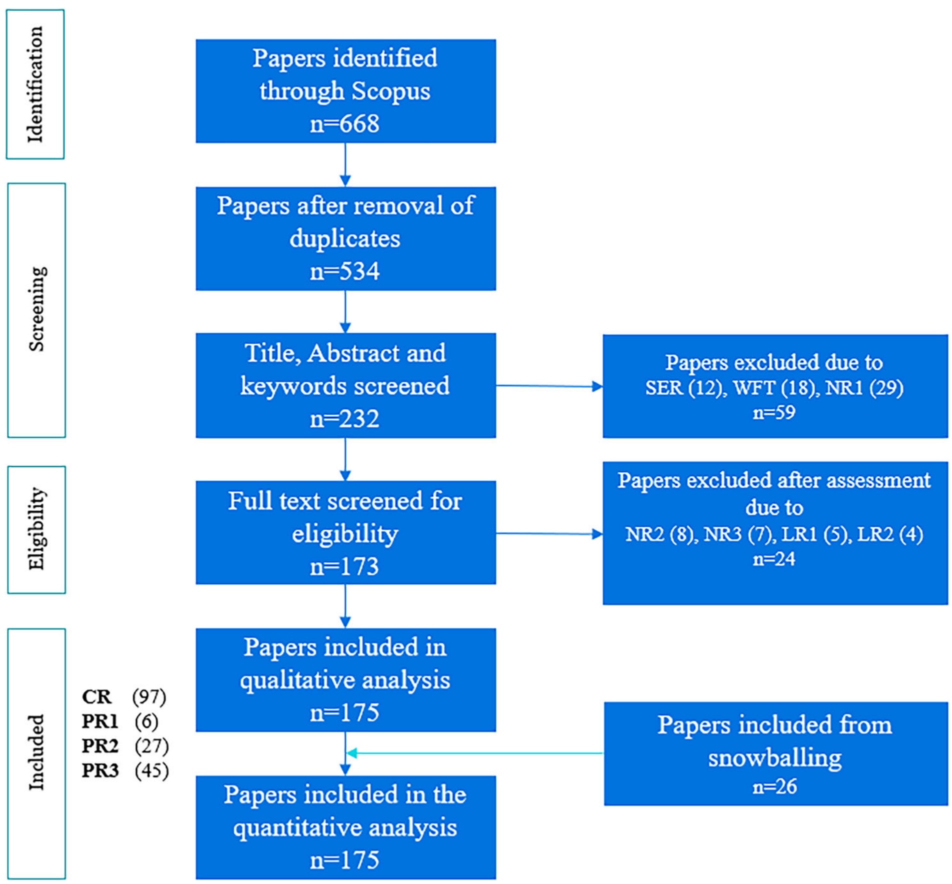

Figure 2. The PRISMA flow chart that reports the different phases of the systematic literature review (SLR).

The systematic search used an electronic database, namely SCOPUS, to collect academic research papers that: (1) were published from 2011 onwards; (2) contained at least one of the identified keywords in either the abstract, title and keywords; (3) were published in journals or conference proceedings; and (4) were written in the English language. Scopus was selected because it covers a high number of peer reviewed journals from a large variety of publishers. Moreover, it has been used successfully by other recent and related SLR papers, for example Liao et al. (2017). After removing duplicates, the first screening process was carried out to exclude for papers where: (1) only titles, abstracts, and keywords were in English (SER); (2) there was no access to their full texts (WFT); or (3) the papers were not academic articles (NR1). All the papers that passed the initial screening process were reviewed by reading their titles, abstracts or, if more information was required to determine inclusion, then the full texts were reviewed. The second screening process was employed to exclude papers that (1) did not discuss any of the three Multi Level Perspectives factors (NR2); or (2) do not focus on human or societal challenges or opportunities associated with IN 4.0 or 5.0 technologies (LR1—LR3). Finally, all eligible papers were studied in detail and classified into the established inclusion criteria sub-categories (PR1-PR3 and CR1).

3.2.2. Data collection

Information within the literature that fit the scope of this review were extracted into a data table. Two of the authors were involved in data extraction. Both authors subsequently cross-checked a random selection of papers to ensure consistency and validity of the data based on the above data extraction framework. For each included paper, two types of information were collated.

First, basic data about the paper, which included source-based criteria (e.g. journal or conference papers, paper authors, year of publication and numbers of citations of each paper). Additionally, the papers were grouped under the following three types:

- Conceptual/Theoretical paper: These are papers that propose conceptual or theoretical solutions without any field or experimental data or industrial applications.
- Discussion paper: these are papers that discuss challenges or opportunities without a comprehensive solution
- Practical paper: the practical papers were further divided into four sub-categories
- Qualitative: These are papers that propose solutions based on qualitative analysis of field or industry data
- Quantitative: These are papers that propose solutions based on quantitative analysis of field or industry data
- Experimental: These are papers that propose solutions based on prototype or experimental studies
- Mixed: These papers propose solutions based on both qualitative and quantitative data analysis

Second, data related to each of the three research subquestions, as follows:

- For the first research question, references within the paper that contain any technological innovations in the era of human centric IN 4.0 e.g. AI, Robotics, Digital Twins, Blockchain, IoT.
- For the second research question, references within the paper that refer to Stakeholder perception, Stakeholder preferences, or Policy/Regulation as drivers for human centric IN 4.0 or IN 5.0.
- For the third research question, references within the paper that refer to external factors -that are beyond the direct influence of actors and cannot be changed at will e.g. Environmental, or broad social cultural factors -as drivers for human centric IN 4.0 or IN 5.0.

3.2.3. Data analysis

Collected data were subjected to both qualitative and quantitative analysis. The qualitative analysis involved thematic and content synthesis through three-stages – line-by-line coding, formulation of descriptive themes and development of analytical themes (Thomas and Harden 2008). Major themes were first derived through a line-by-line reading of all relevant narratives on all three levels of the MLP related to the transition from the fourth to the fifth industrial revolution. Thereafter, analytical themes were formulated from a direct interpretation of the narratives and categorised as either focused on landscape, regime or niche levels. Quantitative analysis involved graphical representation of collected data to illustrate key characteristics and relationships between analytical themes that appeared in the included papers.

4. Characterisation of current research on the transition from technocentric IN 4.0 towards value centric IN 5.0

Based on the six inclusion and exclusion criteria defined in Figure 1 and the PRISMA diagram shown in Figure 2, a total of 175 papers were included in the qualitative and quantitative analysis. This section provides an overview of the included papers and subsequently responds to the research questions for this study.

4.1. Basic data analysis: overview of included papers

118 papers out of the 175 included papers focused on human centric IN 4.0 without mentioning IN 5.0. 56 of the papers discussed IN 5.0 or society 5.0 either alongside IN 4.0 or exclusively. Our analysis shows a rise in a concern for human factors related to IN 4.0 over time. Similarly, we found a persistent increase and rise in interest in IN 5.0 between 2016 and 2022. Next a more detailed investigation was carried out to analyse 1) the included journal conference papers (section 4.1.1), papers with the highest number of citations

(section 4.1.2), content-based characteristics of papers (4.1.3), and keyword analysis of papers (4.1.4).

4.1.1. Analysis of journal and conference papers

The selected papers were categorised with respect to the original sources of the papers. Procedia and IFAC papers were classified as conference papers even though they are classified as journals in some electronic databases. 68% of the included papers, 118 papers, are journal papers, of which 75 were IN 4.0 papers and 43 were IN 5.0 papers. 29% of the included papers, 51 papers, are conference papers, of which 42 were IN 4.0, 9 were IN 5.0 papers. 3% of the included papers were white papers, i.e. four papers, of which one was IN 4.0 and four were IN 5.0 (see Appendix A). White papers were included because they provide useful insights into policies, practices and contextual factors that inform the industrial revolutions.

In terms of journal and conference sources, Computers & Industrial Engineering, the Journal of Manufacturing Systems, and the International Journal of Production Research journals respectively recorded the highest number of publications on MLP factors related to human centric IN 4.0. Sustainability, the Journal of Manufacturing Systems and Applied sciences journals recorded the highest number of publications that discussed MLP factors related to IN 5.0. From 2015 onwards, there has been a steady increase in the number of journal papers that discuss MLP factors pertaining to human centric IN 4.0 and IN 5.0. For the conference papers, there was a parallel rise from 2015 through to 2021, but a decline is apparent for 2022 (see Appendix B).

4.1.2. Analysis of highly cited papers

Table 3 shows the top five papers with the highest number of citations among the included papers for human centric IN 4.0 and IN 5.0. Highly cited papers are useful because they help to indicate impact and influence of key ideas. The most highly cited paper under IN 4.0 (522 citations) was Ivanov and Dolgui (2021), which proposes the digital supply chain twin as useful for supply chain risk management in the wake of Covid-19. This highlights that contextual factors can play a key role in driving technological innovations. This is followed closely by Romero et al's (2016) conceptual paper which first introduced the concept of Operator 4.0 (509 citations). This suggests that Operator 4.0 is an impactful concept amongst studies that focus on human centric aspects of IN 4.0. The most highly cited paper (409 citations) for IN 5.0 was Nahavandi (2019), that introduced IN 5.0 as a human centric solution. This may explain why human centric aspects have generated the most amount of interest on IN 5.0 studies.

Table 3. Top five highly cited human centric IN 4.0 and IN 5.0 papers.

IN 4.0 Papers			IN 5.0 Papers		
AUTHORS	YEAR	CITATIONS	AUTHORS	YEAR	CITATIONS
Ivanov & Dolgui	2021	522	Nahavandi	2019	409
Romero et al	2016	509	Ozdemir & Hekim	2018	308
Longo et al	2017	439	Demir et al	2019	269
Shneiderman	2020	315	Maddikunta et al	2022	205
Stahl & Coeckelberg	2016	219	Xu et al	2021	196

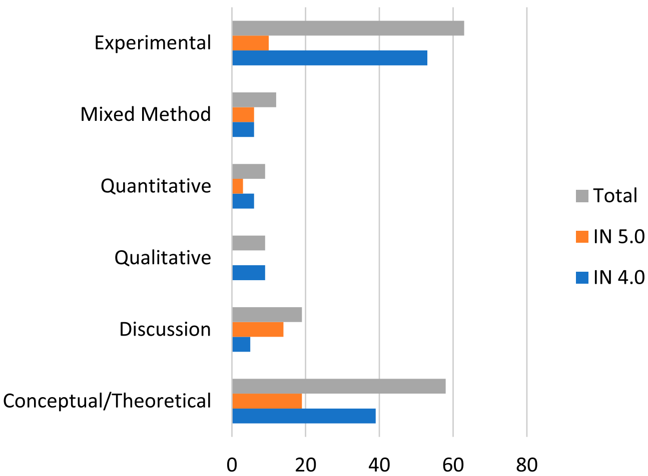

Figure 3. A graphical illustration for methodologies used in included papers.

4.1.3. Analysis of content-based categories of included papers

According to the content-based categories in Figure 3, 19 (11%) are discussion papers, 58 (35%) are conceptual/theoretical papers, nine (5%) are quantitative, nine (5%) are qualitative, 63 (37%) are experimental, and 12 (7%) are mixed methods papers. The limited number of qualitative studies and mixed methods studies compared to experimental and quantitative studies points to the novelty and newness of IN 5.0 and highlights the need for more research in the area.

Empirical papers were further examined using the criteria of high-quality journal (with impact factor of 3 and above) and clear findings or methodology. On this basis, 39 human centric IN 4.0 papers and six IN 5.0 papers were identified. For the human centric IN 4.0 papers, 28 were experimental studies, five were qualitative, three were quantitative and three used a combination of qualitative and quantitative methods. For the IN 5.0 papers, three were experimental, two were mixed and one was quantitative. An illustration of these empirical papers is summarised in Appendix C.

4.1.4. Keyword analysis of papers

To understand the differences and overlaps between the streams of research on human centric IN4.0 and IN

5.0, a key word analysis was conducted. A total of 918 keywords were collected, of which 578 were collected from IN 4.0 papers and 340 were collected from IN 5.0 papers. The 918 collected keywords were firstly examined and grouped into corresponding economic, environmental, social and technological clusters. The top cluster for human centred IN 4.0 papers was social (45%), followed by technology (37%) and economic (48), there were no keywords under environmental. On the other hand, the top cluster for IN 5.0 papers was social (37%) followed by technology (36%), environmental (14%) and economic (13%). This analysis indicates that scholars who publish on human factors of IN4.0 focus more on social and economic aspects with very little emphasis on environmental sustainability. This is probably because environmental aspects are largely absent from the concept of IN 4.0 and part of what IN 5.0 is attempting to address. Interestingly, scholars who publish under the IN 5.0 theme also mention IN 4.0 as key words and, significantly, IN 5.0 papers tend to focus on a wider range of factors including social and environmental as well as economic aspects. However, both streams of research place almost equal emphasis on technologies which indicates that the emerging/disruptive technologies are believed to be largely responsible for the fourth and fifth industrial revolutions. Figures 4 and 5 below, provide visual representations of key words that appeared most frequently within human centric IN 4.0 and IN 5.0 papers.

4.2. Data analysis with specific purposes: three research questions

The data analysis for the three questions include both qualitative and quantitative analysis.

4.2.1. Impact of technological innovations (niche) on human and societal challenges

Overall, 120 papers (97 human centric IN 4.0 and 23 IN 5.0) were identified that discussed seven categories of opportunities intended to resolve challenges related to either economic, social, or environmental sustainability using several enabling technologies as indicated in Appendix D1 and D2.

Economic sustainability

Efficiency without human replacement and Flexible production are two key themes that appear in the papers that discuss economic sustainability using IN 4.0 or IN 5.0.

Efficiency without human replacement

The most frequently discussed theme under economic sustainability among included papers is efficiency without human replacement. Between 2015 and 2022, this theme is mentioned every year which indicates its importance. Additionally, from 2020 a wider range of technologies have been associated with the theme. For the most part, the included human centric IN4.0 and IN 5.0 papers mention concepts such human cyber physical systems (HCPS) that enable the combination of both artificial

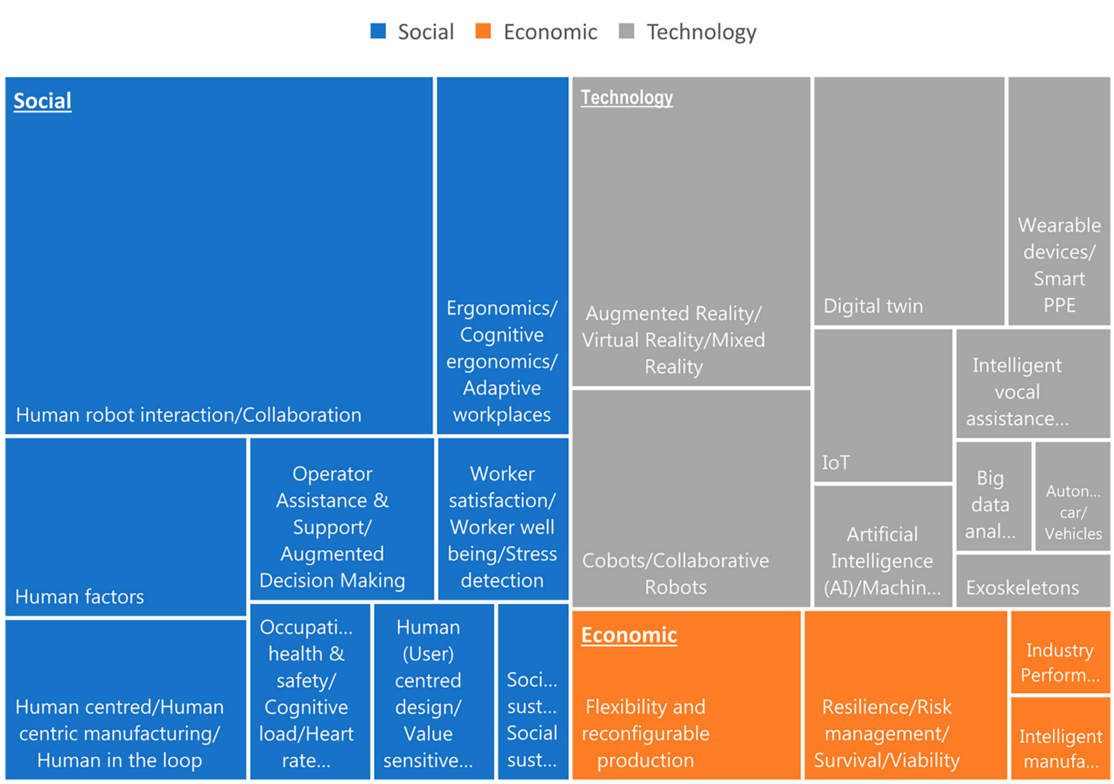

Figure 4. Cluster map for frequently appearing keywords in human centric IN 4.0 papers.

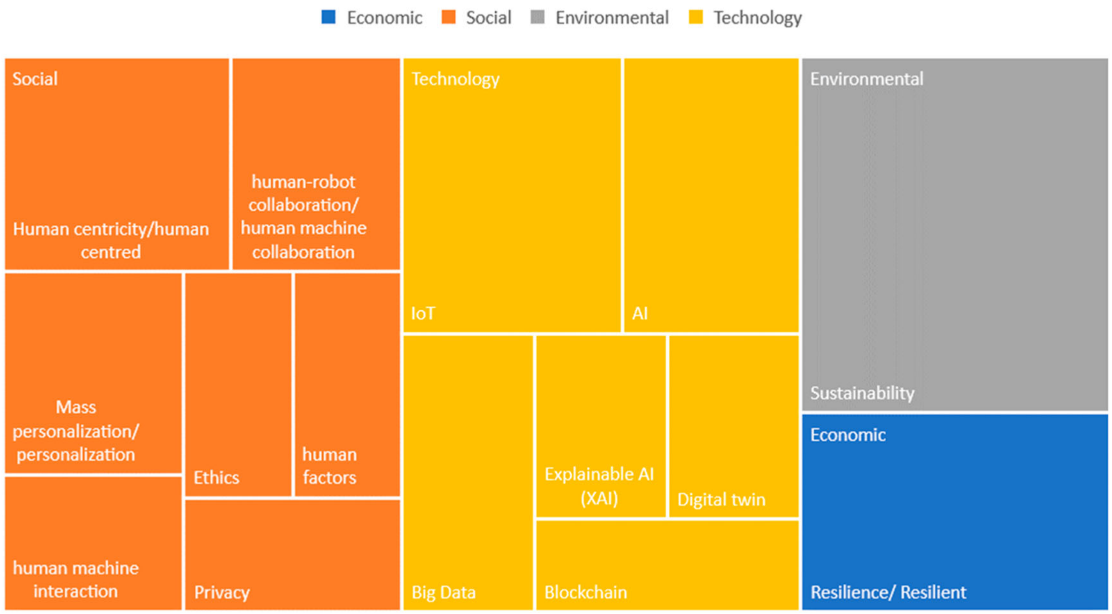

Figure 5. Cluster map for frequently appearing keywords in IN 5.0 papers.

and human intelligence, thereby retaining humans in the decision-making loop and empowering the human worker. In addition, a variety of technologies are mentioned that allow effective collaboration of humans and machines to improve efficiency in manufacturing factories of the future.

Flexible production/resilience

Overall, between 2015 and 2022, the theme of Flexible production/Resilience appears less frequently than the theme of efficiency without human replacement. However, from 2020 onwards, there has been more discussion around this theme, particularly in relation to technologies that enable resilience through the ability to adapt in the event of disruptions. This increase in attention may, in part, be attributable to the global disruption caused by the COVID-19 Pandemic.

Tables in Appendices D1 and D2 illustrate the names of authors, years of publication of papers that mention efficiency without human replacement and Flexible production/Resilience between 2015 and 2022, as well as the human centric IN 4.0 and IN5.0 technologies that enable them. For example, in Appendix D1, Ivanov and Dolgui (2019) discuss Digital Twins and Artificial intelligence as technologies related to Flexible production/Resilience.

Social sustainability

Physical support/safety, Cognitive & Perceptual support and Trust are three key themes that appear in the papers that discuss social sustainability using IN 4.0 or IN 5.0.

Cognitive & perceptual support

The most frequently discussed theme under Social sustainability among included papers is Cognitive & Perceptual support. This theme is mentioned each year between 2015 and 2022, indicating its importance. For the most part, papers which discuss Cognitive & Perceptual support, identify a number of technologies that can extend operators capabilities associated with learning, training, knowledge sharing, decision making and perception.

Physical support/ safety

Physical support/ safety is less frequently mentioned than Cognitive & Perceptual support but shows a similar trend. Again, between 2015 to 2022, this theme is mentioned every year. The included human centric IN 4.0 and IN 5.0 papers that discuss Physical support/safety identify several technologies that support workers with physical stress or repetitive tasks and physical ergonomic support, thus improving workers' safety and well-being through positive effects on their health, satisfaction, and performance.

Trust

Trust is the least discussed theme out of the three identified themes under social sustainability, though it appears more frequently from 2020 onwards. Included human centric IN 4.0 and IN 5.0 papers that discuss Trust focus on how to make the behaviour of machines more transparent or intelligible to humans; which makes them useful for resolving issues related to Trust and the lack of adoption of emerging technologies.

Tables in Appendices D1 and D2 illustrates the names of authors, year of publication that have been mentioned alongside Cognitive & Perceptual support, Physical support/safety, and Trust between 2015 and 2022, as well as the technologies that enable them for included papers on human centric IN 4.0 and IN 5.0 respectively. For example, in Appendix D1, Rožanec et al (2022a) discuss next generation Digital Twins as a technology that is related to Cognitive & Perceptual support.

Environmental sustainability

Environmental sustainability appears more frequently from 2019 onwards. Reduction in Wastage/Energy efficiency and reduction in pollution are two key themes that appear in the papers that discuss Environmental sustainability alongside human centric IN 4.0 or IN 5.0.

Reduction in wastage, energy efficiency

The most frequently mentioned theme under Environmental sustainability is Reduction in Wastage/Energy efficiency. Included human centric IN 4.0 papers and IN 5.0 that discuss this theme discuss protection of the planet through waste minimisation and optimisation of resources including relevant technologies.

Reduction in pollution

Human centric IN 4.0 and IN 5.0 papers that discuss Trust typically also mention technologies that are relevant for promoting greener and more environmentally sustainable environments by reducing pollution.

Tables in Appendices D1 and D2 illustrates the names of authors, year of publication that have been mentioned alongside Reduction in Wastage/Energy efficiency and reduction in pollution between 2015 and 2022 as well as the technologies that enable them for included papers on human centric IN 4.0 and IN 5.0 respectively. For example, as depicted in Appendix D1, in the study conducted by Machado et al. (2021), IoT and Cloud computing were discussed as technologies with an impact on Pollution reduction.

Table 4. Innovations and opportunities discussed in human centric IN 4.0 papers.

	Economical Sustainability		Social Sustainability			Environmental Sustainability	
	Efficiency without human replacement	Flexible production/Resilience	Physical support/safety	Cognitive & Perceptual support	Trust	Reduction in Wastage/Energy efficiency	Pollution reduction
Cobots/Advanced Robotics	**27**	9	22	26	0	0	0
Augmented Reality	17	4	14	**22**	0	1	0
Virtual Reality	11	4	11	**12**	0	0	0
Mixed Reality	**3**	2	2	**3**	0	0	0
Extended reality	2	0	1	**5**	0	0	0
Digital Twins	**9**	5	5	6	1	1	0
Actionable Cognitive Twins (Next generation Digital Twins)	0	0	0	**1**	0	0	0
Exoskeletons	5	3	**8**	7	0	0	0
IOT and sensor technologies	21	11	**26**	21	0	0	1
Explainable AI	2	0	0	0	**1**	0	0
Video camera	**4**	2	1	**4**	0	0	0
Additive Manufacturing	0	0	1	**2**	0	1	0
PPE	0	0	**2**	0	0	0	0
Machine Learning	**8**	4	7	**8**	0	0	0
CAD	**2**	**2**	**2**	0	0	0	0
Cloud computing	5	0	4	**6**	0	0	1
Big data analytics	6	1	**8**	7	0	0	0
Autonomous vehicles	**4**	2	3	2	0	0	0
Drones	**3**	1	**3**	**3**	0	0	0
Artificial Intelligence	**9**	3	6	**9**	1	0	0
Blockchain	**2**	1	**2**	**2**	0	1	0
Social collaborative platform	4	0	**5**	4	0	0	0
Intelligent Personal Assistant	3	0	1	**4**	0	0	0
5G	**1**	**1**	0	0	0	0	0

Overview of key enabling technologies for economic, social, and environmental sustainability

Table 4 indicates the number of times each technology was discussed alongside a particular opportunity in the same study among the included human centric IN 4.0 papers. The boldened values in the table highlight the technologies and challenges that appear more frequently together in the same paper. For example, analysis shows that Cobots/Advanced Robotics are most frequently discussed alongside Efficiency without human replacement (27 times), IoT & sensors technologies are most frequently discussed alongside Physical support/safety (26 times), and Augmented Reality is most frequently discussed alongside Cognitive & Perceptual support (22 times), respectively. This suggests that Cobots/ Advanced Robotics, AR and IoT may be useful for resolving issues pertaining to Economic sustainability (Efficiency without human replacement) and Social sustainability (Physical support/safety and Cognitive & Perceptual support). A brief definition of these technologies is provided in Appendix E1.

For the IN 5.0 papers, Cobots/Advanced Robotics and Advanced AI are most frequently discussed alongside Efficiency without human replacement (6 times each), Cobots/ Advanced Robotics is most frequently discussed along with Physical support (5 times), while Advanced Robotics, Advanced Blockchain and advanced AI are more frequently discussed alongside Waste reduction/Energy efficiency (4 times each), advanced AI is also discussed alongside Pollution reduction (see Table 5). This suggests that Cobots/Advanced Robotics, Advanced Blockchain and Advanced AI may resolve challenges pertaining to Economic efficiency (Efficiency without human replacement), Social sustainability (Physical support/safety), and Environmental sustainability (Waste reduction/Energy efficiency and Pollution reduction).

Table 5. Innovations and opportunities discussed in IN 5.0 papers.

	Economical sustainability		Social Sustainability			Environmental sustainability	
	Efficiency without human replacement	Flexible production/Resilience	Physical support/safety	Cognitive & Perceptual support	Trust	Reduction in Wastage/Energy efficiency	Pollution reduction
Cobot/Advanced Robotics	**6**	2	5	3	1	4	1
Advanced Blockchain	2	1	2	1	3	**4**	1
Advanced AI	**6**	3	0	3	3	4	4
Machine learning	**4**	3	0	2	1	3	3
Digital Twins	**1**	**1**	0	0	0	0	1
Human Digital Twins	**1**	0	0	0	0	0	0
Advanced/New generation IoT	**5**	2	0	1	2	2	3
6G	**1**	**1**	0	**1**	**1**	**1**	0
Advanced Extended reality	2	1	1	**3**	2	1	0

A brief definition of these technologies is provided in Appendix E2.

4.2.2. The role of policy/regulations, stakeholder perceptions and expectations (regime) in the from technocentric IN 4.0 towards value centric IN 5.0

Overall, 69 papers (34 IN 4.0 and 35 IN 5.0 papers) identified regime level factors linked to formal rules such as policies & regulation as well as informal 'norms' including stakeholder perceptions and expectations about emerging technologies.

Policy/regulations

Among the IN 4.0 papers, the convention on the rights of persons with disabilities (CRPD) (Mark et al. 2019) is discussed as a driver for the use of physical and cognitive assistance support technologies. Responsible research and innovation (Stahl and Coeckelbergh 2016) and corresponding initiatives such as value sensitive design is discussed as one of the drivers for designing AI for explainability and verifiability (Umbrello and Yampolskiy 2022).

Many IN 5.0 papers discussed policies such as United Nations sustainable developmental goals UN SDG (Althabhawi, Zainol, and Bagheri 2022; Amadasun et al. 2021; Ávila-Gutiérrez, Suarez-Fernandez de Miranda, and Aguayo-González 2022; Carayannis, Draper, and Bhaneja 2021; Ghobakhloo et al. 2022; Potocan, Mulej, and Nedelko 2021; Renda et al. 2022; Roring and How 2022; Sindhwani et al. 2022; Taj and Jhanjhi 2022). Others focus on occupational Health and Safety policy (Ávila-Gutiérrez, Suarez-Fernandez de Miranda, and Aguayo-González 2022) or regulations around responsible implementation science (Ozdemir and Hekim 2018) as key drivers for IN 5.0; on the basis that the technocentric and economic focus of the fourth revolution cannot support the achievement of sustainable development in ways that protect planetary boundaries, nor address deep social tensions.

Stakeholders perception

Stakeholders' perceptions relating to Technology readiness, Job security, Trust, Autonomy, Occupational well-being & Social connectedness, Health & Safety and Implementation cost were identified in the included human centric IN 4.0 and IN 5.0 papers.

Technology readiness

Lack of Technology readiness or 'insufficient know-how' amongst some workers was noted in relation to the use of technologies such as IoT (Lall, Torvatn, and Seim 2017), cobots or AR (Cimini et al. 2019; Fast-Berglund and Romero 2019; Kaasinen et al. 2020; Neumann et al. 2021). Moreover, a lack of buy-in from other key stakeholders is also discussed as a barrier towards the adoption of IN 4.0 technologies.

Job security

There is an implicit fear or understanding that unemployment will rise as the use of automation with IN 4.0 technologies increases (Adam, Aringer-Walch, and Bengler 2019; Berrah et al. 2021; Cimini et al. 2020). For example, improved robotic systems (Weiss et al. 2016) and the use of Drones (Cimini et al. 2020) have been associated with fear of job loss for manual and delivery workers. The societal desirability of enhanced job security is also discussed in IN 5.0 papers as a key factor that underpins human centricity and the non-replacement of humans in the fifth industrial revolution (Demir, Döven, and Sezen 2019; Huang et al. 2022; Longo, Nicoletti, and Padovano 2022; Renda et al. 2022).

Trust

Distrust of IN 4.0 technologies such as AI, ML, IoT and wearable sensors and Big data analytics, linked to privacy/ data security concerns of being monitored and controlled is discussed in human centric IN 4.0 papers (Bernal et al. 2017; Berrah et al. 2021; Cimini et al. 2020; Fletcher et al. 2020; Heikkilä, Honka, and Kaasinen 2018; Kaasinen et al. 2020; Rabelo, Romero, and Zambiasi 2018; Wanasinghe et al. 2021) and IN 5.0 papers (Althabhawi, Zainol, and Bagheri 2022; Demir, Döven, and Sezen 2019; Gladden 2019; Kaasinen et al. 2022; Longo, Padovano, and Umbrello 2020; Sachsenmeier 2016).

Autonomy

Several IN 4.0 papers (Berrah et al. 2021; Fletcher et al. 2020; Garcia et al. 2019; Gil et al. 2019; Heikkilä, Honka, and Kaasinen 2018; Kaasinen et al. 2020; Moencks et al. 2022b; Tancredi et al. 2020) and IN 5 papers (Carayannis, Draper, and Bhaneja 2021; Kaasinen et al. 2022; Longo, Padovano, and Umbrello 2020; Müller 2020; Nagy et al. 2022; Renda et al. 2022) identified existing concerns regarding human intervention in control systems (i.e. the human-in-the-loop) over fully automated logistics systems, as well as their involvement during the design and implementation of disruptive technologies.

Occupational wellbeing and Social Connectedness
Some human centric IN 4.0 papers discussed concerns related to Occupational wellbeing issues such as cognitive or perceptual overload which could lead to work related stress (Brunzini et al. 2021; Mattsson et al. 2020; Rojas, Wehrle, and Vidoni 2020) or concern about technologies leading to social problems at work (Kadir and Broberg 2021). Similarly, social concerns related to a collaborative work environment were discussed in IN 5.0 papers (Longo, Padovano, and Umbrello 2020; Lu et al. 2022; Nagy et al. 2022; Renda et al. 2022; Wahyuningtyas, Disastra, and Rismayani 2022).

Health & Safety
Health & Safety is identified as a key concern and one of the principal reasons for low adoption of Autonomous robots, vehicles or cobots in IN 4.0 papers (Berg et al. 2018; Faber, Bützler, and Schlick 2015; Fletcher et al. 2020; Longo, Padovano, and Umbrello 2020; Neumann et al. 2021; Shneiderman 2020; Tancredi et al. 2020; Zhang et al. 2022) as well as IN 5.0 papers (Longo, Padovano, and Umbrello 2020; Nagy et al. 2022)

Implementation Cost
A lack of financial resources or cost benefit and effectuation has been cited as one the greatest barriers to the adoption of IN 4.0 technologies (Cimini et al. 2020; Herceg et al. 2020; Moencks et al. 2022a; Wanasinghe et al. 2021) such as Cobots/Robots (Fast-Berglund and Romero 2019; Neumann et al. 2021), Exoskeletons (Longo, Padovano, and Umbrello 2020) and Blockchain (Choi et al. 2022).

Stakeholder expectations
Stakeholder expectations such as mass personalisation, access to open data and Dignity/Justice and Fairness were identified as key drivers for the transition towards IN 5.0.

Mass Customization/ Personalization
Consumers' demand for individualisation and personalisation is discussed in human centric IN 5.0 papers (Cimini et al. 2020; Martinez et al. 2021; Zhang et al. 2022). This shift in consumer emphasis from mass production in IN 4.0 towards mass personalisation in the IN 5.0 era is suggested as a key reason behind the fifth industrial revolution (Maddikunta et al. 2022; Paschek, Luminosu, and Ocakci 2022; Pathak et al. 2019; Sharma et al. 2022).

Data Accessibility
Open (government) data initiative as well as users' intent for open data are changing continuously. Recently, and in line with IoT and smart city trends, real-time data and sensor-generated data, which is accessible, meaningful and useful, is now an expectation of many stakeholders (Moencks et al. 2022a; Nikiforova 2021; Soltysik-Piorunkiewicz and Zdonek 2021; Taj and Jhanjhi 2022).

Dignity, Justice and Fairness
Some IN 4.0 papers (Berrah et al. 2021; Jiao et al. 2020; Mark et al. 2019; Stahl and Coeckelbergh 2016; Umbrello and Yampolskiy 2022) and IN 5.0 (Ávila-Gutiérrez, Suarez-Fernandez de Miranda, and Aguayo-González 2022; Gladden 2019; Longo, Padovano, and Umbrello 2020; Lu et al. 2022) papers discussed that stakeholders increasingly expect ethics in the form of justice and fairness and dignity to be incorporated into the design of emerging technologies.

Rising demand for entertainment and gaming
Among the IN 5.0 papers, increasing demand for media, entertainment and growth in gaming industries are discussed as key factors that have led to the emergence of a metaverse market (Mourtzis et al. 2022).

Overview of key regime factors for human centric IN 4.0 and IN 5.0
Table 6 summarises the regime factors that are most frequently discussed in human centric IN 4.0 papers; which are Trust/Privacy & Security (16 times), Health & Safety (11 times) and Technology readiness (9 times) which are all categorised under Stakeholder Perception. Dignity, Justice & Fairness (5 times) are more frequently discussed under stakeholder expectation.

As depicted in Table 7, for the IN 5.0 papers the most frequently discussed regime factors are Mass Customization/ Personalization (12 times), United Nations Development Program-Sustainable Development Goals -UNDP (SDG) (11 times) and Trust/ Privacy & Data Security (8 times) which are categorised under Stakeholder expectation, Policy, and Stakeholder perception, respectively.

4.2.3. *The influence of the contextual development (landscape) on the technocentric IN 4.0 towards value centric IN 5.0*
Overall 23 papers (11 IN 4.0 and 12 IN 5.0) were identified that discussed Economic, Socio-Cultural and Environmental factors as key contextual developments that create a need for IN 4.0 and/or IN 5.0 technologies.

Table 6. Regime factors discussed in human centric IN 4.0 papers.

	Policy	Stakeholders' Perception							Stakeholders' Expectation		
	Policy/Regulation	Technology readiness	Job security	Trust/Privacy & Data security	Autonomy	Occupational wellbeing/ Social connectedness	Health & Safety	Implementation cost	Mass Customization/ Personalization	Data Accessibility	Dignity, Justice & Fairness
Policy/Regulation	**2**	1	0	**2**	1	0	0	0	0	0	**2**
Technology readiness	1	**9**	1	6	2	0	3	3	1	0	1
Job security	0	1	**5**	2	2	2	0	2	1	0	1
Trust/ Privacy & Data Security	2	6	2	**16**	6	0	5	4	1	0	3
Autonomy	1	2	2	6	**8**	0	3	3	1	0	2
Occupational wellbeing/Social connectedness	0	0	2	0	0	**5**	1	0	0	0	0
Health & Safety	0	3	0	5	3	1	**11**	2	1	0	0
Implementation cost	0	3	2	4	3	0	2	**6**	1	0	1
Mass Customization/ Personalization	0	1	1	1	1	0	1	1	**3**	0	0
Data Accessibility	0	0	0	0	0	0	0	0	0	**1**	0
Dignity, Justice & Fairness	2	1	1	3	2	0	0	1	0	0	**5**

Table 7. Regime factors discussed in IN 5.0 papers.

	Policy		Perception					Expectation			
	OHS	UNDP/SDG	Job security	Trust/Privacy & Data security	Autonomy	Occupational wellbeing/ Social connectedness	Health & Safety	Mass Customization/ Personalization	Data Accessibility	Dignity, Justice & Fairness	Rising demand for entertainment & gaming
Occupational Health & Safety (OHS)	**1**	0	0	0	0	0	0	0	0	**1**	0
UNDP/SDG	0	**11**	1	2	2	1	0	0	0	0	0
Job security	0	1	**4**	3	2	2	0	0	0	0	0
Trust/Privacy & Data security	0	2	3	**8**	3	2	0	0	0	2	0
Autonomy	0	2	2	3	**6**	3	1	1	0	1	0
Occupational wellbeing/Social Connectedness	0	1	2	2	3	**5**	2	1	0	1	0
Health & Safety	0	0	0	0	1	**2**	**2**	0	0	1	0
Mass Customization/ Personalization	0	0	0	0	1	1	0	**12**	1	0	1
Data Accessibility	0	0	0	0	0	0	0	1	**3**	0	0
Dignity, Justice & Fairness	1	0	0	2	1	1	1	0	0	**4**	0
Rising demand for entertainment & gaming	0	0	0	0	0	0	0	**1**	0	0	**1**

Economic factors

The Financial crisis of 2008 was discussed as a key contextual factor which informed the fourth industrial revolution and the introduction of IN 4.0 technologies (Kagermann and Wahlster 2022).

Socio-cultural Factors

The Ageing of the working population is discussed as a driver for human centric IN 4.0 (Digiesi et al. 2020; Kagermann, Wahlster, and Helbig 2012; Panagou, Fruggiero, and Lambiase 2021; Peruzzini and Pellicciari 2017; Romero et al. 2015; Stahl and Coeckelbergh 2016) and IN 5.0 (Ávila-Gutiérrez, Suarez-Fernandez de Miranda, and Aguayo-González 2022; Breque, Nul, and Petridis 2021; Huang et al. 2022; Müller 2020; Renda et al. 2022).

Environmental factors

Among IN 4.0 papers, environmental factors such as the Covid-19 Pandemic (Dolgui and Ivanov 2021; Ivanov and Dolgui 2021; Lv et al. 2021; Umbrello and Yampolskiy 2022) and Resource/Energy deficiency (Kagermann, Wahlster, and Helbig 2012) are discussed as key drivers for IN 4.0. Among the IN 5.0 papers, the Covid-19 Pandemic (Breque, Nul, and Petridis 2021; Müller 2020; Nikiforova 2021; Renda et al. 2022; Romero and Stahre 2021; Sarfraz et al. 2021), Resource/Energy deficiency (Huang et al. 2022; Maddikunta et al. 2022), and Climate change issues including global warming (Breque, Nul, and Petridis 2021; Demir, Döven, and Sezen 2019; Mavrodieva and Shaw 2020; Müller 2020; Renda et al.

Table 8. Landscape factors discussed in human centric IN 4.0 papers.

	Economic	Socio-Cultural	Environmental	
	Financial crisis	Ageing population	Pandemic	Resource/ Energy deficiency
Financial crisis	**1**	0	0	0
Ageing	0	**6**	0	1
Pandemic	0	0	**4**	0
Resource/Energy deficiency	0	**1**	0	**1**

Table 9. Landscape factors discussed in IN 5.0 papers.

	Socio-Cultural	Environmental Factors			
	Ageing population	Pandemic	Resource/ Energy deficiency	Climate change	Air pollution
Ageing	**5**	3	1	3	1
Pandemic	3	**6**	0	3	0
Resource/Energy deficiency	1	0	**2**	0	1
Climate change	3	3	0	**5**	0
Air pollution	1	0	1	0	**2**

2022) and Air pollution (Huang et al. 2022; Sharma et al. 2022) were discussed.

Overview of key landscape factors in human centric IN 4.0 and IN 5.0

There is more emphasis on sociocultural and environmental factors in studied IN 4.0 papers. Discussed sociocultural factors include Ageing population (6 times). The second highly discussed contextual factor is environmental including Pandemic (4 times) see Table 8.

For the IN 5.0 papers, there is more emphasis on environmental factors (15 times) compared to sociocultural-ageing population (5 times) as illustrated in Table 9. Specifically, the Covid 19 Pandemic (6 times) and Climate change (5 times) are discussed more frequently under environmental factors in included IN 5.0 papers.

5. Discussion

Combining the results of the qualitative and quantitative analysis in Section 4, this section summarises the key aspects and implications of the transition from technocentric IN 4.0 towards value centric IN 5.0 for both practitioners and researchers.

Overall, analysis indicates that the niche innovations and technologies discussed in human centric IN 4.0 and IN 5.0 papers were symbiotic (Geels, 2006) as similar technologies were discussed across both groups (e.g. IoT, AI, VR, AR, Cobots, Exoskeletons, Wearable Sensors, Human Digital Twins, Explainable AI).

Within IN 5.0, there are a few new technological improvements or advancements which did not previously appear in studies on human centric IN 4.0. For example, Advanced AI including AI with IoT (Maddikunta et al. 2022), advanced IoT including internet of No Things (6G), Internet of Abilities, Internet of Things Services and People (IoTSP) (Maddikunta et al. 2022; Mourtzis et al. 2022), Advanced Blockchain including Blockchain integrated with IoT, i.e. B-IoT (Maier 2021), and Advanced Robotics including persuasive robots (Maddikunta et al. 2022). However, there are also a few new technological improvements discussed in recent human centric IN 4.0 papers that do not appear in IN 5.0 papers e.g. Actionable Cognitive Twins. Additionally, there is more emphasis on environmental sustainability opportunities in IN 5.0 than in human centric IN 4.0 papers.

For the regime factors, there are also variations between human centric IN 4.0 and IN 5.0 papers. For example, Implementation cost is discussed in IN 4.0 papers as a key stakeholder perception while UNDP (SDG), Accessibility and Rising demand for entertainment and gaming are discussed under Policy and Stakeholder expectations categories, respectively in IN 5.0. This is more likely due to the shift from shareholder values in IN 4.0 towards stakeholder values in IN 5.0. However, the value centric IN 5.0 includes Human centricity, Resilience and environmental sustainability (Breque, Nul, and Petridis 2021). Therefore, human centric IN 4.0 research can be considered as a part of the value centric IN 5.0 agenda. Hence, with the combination of the regime factors discussed in both human centric IN 4.0 and IN 5.0, it could be argued that Trust, Mass Customization/Personalization, Autonomy, Policy, and Health & Safety are the most important regime factors.

For the landscape factors, the key variations are economic, which appear in humancentric IN 4.0 papers but are less emphasised in IN 5.0 papers. On the other hand, environmental factors appear most frequently and with wider dimensions including Climate change and Air pollution in IN 5.0 included papers. This trend is likely a consequence of new societal trends and pressures over more recent years.

Overall, our MLP analysis indicates that there is no single cause or explanation for the transition from technocentric IN 4.0 towards value centric regime of IN 5.0. Instead, the transition is happening as a result of landscape and niche level forces that link up and reinforce one another as indicated in Figure 6. The common view is that major transitions come about through breakthroughs of technological discontinuities. However this study provides support and contributes to the alternative explanation of gradual and stepwise reconfiguration (Geels, 2006) as the pattern by which the transition from IN 4.0 towards IN 5.0 is taking place.

Analysis shows that this reconfiguration pattern occurred through significant disruptions in the landscape

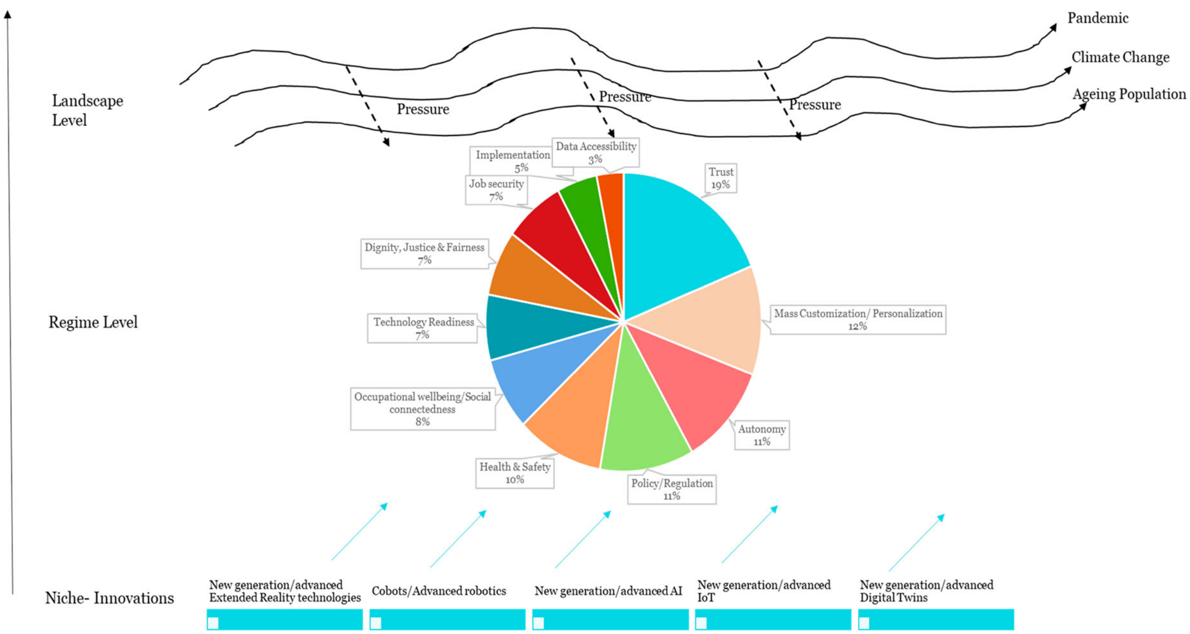

Figure 6. Multilevel perspective overview of the transition.

due to environmental factors such as Covid-19 Pandemic, Climate change and resource deficiencies, that have led to intense pressure in the technocentric regime, resulting in policy changes, as well as new stakeholder expectations leading towards a new value centric regime. These landscape developments have also created windows of opportunity for the adoption of new technologies which in turn, generate opportunities and challenges. On the other hand, the new niche innovations can be thought of as add-ons that continue to improve the functioning of the regime (c.f. Geels, 2006). Overtime, these stepwise changes in the regime are leading towards a gradual replacement of technocentric regime towards the value centric regime.

Our study identified that the principles of IN 5.0 i.e. economic (resilience), social (human centricity), and environmental sustainability are used by both humancentric IN 4.0 and IN 5.0 studies. However, the keyword of IN 5.0 is not yet widely adopted by researchers and even when it is adopted it is used alongside IN 4.0. This indicates that the transition toward value centric IN 5.0 is a step wise and incremental, but critically necessary advancement that builds on IN 4.0 technologies under a different paradigm which includes more emphasis on social and environmental sustainability.

5.1. Implications for practitioners

This study highlights that to successfully explore economic, social and environmental sustainability, it is important to consider landscape, regime and niche level factors. In other words, thinking about the different layers of MLP helps us to understand the nature of the processes taking place, and in turn points to mechanisms that might be employed to direct the kinds of changes desired by the government and other stakeholders.

As seen in Figure 6, at the landscape level factors such as Financial crisis, Pandemic, Climate change and Population ageing are impacting the society at large and by extension, firms within them. The negative impact of such issues can be mitigated by the use of certain innovative technologies such as advanced Extended reality technologies i.e. AR, VR, and MR, Cobots/Advanced Robotics, advanced AI, advanced IoT, Advanced Digital Twins. Practitioners need to be aware of specific technologies as well as their potential impact or perception by the workforce and society. Where negative impacts or perceptions are identified, practical steps should be taken to overcome them. For example, adverse stakeholder perceptions around job loss can be overcome through training and upskilling of the workforce as well as in depth information to allay any fears around Safety & Health or Privacy & Data Security concerns.

Firms need to carefully consider their current challenges and risks based on policies such as UNDP goals, Occupational Health & Safety and prioritise them in order to identify the most critical technologies to address the challenges.

5.2. Directions for future studies

Overall, the SLR indicates that more emphasis has been devoted towards niche innovations within humancentric IN 4.0 and IN 5.0 studies (120 papers). On the other hand, studies relevant to the regime and landscape levels are fewer (69 and 23 papers, respectively). This indicates that more studies are required to explore the landscape and regime factors which inform the transition toward value centric IN 5.0. Even within the niche innovation studies, there is room to explore any newly emerged technologies. Moreover, it has been identified that some of the current technologies are not ready for immediate application as they require some further developments. Although some of these technologies have been effectively applied in the context of laboratory or prototype experiments, they would need to be adapted and improved in order for them to be useful in real industrial environments. For example, eye tracking technologies could be less intrusive and more comfortable for users (Peruzzini, Grandi, and Pellicciari 2020).

The empirical studies (see Appendix C) provide evidence that IN 4.0 and IN 5.0 technologies are useful for social and economic sustainability. However, none of the empirical studies is focused on environmental sustainability, highlighting the need for more empirical investigation in the area. Additionally, most of the studies are conducted in experimental lab environments, hence it is important to investigate the outcome of the case studies in the context of real production, manufacturing or organisational systems. The majority of the studies are based on simple or few use cases involving one to three industrial cases, and based on a limited involvement of workers and machine function. Therefore, it will be valuable to test the implementation of the systems in more complex use cases. Moreover, the studies indicate the importance of developing and analysing more in-depth case studies of both successful and failed IN 4.0 and IN 5.0 performance system implementations to understand their specific features and advantages/disadvantages and, consequently, to develop and propose better theoretical models and managerial practices. Hence, more empirical studies could be conducted to answer the question of 'to what extent are economic, social and environmental sustainability goals achieved by adopting IN 5.0 technologies and what kinds of challenges are encountered or resolved by implementation of those technologies?'.

Compared to niche level empirical papers, there were fewer empirical studies on landscape and regime factors. As the regime level is regarded as the 'core' layer of MLP (Geels 2002), future empirical studies could explore regime level factors that enable and shape the transition from IN 4.0 towards IN 5.0 in practice. This indicates that there is more room to explore regulation, stakeholder expectations and perceptions with respect to the transition from IN 4.0 towards IN 5.0 in real world scenarios. Particularly, there were no qualitative studies conducted in papers that discuss IN 5.0. This is most likely because the concept of IN 5.0 is still new. Hence future studies can explore this identified gap. For example, a qualitative study can explore questions such as 'what are the experiences of key stakeholders in the adoption of IN 5.0 technologies?' Moreover, a direction for another study could be to provide a complete overview of the empirical insights gleaned from the implementation of IN 5.0 technologies. Finally, other transition theories such as Strategic Niche Management (SNM) and Technological Innovation Systems (TIS) or a combination of both can be used by future studies to explore the transition towards IN 5.0.

6. Conclusion

Although researchers have identified that the developed world is moving from technocentric IN 4.0 towards value centric IN 5.0, there are insufficient studies that explore this transition. Drawing on a multilevel perspective of socio-technical transitions, this paper explored the findings of a systematic literature review of the key factors that explain the transition from the technocentric IN 4.0 towards value centric IN5.0. To explore this transition, a literature sample consisting of 175 journal and conference and white papers were analysed to gain insights into how the socio technical landscape, and niche innovations driving the regime transition from technocentric IN 4.0 towards value centric IN 5.0 are discussed in existing studies.

This study has answered three key questions. Firstly, it identifies challenges under the three sustainability pillars of economic, social and environmental. The findings demonstrate that Cobots, IoT and AI are key innovations mentioned within IN 4.0 papers to address economic and social sustainability issues. Similarly, Cobots/Advanced Robotics, Advanced AI and Advanced Blockchain are the key innovations mentioned within IN 5.0 papers to address Economic, Social and Environmental sustainability. The study also identifies UNDP sustainable goals, Mass Customization, Trust/Privacy and Data security as key regime factors that influence the transition from technocentric IN 4.0 toward value centric IN 5.0. The broader contextual or landscape factors driving the transition are identified as Socio-Cultural factors including Ageing population and Energy efficiency as well as Environmental factors such as Climate change and the Pandemic.

This study has two main contributions. Firstly, by synthesising the literature on humancentric IN 4.0 and IN 5.0, the study highlights the commonalities and differences between them. Secondly, based on a review of existing literature, this research provides an in-depth overview of the key contextual, regime and niche level factors that influence the transition.

Like other systematic literature reviews, our study had some limitations. During the definition of keywords, we may have missed relevant keywords, however in an attempt to overcome this, we used a snowballing approach. We used MLP which has fairly low systemicity compared to transition theories such as Strategic Niche Management (SNM) and Technological Innovation Systems (TIS) (Panetti et al. 2018). Therefore, future studies might explore other transition theories or a combination of theories.

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Notes on contributors

Dr Etieno Enang is a Lecturer in International Business and Strategy at the University of Liverpool. Her research interests resonate around how management theory and practice can contribute to making organisations, institutions and societies more just, equitable and sustainable. Starting from this broad interest, her research focuses predominantly – but not exclusively- on critical research methodologies, processes and strategies to decolonise research and knowledge. More recently, she has begun to explore the implications, possibilities and challenges around the transition from the fourth towards the fifth industrial revolution.

Dr Mahdi Bashiri is an associate professor at the Research Centre for Business in Society at Coventry University. He has over 18 years of academic experience with a particular interest in operations and supply chain management, operations research, transportation planning, and Heuristic and Matheuristic algorithms. Also, he has participated in industrial and business projects at different levels. He has been involved in two UKRI-funded projects. He has supervised more than 8 PhD students and more than 60 MSc students. He is an active reviewer for reputable academic journals. He is a recipient of the 2013 young national top scientist award from the Academy of Sciences of the Islamic Republic of Iran.

Professor David Jarvis has played formative roles in the conception, establishment, and leadership of two research centres at Coventry University, most recently in 2014, the Centre for Business in Society (CBiS). His focus on socio-economic change has, over a twenty-year period, generated a personal portfolio of more than 70 research, consultancy, and evaluation projects for public, private, and third sector clients and collaborators. Projects completed fall into two broad categories, pre- and post-2014. Prior to 2014, projects addressed aspects of social and economic regeneration, especially as they related to the most disadvantaged individuals, communities, and neighbourhoods in England. Since 2014, the principal focus has been on economic change and impact viewed through accessibility and connectivity lenses, including consideration of winners and losers in low carbon socio-technical transitions.

Data availability statement

The data that support the findings of this study are available from the corresponding author, [MB], upon reasonable request.

ORCID

Etieno Enang http://orcid.org/0000-0003-0982-1588
Mahdi Bashiri http://orcid.org/0000-0002-5448-1773
David Jarvis http://orcid.org/0000-0002-4245-2748

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Appendices

Appendix A. Summary of paper sources

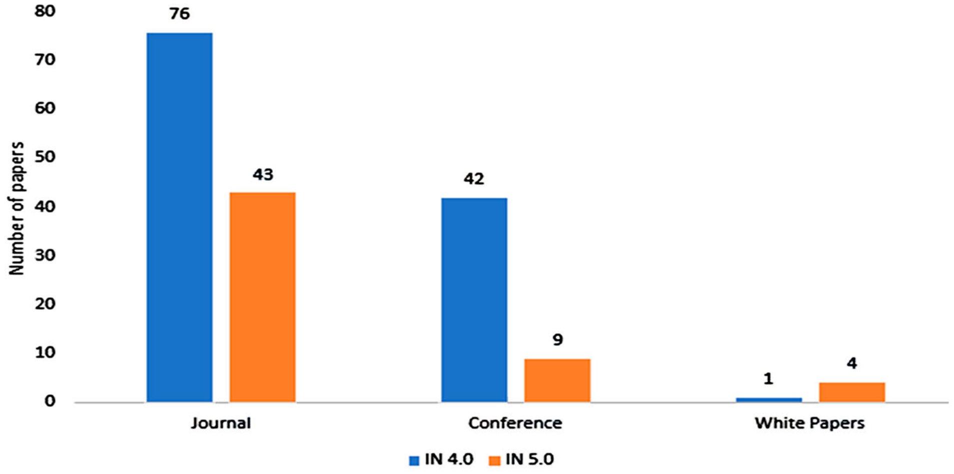

Figure A1. A graphical illustration of paper sources.

Appendix B. Publication trend overtime

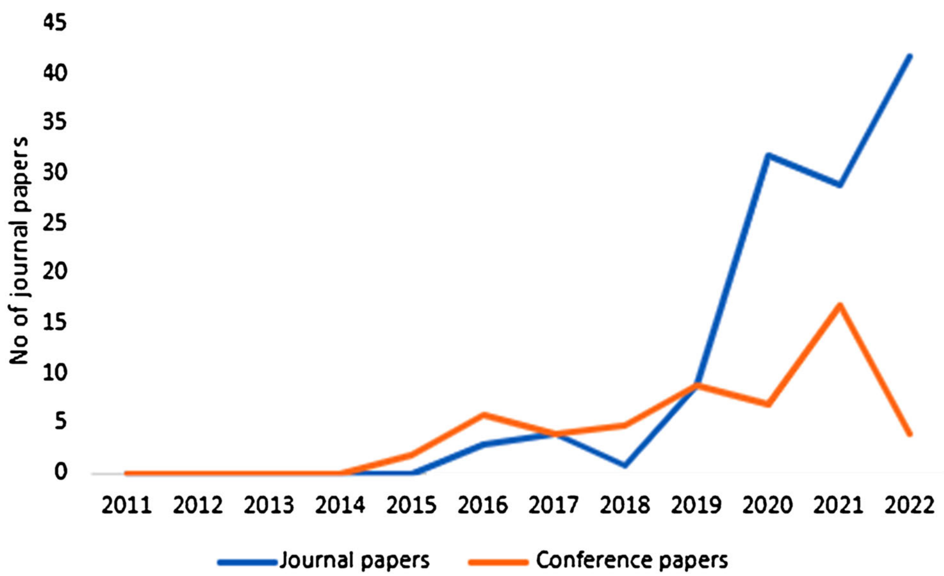

Figure A2. A graphical illustration for publication trend overtime.

Appendix C. Summarised overview of empirical studies

IN 4.0/5.0	AUTHORS	METHODOLOGY	INDUSTRY	Landscape	Regime	Niche	Summarised Outcomes
IN 4.0	Baroroh and Chu (2022)	Experimentation, L8 Taguchi and regression	–	–		Mixed Reality	MR tool is advantageous in terms of planning quality and flexibility to realising human-centric production system design as well as feasibility.
IN 4.0	Bortolini et al (2020a)	Experimentation	Manufacturing	-	Occupational wellbeing	Motion Analysis System	Motion Analysis System (MAS) is a valuable hardware/software architecture highlighting the productive and ergonomic aspects of possible improvement
IN 4.0	Ciccarelli et al. (2022b)	Case study, Experimentation	-	-	Occupational well-being and business performance	-	Presents a tool for monitoring of operators' activities, data analysis, and corrective actions to achieve social sustainability of the workplace.
IN 4.0	Cohen et al. (2021)	Mathematical model-based analysis	-	-	Productivity	Cobots	A productivity-based model for assisting the decision on acquisition and deployment for a single workstation.
IN 4.0	Fang and Hong (2022)	Neural Net-work based integration	Manufacturing	-	-	Advancement in AR	A system to alleviate the cognitive load for the operators within interactive AR assembly tasks with human-centred intelligence
IN 4.0	Feng et al. (2022)		-	-	Reliability and safety	Human-cyber-physical system (HCPS), NGAI (next generation AI)	An improved asymmetric multitask learning (AMTL) is provided based on the Humans interact with next generation AI (NGAI).
IN 4.0	Fletcher et al. (2020)	Survey, 4 Case studies	-	-	Technical efficiency, Worker satisfaction	Human-automation assembly systems	Requirements for creating adaptive automation assembly system to produce enhanced socio-technical assembly systems with augmented human-system interaction to improve performance measures, worker satisfaction and socio-economic sustainability.
IN 4.0	Gil et al. (2019)	Experiment	Automotive	-	-	Hil-ACPS (Human-in-the-loop autonomous Cyber-Physical Systems)	A conceptual framework to characterise the cooperation between humans and autonomous *CPSs* with proper human integration. This work paves the way for Human Integration design in ACPSs. A conceptual framework to identify the aspects in order to design human participation with an engineering point of view.
IN 4.0	Gorecky, Khamis, and Mura (2017)	Experiment, Case study	Automotive	-	-	Virtual training in the factory	A designed, implemented and evaluated virtual training system (VISTRA). Challenges identified and showed how VISTRA can address them.
IN 4.0	Jiao et al. (2020)	A method based on Game theory	-	-	Trust	AI	A research roadmap towards cyber-physical-human analysis is deliberated to reveal a variety of opportunities of developing novel methods for enhancing affective cognition and perception learning, trust dynamics modelling, human cognitive performance prediction, as well as human-automation interaction optimisation
IN 4.0	Kadir and Broberg (2021)	Explorative case studies, Semi-structured case studies	-	-	Human factors and ergonomics	-	A framework for (re)designing industrial work systems in the transition towards Industry 4.0 is created. The framework combines human factors and ergonomics, work system modelling, and strategy design
IN 4.0	Kaasinen et al. (2020)	Interviews with 44 workers, 4 focus groups	Manufacturing	-	Human engagement	-	There is a need for knowledge sharing and adaptive learning solutions that would support personalised competence development and learning while working.

(*continued*).

IN 4.0/5.0	AUTHORS	METHODOLOGY	INDUSTRY	Landscape	Regime	Niche	Summarised Outcomes
IN 4.0	Lithoxoidou et al., (2020)	Qualitative 15 interviews	-	-	Human engagement	Gamification tools	Change of industries is necessary by boosting human contact and eliminating alienation through right use of technology which can facilitate the change, communication, engagement and knowledge exchange.
IN 4.0	Longo, Nicoletti, and Padovano (2017)	Quantitative experiment, Statistical tests	-	-	-	AR, Intelligent Personal Assistants	A proposed human-centred approach along with its implementation and deployment in order to align (and enhance) operators' capabilities/competencies with the new smart factory context with an investigation on labour performances. They realised that operators trained by SOPHOS-MS (which relies on AR on intelligent personal assistant with vocal interaction capabilities) outperform traditionally-trained operators.
IN 4.0	Longo, Padovano, and Umbrello (2020)	Quantitative data, Survey collected from top managers of 20 partner companies	-	-	-	Extended Reality and AI	A proposed KNOW4I platform to support the smart operator through a suite of Smart Utilities and Objects. Satisfactory results were recorded.
IN 4.0	Longo, Nicoletti, and Padovano (2022)	Mixed method, Quantitative experiment, Interviews	Manufacturing	-	-	Mixed Reality	Extended the KNOW4I platform in form of an ontology-based architecture capable of improving the capabilities of the smart operator by focusing on mixed reality. Findings show that the extended platform can effectively and efficiently support the smart operator.
IN 4.0	Lv et al. (2021)	Experiment (in a case), D-DDPG as optimisation model in Digital Twin.	Manufacturing	-	Human-machine collaboration	Digital Twin	Digital Twin based Human Robot Collaboration (HRC) assembly has a significant effect on improving assembly efficiency and safety.
IN 4.0	Ma et al. (2022)	Quantitative experiment	-	-	-	Digital twin model of human robot collaboration	The method is useful to dynamically adjust the collaborative relationship between human and robots
IN 4.0	Manitsaris et al. (2020)	Quantitative experiment- Gesture Operational model	-	-	-	Human centred AI	Enabling inspectors to visualise data files from database and real-time data access using an Augmented Reality environment
IN 4.0	Martinez et al. (2021)	Experiment using digital twin demonstrator	-	-	-	Digital twin	The obtained results confirmed how the proposed demonstrator allows for seamless interaction among the operator, the computer and the machine (i.e. the robot).
IN 4.0	Mertes et al. (2022)	Quantitative Experiment	-	-	-	5G Based human machine interaction	Better interaction with human and machine, improved ergonomics, fast response to changing environmental systems, cost savings.
IN 4.0	Moencks et al. (2022a)	Procedural Action Research, 39 industry expert interviews	Automotive, Consulting, Software, Venture capital, Manufacturing, Energy	-Socio cultural, environmental	Policy, human factors-decision making capabilities		Canvas is a strategic technology management tool aimed at systematically guiding users through the complex transformation towards HTI and the future of work on the shop floor. The Canvas contributes to the development of industrial human-technology systems by placing the value-added for production systems at the heart of management decisions.
IN 4.0	Moencks et al. (2022b)	Multimethod research, 27 qualitative expert interviews, Ethnographic observations of three industrial contexts	Automotive, Aviation, Food	-	Human factors, cognitive ergonomics	-	Stakeholders feel that operator assistance systems (OAS) will be beneficial on shop floors if they are designed to improve cognitive abilities, such as inductive reasoning.

(continued).

IN 4.0/5.0	AUTHORS	METHODOLOGY	INDUSTRY	Landscape	Regime	Niche	Summarised Outcomes
IN 4.0	Mourtzis, Angelopoulos, and Panopoulos (2021)	Quantitative modelling-experiment	-	-	-	Augmented Reality	User awareness of the machine increased by 10%, there was 25% reduction of system response and reduction in machine downtime
IN 4.0	Naqvi et al. (2022)	Quantitative modelling, Case study based open source dataset of maintenance work order (MWO)	Mining	-	-	Advanced Digital Twins	Results indicate that the state-of-the-art Natural language processing (NLP) can be used to process human knowledge in maintenance work orders (MWOs), and generates interesting patterns
IN 4.0	Papetti et al. (2020a)	Experiment, industry use case	Foot wear	-	Human factors/ ergonomics	IoT sensor technology	Findings indicate objective data collection through wearable devices is appreciated by users. The data collection and analysis required few resources; i.e. time money and people
IN 4.0	Park, Jun, and Yun (2022)	Quantitative experiment	-	-		Advanced/ Collaborative robots	Results show a high success rate from the robotic bin picking platforms from the first 74% was increased to 87% and the ability to find pickable objects in a bin increased from 14.5 blocks in 28.3 s to 18.75 blocks in 17.3 s
IN 4.0	Peruzzini, Grandi, and Pellicciari (2020)	Quantitative experiment-simulation, User observation and monitoring	Agricultural, Automobile	-	Human factors/ ergonomics	Wearable sensors	the human monitoring system provided useful ergonomic advantages, the adoption of human monitoring tools was found not too invasive and operators accepted them in a positive way because they felt more secure and controlled
IN 4.0	Peruzzini and Pellicciari (2017)	Quantitative and qualitative metrics of user performance	Wood working	-	Human factors/ cognitive ergonomics	IoT sensor technology	Technology successfully supports the workers during task execution. There is total reduction of human errors by 100% and improved system efficiency and production capabilities.
IN 4.0	Pinzone et al. (2020)	Qualitative, Conceptual framework and interviews	Manufacturing	-	-	CyFL Matrix for cyber physical production systems	The CyFL Matrix gives a comprehensive understanding of the impacts of implementing a CPPS-oriented solution and facilitates the identification and organisation of performances on production and social sustainability aspects.
IN 4.0	Qiu et al. (2022)	Quantitative experiment, Simulation- case study of the optimisation of time consumption	-	-	-	Advanced robotics	The results of the numerical experiment verify the effectiveness of reduction of the computation complexity. The method an reduce the time consumption by 4.9%. It also frees up human workers and improves their quality of life.
IN 4.0	Robert, Giuliani, and Gurau (2022)	Case study- Qualitative, 30 semi structured interviews with employees & managers of Schneider electric, participant observation	Energy, Automation, Services	-	Technology readiness, Change management	-	Findings outline the importance of the active participation of employees in the implementation of new performance management systems, and the effects are significant, especially in terms of learning, personal motivation and even enjoyment.
IN 4.0	Rozanec et al. (2022a)	Experiment, Two use cases, Qualitative and quantitative	Automotive	-	-	Actionable cognitive twins	Results indicate a reduction in complexity regarding to the production planning and demand forecasting process. Such automation saves time and achieves more accurate results.
IN 4.0	Segura et al. (2020)	Conceptual framework and experiment	-	-	-	Visual computing technologies, AR, VR and MR	Findings show that interactive platform can help the Operator (as well as other roles, such as managers) to better understand and easily detect faulty production situations. Visual computing technologies can assist operators with disabilities by complementing their intellectual or physical limitations.

(*continued*).

IN 4.0/5.0	AUTHORS	METHODOLOGY	INDUSTRY	Landscape	Regime	Niche	Summarised Outcomes
IN 4.0	Wong and Chui (2022)	Simulation Experiment	-	-	-	Cognitive Engine Process Controller	CEPC augments human decision-making for process control. This is advantageous for mass personalisation production (MPP) in a cyber-physical system (CPS) where multiple customised products with unique requirements can be manufactured simultaneously
IN 4.0	Yan and Wang (2022)	Conceptual model and Experiment	-	-	-	You only look once (YOLO) and Visual Geometry Group 16 (VGG16)	The average accuracy was over 96%. This model can not only be used to effectively monitor whether an action is missing in real time, support quality traceability and improve product quality, but also to complete the automatic analysis of action execution times with an average error of 0.3 s and realise the optimisation and improvement of action execution patterns.
IN 4.0	Zhang et al. (2022)	Experiment carried out on the training set of a self-built data set	-	-	-	Cobots	The results indicate that the accuracy of the proposed behaviour recognition based on self-attention method is 91%. At the same time, it is proved that the reinforcement learning method is theoretically feasible to provide adaptive decision-making for robots in human-machine collaboration.
IN 4.0	Zolotova et al (2020)	Experiments based on three laboratories use cases	Healthcare	-	-	Human Cyber Physical Production Systems	The case studies illustrate the possible applications of smart and cognitive solutions to support the operator in the era of IN 4.0. However, it is recommended to use a combination of different technologies to get the best results.
IN 4.0	Zhu et al. (2022)	Optimisation modelling and experiment	-	-	-	Cobots, Digital Twins.	The results show that the proposed method can assign the operation tasks to operator and robot reasonably resulting in reasonable configuration of intelligent manufacturing system.
IN 5.0	Fraga-Lamas, Varela-Barbeito, and Fernandez-Carames (2021)	Experiment, Case Study	Shipbuilding			Sensor Technologies, IoT	Sensor technologies particularly passive and active Ultra high frequency (UHF) radio frequency identification RFID systems are useful for traceability and inventory management in the shipbuilding industry
IN 5.0	Ghobakhloo et al. (2022)	Review and Quantitative analysis of 11 expert views, roadmap		SDG			Results revealed that Industry 5.0 delivers sustainable development values through 16 functions
IN 5.0	Nagy et al. (2022)	Quantitative experiment-Hypergraph analysis				Human machine collaboration	This work highlighted that hypergraphs could support the analysis and design of collaborative and interactive schemes for manufacturing systems.
IN 5.0	Sharma et al. (2022)	Mixed Qualitative and quantitative analysis- Decision making method (AHP-ELECTRE-DEMATEL)			Policy, change management/ Technology readiness	VR	'Linking virtual reality and reality' is found to be the most critical deterrent to the adoption of industry 5.0. The findings also highlight the problems with the adoption of high-tech innovations due to lack of standardisation and fair benchmarking policies on industry 5.0.
IN 5.0	Sindhwani et al. (2022)	Quantitative analysis- a hybrid approach of Pythagorean fuzzy analytical hierarchy process-combined compromise solution					The findings show that the criterion of personal customisation obtained the highest weight followed by human machine collaboration, which will create a smart cognitive environment for humans
IN 5.0	Wahyuningtyas, Disastra, and Rismayani (2022)	Quantitative-SEM-PLS model surveys-questionnaires to 386 leaders of cooperatives in West Java			Policy, change management/ Technology readiness		Digital capability positively influences competitiveness; digital orientation has a positive and significant influence on digital innovation and competitiveness; government support has a positive and significant influence on digital innovation and competitiveness

Appendix D1. Summary of IN 4.0 reviewed papers regarding technologies and sustainability pillars

Reference		Technologies																											Economic		Social			Env	
AUTHORS	YEAR	Cobots/Robots	Augmented Reality	Virtual Reality	Mixed Reality	Extended Reality	Digital Twins	Next generation Digital Twins	Exoskeletons	Environmental sensors	IoT	IIOT	Explainable AI	Wearable sensors	Video camera	Additive Manufacturing	PPE	Machine Learning	CAD	Cloud computing	Big data analytics	Autonomous vehicles	Drones	Artificial Intelligence	Blockchain	Social collaborative platform	Intelligent Personal Assistant	5G	Efficiency without human replacement	Flexible production/ Resilience	Physical support/ safety	Cognitive & Perceptual support	Trust	Reduction in Wastage/Energy Efficiency	Pollution reduction
(Romero et al.)	2015																	X											x		X	X			
Kymäläinen et al	2016		X																													X			
Mattsson, Partini, and Fast-Berglund	2016													X																X	X				
Nguyen et al	2016										X										X										X				
Romero et al	2016	.	X	X					X		X			X				X			X			X		X			X		X	X			
Saggiomo et al	2016		X																										X			X			
Thomas et al	2016	X												X																	X				
Berg & Reinhart	2017	X																											X			X			
Bernal et al	2017										X			X			X														X				
Gorecky et al.	2017			X																									X			X			
Lall et al	2017	X																														X			
Longo et al	2017		X																								X		X			X			
Mourtzis et al	2017		X																	X									X			X			
Peruzzini & Pellicciari	2017			X						X														X					X		X	X			
Podgorski et al	2017										X			X			X														X				
Berg et al.	2018	X								X																			X	X	X				
Heikkila et al.	2018										X																				X				
Rabelo et al.	2018																										X		X			X			
Schlagowski, Merkel, and Meitinger	2018		X																										X			X			
Schiffeler et al	2018	X	X																													X			
Cimini et al	2019										X											X	X						X	X	X	X			
Garcia et al	2019	X																											X			X			
Gil et al	2019										X											X		X					X						
Golan, Cohen, and Singer	2020	X																														X			
Gualtieri et al	2019	X																											X		X				
Ivanov & Dolgui	2019						X																		X					X				X	
Kildal et al	2019	X																											X			X			
Lithoxoidou et al	2020		X																							X					X				
Mark et al	2019	X							X					X																	X	X			
Zhou et al	2019																							X					X	X		X			
Bortolini et al	2020a													X				X	X										X	X	X				
Bortolini et al	2020b										X																		X	X	X				
Bousdekis et al.	2020						X						X																X				X		
Cimini et al	2020	X	X	X							X			X						X	X								X		X	X			
Di Donato et al.	2020			X										X															X		X	X			
Digiesi et al	2020													X																		X			
Fletcher et al	2020	X	X	X					X													X							X	X	X	X			
Gualteri et al.	2020	X																											X		X	X			
Kaasinen et al	2020	X	X	X							X							X			X			X					X		X	X			
Konstantinidis et al	2020					X																							X			X			
Longo & Padovano	2020																										X					X			
Manitsaris et al	2020	X																X						X					X		X				
Mark, Rauch, and Matt	2021		X		X																											X			
Papetti et al	2020a													X																	X				
Papetti et al	2020b									X				X															X		X	X			
Peruzzini et al.	2020				X						X				X														X	X	X	X			
Pinzone et al	2020	X	X	X					X		X			X							X			X					X	X	X	X			
Pilati et al	2020		X												X														X			X			
Rojas et al.	2020	X																											X		X	X			

(*continued*).

Reference		Technologies																											Economic		Social			Env	
AUTHORS	YEAR	Cobots/Robots	Augmented Reality	Virtual Reality	Mixed Reality	Extended Reality	Digital Twins	Next generation Digital Twins	Exoskeletons	Environmental sensors	IoT	IIOT	Explainable AI	Wearable sensors	Video camera	Additive Manufacturing	PPE	Machine Learning	CAD	Cloud computing	Big data analytics	Autonomous vehicles	Drones	Artificial Intelligence	Blockchain	Social collaborative platform	Intelligent Personal Assistant	5G	Efficiency without human replacement	Flexible production/ Resilience	Physical support/ safety	Cognitive & Perceptual support	Trust	Reduction in Wastage/Energy Efficiency	Pollution reduction
Shneiderman	2020																							X									X		
Segura et al	2020	X	X	X	X		X																		X	X			X		X	X			
Serras et al	2020	X	X			X																										X			
Sun et al	2020											X		X																		X			
Tancredi et al	2020		X																												X				
Taylor et al	2020	X							X							X						X													
Wang et al	2020																	X						X								X			
Zolotova et al	2020		X									X		X							X					X			X		X	X			
Aivaliotis et al	2021	X	X																										X	X	X				
Arkouli et al	2021		X	X			X		X																					X	X				
Bortolini et al.	2021													X				X	X										X	X	X				
Brunzini et al.	2021			X										X	X														X	X		X			
Carlos et al	2021														X														X			X			
Cimini et al	2021		X																	X			X	X					X		X	X			
Cohen et al.	2021	X																											X			X			
Fruggiero et al	2021	X																											X		X	X			
Garcia et al	2021	X																X						X					X	X		X			
Habib et al	2021	X					X															X							X		X				
Karagiannis et al	2021			X																											X	X			
Lv et al	2021	X					X																									X			
Machado et al	2021										X									X															X
Maharjan et al.	2021		X																										X			X			
Martinez et al	2021	X					X																						X	X		X			
Merati et al	2021	X																											X	X	X				
Mourtzis et al	2021		X																	X									X			X			
Palasciano et al	2021						X					X																	X			X			
Panagou et al.	2021	X		X										X															X		X	X			
Villalba-Diez and Zheng	2021											X		X															X			X			
Wanasinghe et al	2021	X	X			X	X		X					X						X	X		X		X	X	X		X		X	X			
Baroroh and Chu	2022				X																								X	X					
Ciccarelli et al.	2022		X				X					X				X				X	X										X	X			
Ciccarelli et al.	2022								X		X							X													X	X			
Danys et al	2022											X																	X	X					
Fang and Hong	2022					X																										X			
Feng et al	2022																	X											X						
Longo et al	2022					X																		X								X			
Ma et al	2022	X					X																						X	X					
Mertes et al	2022																											X	X	X					
Moencks et al	2022a	X							X																				X		X	X			
Moencks et al	2022b		X													X																X		X	
Naqvi et al	2022						X						X																X						
Park et al	2022	X																													X	X			
Qiu et al	2022	X																											X		X	X			
Rozanec et al	2022a							X																								X			
Wong & Chui	2022	X																X														X			
Yan & Wangl	2022										X							X												X		X			
Zhu et al	2022	X					X																						X	X					

Appendix D2. Summary of IN 5.0 reviewed papers regarding technologies and sustainability pillars

References		Technologies									Economical		Social			Environmental	
AUTHORS	YEAR	Cobot/Robot	Advanced Blockchain	Advanced AI	Machine learning	Digital twins	Human Digital Twins	Advanced/New generation IoT	6G	Advanced Extended reality	Efficiency without human replacement	Flexible production/Resilience	Physical support/ safety	Cognitive & Perceptual support	Trust	Reduction in Wastage/ Energy Efficiency	Pollution reduction
Nahavandi	2019	X	X								X		X			X	
Foresti et al	2020			X							X						
Chen et al	2021			X	X	X		X			X	X					X
Colla et al	2021	X										X		X	X	X	
Fonda & Meneghetti	2022	X									X		X	X			
Fraga-Lamas, Varela-Barbeito, and Fernandez-Carames	2021							X							X		
Maddikunta et al	2022	X	X										X			X	
Maier et al	2021		X	X	X			X	X	X	X	X		X	X	X	
Nikiforova	2021							X									X
Romero & Stahre	2021	X										X	X				
Aceta et al	2022	X									X						
Althabhawi et al.	2022		X												X		
Huang et al	2022	X		X	X		X				X					X	X
Lu et al	2022						X						X		X		
Mourtzis et al	2022			X	X						X	X		X		X	X
Mourtzis et al	2022									X				X	X		
Muslikhin et al	2021	X						X			X						
Noor-A-Rahim et al.	2022							X			X					X	
Roring & How	2022							X			X						X
Rozanec et al	2022b			X							X			X	X		
Taj & Jhanjhi	2022			X											X	X	X
Verma et al.	2022		X												X	X	X
Wang	2022	X								X	X		X	X			

Appendix E1. Definition of technologies for IN 4.0

Technologies	Brief Description
Cobots/Advanced Robotics	Refers to robots that are embedded with sensors. They are designed to work in a collaborative manner with humans, thus making human capabilities more efficient
Augmented Reality	Technology that allows users to interact with their physical environment through the overlay of digital information
Virtual Reality	Technology that enables users to get a sensory experience on real things in a similar way to the one that they use when they interface normally with physical world
Mixed Reality	Involves the combination of both augmented and virtual reality. It merges the real and virtual worlds along a virtual continuum
Extended reality	Refer to technologies such as virtual reality, augmented reality, and mixed reality that enhance and support industry 4.0 in diverse settings
Digital Twins	Refers to digital replicas of a physical system or an object It effortlessly integrates data between a physical machine and its digital replica in the virtual world, in real time or through historical data
Actionable Cognitive Twins (Next generation Digital Twins)	Are the next generation digital twins enhanced with cognitive capabilities through a knowledge graph and Artificial Intelligence models that provide insights and decision-making options to the users
Exoskeletons	Are wearable devices that are worn between one or more joints on the human body and can perform physical work. With some exceptions, industrial exoskeletons are able-bodied devices designed to augment workers who are performing specific, repetitive physical tasks
IOT and sensor technologies	Include devices equipped with self-identification capabilities, localisation, diagnosis status, data acquisition, processing and implementation, which are connected through standard communication protocols
Explainable AI	Refers to technologies that produce human-understandable explanations of AI-based systems information and decisions
Additive Manufacturing	Refers to a set of technologies capable of joining materials to build a complete assembly from 3D model data developed using certain software tools, usually layer by layer, in contrast to subtractive manufacturing method
PPE	Refers to technology that is worn to minimise exposure to hazards that cause serious workplace injuries and illnesses. Smart PPE can collect and monitor data on the user, work environment and its own functioning
Machine Learning	Refers to a branch of AI and computer science which focuses on the use of data and algorithms to imitate the way that humans learn.
Cloud computing	Cloud computing is a technology that enables the storage of large amounts of data that can be accessed using the internet.
Big data analytics	Refers to technologies that are used to process large volumes of data. The data can come from IoT systems connected to the productive layer (e.g. with sensors and associated equipment), or the exchange between IT systems for production and warehouse management.
Autonomous vehicles	Technology that relies on sensors, actuators, complex algorithms, machine learning systems, and powerful processors to execute software
Drones	Refers to unpiloted aircrafts, sometimes known as unmanned aerial vehicles (UAV) which are equipped with various sensors
Artificial Intelligence	Refers to the computer science-based technologies that can be used with machine learning to generate intelligent sensors, edge computing and smart production systems
Blockchain	Blockchain is a technology that enables the secure sharing of information. Data, obviously, is stored in a database. Transactions are recorded in an account book called a ledger. Blockchain allows for the permanent, immutable, and transparent recording of data and transactions
Social collaborative platform	Refers to technologies that create communities of social networks that improve workers overall performance through supporting innovation, strengthening crowd sourcing and boosting innovation
Intelligent Personal Assistant	Refer to technologies that use AI and data processing to assist in the performance of a wide range of tasks e.g. information searches, managing appointments etc
5G	Refers to a technology that enables the connection of everyone and everything including machine, objects, and devices

Appendix E2. Definition of technologies for IN 5.0

Technologies	Brief Description
Cobot/Advanced Robotics	Refers to robots that are embedded with sensors. They are designed to work in a collaborative manner with humans, thus making human capabilities more efficient
Advanced Blockchain	Advanced Blockchain is a technology that allows secure and high level of protection for data by using immutable and distributed ledger through a compartmentalised and distributed approach.
Advanced AI	Advanced AI or augmented intelligence are technologies that allow synergies between human and computer intelligence to improve human decision making.
Machine Learning	Refers to a branch of AI and computer science which focuses on the use of data and algorithms to imitate the way that humans learn.
Digital twins	Refers to digital replicas of a physical system or an object It effortlessly integrates data between a physical machine and its digital replica in the virtual world, in real time or through historical data
Human Digital Twins	Human Digital Twin is a technology that produces a copy of the real human in the cyberspace.
Advanced/New generation IoT	New generation IoT refers to technologies with embedded intelligence that rely on high connectivity and processing capabilities for the real-time analysis of information.
6G	6G refers to the sixth-generation mobile technology with integrated AI capabilities.
Advanced Extended reality	Extended Reality (XR) refers to technologies that combine both real and virtual environments.