



HAL
open science

Conceptualizing Sustainable Artificial Intelligence Development

Christian Zinke-Wehlmann, Julia Friedrich, Amit Kirschenbaum, Mandy
Wölke, Anja Brückner

► **To cite this version:**

Christian Zinke-Wehlmann, Julia Friedrich, Amit Kirschenbaum, Mandy Wölke, Anja Brückner. Conceptualizing Sustainable Artificial Intelligence Development. 23th Working Conference on Virtual Enterprises (PRO-VE), Sep 2022, Lisbon, Portugal. pp.545-554, 10.1007/978-3-031-14844-6_43. hal-04642045

HAL Id: hal-04642045

<https://inria.hal.science/hal-04642045v1>

Submitted on 9 Jul 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License



This document is the original author manuscript of a paper submitted to an IFIP conference proceedings or other IFIP publication by Springer Nature. As such, there may be some differences in the official published version of the paper. Such differences, if any, are usually due to reformatting during preparation for publication or minor corrections made by the author(s) during final proofreading of the publication manuscript.

Conceptualizing Sustainable Artificial Intelligence Development

Christian Zinke-Wehlmann¹, Julia Friedrich¹, Amit Kirschenbaum¹, Mandy Wölke¹, Anja Brückner²

¹ Institute of Applied Informatics-University of Leipzig
{zinke,friedrich,Kirschenbaum,woelke}@infai.org

² University of Leipzig
{anja.brueckner}@uni-leipzig.org

Abstract. The next level of digitalization in (smart) manufacturing will be the broad implementation of Artificial Intelligence (AI). As in every evolutionary step, AI will not only affect the processes it is implemented in but will also have an impact on the way employees and organizations work. The paper underpins the importance of changing the collaboration schema with the development of AI – and its social impact. Nevertheless, technological innovation is mainly driven by economic pressure nowadays, but the demand for sustainability and ethical development of AI has become of significant importance, especially for the manufacturing sector. With this paper, we would like to offer a conceptual approach on how sustainability issues can be brought together with AI development in the industry to create ecological, economic, and social value. Based on Design Science Research, a concept is developed that illuminates the possibilities of sustainable AI development at the different impact levels.

Keywords: AI, Sustainability, Value in Work, Value from AI.

1 Introduction

Within the last 25 years, digitalization processes, including platform economy, the Internet of Things or Big Data technologies, have already changed the way people live and work. Industry 4.0 is the next evolutionary step in this technology-driven transformation, and it comes along with novel business models and collaboration approaches, supported by developments of collaboration networks, as shown in [1]. This next wave of digitalization has already started, bringing methods and tools of Artificial Intelligence (AI) into practice – with a huge impact on Industry and Society – as Makridakis predicted by stating that the “AI revolution aims to substitute, supplement and amplify practically all tasks currently performed by humans” [2]. Further, AI is mainly understood as “systems that display intelligent behavior by analyzing their environment and taking action — with some degree of autonomy — to achieve specific goals.” [3]. Thus, by definition, AI will act within manufacturing and industrial processes – consequently, it will also have an impact on collaboration as well

as the value (co-)creation within manufacturing. Nowadays, methods of AI are already a crucial part of smart manufacturing and the evolution of Industry 4.0, focusing mainly on process optimization, predictive maintenance, quality control as well as human-robotic interaction and ergonomics [4]. These AI development activities are mostly driven by economic benefits (e.g., quality raise, novel business models or speed up manufacturing by automation/optimization of routines). Human or ecological factors are considered at most secondarily, often only in the context of implementation.

However, while novel AI technology pushes industry into novel innovation tracks, customers pull with a growing demand for sustainability [5] in products, services as well as supply chains¹. Sustainability issues and AI developments address “all layers of the manufacturing systems, from the shop floor to the production management systems and value-chain networks” [1]. Thus, both forces should be taken into consideration for future developments in collaborative networks. Reaching a sustainable industry and society is a global task with many implications and necessary actions on different levels – society, industry, and politics. Since AI has the potential to enable and support sustainable development, especially in the manufacturing industry, the question is how to conduct sustainable AI development. Current discussions in AI development focus on ethical developments [6] and the human-centered use of AI [7] as well as the top-level impact of AI [8]. Up to now, there is no systematic linkage between concrete values, their impact on work tasks or human level and, more generic, descriptions of values and impacts on the society, organizations, or collaborative networks. For a broader view of sustainability in concrete AI development, synergies between existing approaches must be exploited. As an example, prioritizing the human perspective or society in AI development may lead to environmentally unsustainable behavior within the organization or collaborative network - e.g., due to high energy consumption, AI continues deployment processes in work tasks with little relief. The conflicting goals between ecological, social, and economic values in AI development processes on different levels must be brought into focus and awareness must also be raised in the scientific discussion. Therefore, the paper aims to analyze the link between sustainability issues and AI development, highlighting the different levels of analysis (micro-, meso- and macro). Therefore, the research interest is to explore the dimensions and potential methods for sustainable AI development processes.

2 Methodological Remarks

Methodologically, this is a conceptual and positioning paper bridging sustainability models, collaborative networks, and AI development to finally lay the ground for the analysis, design and evaluation of sustainable AI solution development within industries. Further, the overall methodology is conducted within the Design Science Research strongly linked to the development of novel socio-technical systems [9]. Following Hevner and Gregor [10], the paper focuses on the development of a

¹ See also recent marketing studies from Simon&Kucher “Global Sustainability Study” https://www.simon-kucher.com/sites/default/files/studies/Simon-Kucher_Global_Sustainability_Study_2021.pdf

descriptive knowledge base, by systematical synthesis, describing the different phenomena and building a theoretical background for defining solutions objectives as well as design principles for sustainable AI development. Thus, the new design research contribution is an important extension of an existing artifact or the application of an existing artifact in a new application domain. To do so, we explore the theoretical dimensions of sustainable AI by doing a review using “sustainable AI” as a search string in EBSCO Discovery Service - a bibliographic search system – we identify only 4 papers with the search string in the title with significant relevance for our research question. In the next step, we screen relevant literature taking sustainability or sustainability aspects as well as AI development and design into consideration by using different search strings combining “sustainability”, “AI” as well as “AI development” on EBSCO and Google Scholar (publications not older than 5 years with relevant title and abstract). The screening has the goal to give a brief overview of relevant topics and approaches and not to do a full systematic review of all research trees.

3 Theoretical Review and Background

A definition of the concept of sustainable AI is still in process. Bjørlo et al. [11] define it as “the extent to which AI technology is developed in a direction that meets the needs of the present without compromising the ability of future generations to meet their own needs.”, which goes along with Halsband’s [12] conclusion “that recent calls for more sustainable AI are based on a narrow understanding of sustainability, it instructed a return to intergenerational justice as a central ethical dimension of sustainability”. A broader (re-)view can be found in [13]. The authors review seven definitions of sustainable AI with a focus on the public sector, identifying “diversity, capacity for learning, capacity for self-organization common meaning, and trust” as boundary conditions for sustainable AI.

However, to ensure completeness and better understanding, we provide the general ideas of AI before focusing on sustainable AI. Following AI Watch [10] and the High-Level Expert Group on Artificial Intelligence [11], AI can be defined as follows: “Artificial intelligence (AI) systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behavior by analyzing how the environment is affected by their previous actions.” [10]. The broad definition opens space for different AI domains and subdomains. They can be divided into two subsections - the core (goal-oriented) and transversal (supporting, supplementing) section [10]. Core AI sections are: Reasoning, Planning, Learning, Communication, and Perception. Transversal sections are: Integration and Interaction, Services, Ethics, and Philosophy. While Ethics refers to a humanized point of view on AI, sustainability is not yet mentioned as a transversal section for AI. Sustainability has three related dimensions: economic, social and

ecological, which are collectively termed Triple-bottom-line, and can be combined/synthesised with the Sustainable Development Goals (SDG) [14].

“That AI will have a major impact on society is no longer in question. The current debate turns instead on how far this impact will be positive or negative, for whom, in which ways, in which places, and on what timescale” [6]. As Vinuesa et al. [15] analyze, AI can support 134 targets (79%) across all Sustainable Development Goals (e.g., in SDG 1 - no poverty or SDG 4 - quality education), but also has the potential to negatively impact 59 SDG targets (35%) – e.g., by requiring huge natural resources on runtime, by biased models reject gender equality (SDG 5) or by supporting anti-democratic nations [15]. However, in smart manufacturing, AI may have many positive effects in addition to the SDG – such as productivity, energy-saving, and saving scarce resources [4]. On the other hand, studies in other domains like the financial sector² show that AI may displace jobs [8]. AI brings a change in value creation, labor, labor market, and economy – and therefore has the potential to change skill demands and job opportunities [16]. The implementation and (sustainable) success of AI technologies depend on context and usage. It may have unintended consequences – which is why all those factors need to be considered in AI development processes.

Nevertheless, it is important to shape our digitized society and the associated forward-looking technologies based on sustainability values, such as human dignity, diversity, participation, well-being, and quality of life [17]. To do so and enhance individual and societal well-being, human-centered approaches for AI rise up [7]. Human-oriented AI is a design approach that focuses on the human being with all his needs, emotions, motivations, and perspectives [7]. As an answer to the dystopian ideas, in which machines handle tasks completely autonomous and humans lose control over AI and will ultimately become dominated by it, the concept of human-centered AI describes the prospect of humans being empowered in the exercise of their cognitive abilities through the use of AI methods [18]. AI supports the individual through robotics and intelligent assistance systems by taking over physically and mentally stressful routine tasks. Human-centered AI fosters the idea of maximizing human control and autonomy of decisions and the benefits of machine autonomy and automation through AI [19]. Human-centered AI materializes the ethical dimensions/principles of being beneficial to humanity, being non-maleficence, supporting human autonomy, addressing the principle of justice, and holding explicability (incl. intelligibility and accountability) [20]. Both AI ethics, which provides a broader view of AI impacts (at the macro level), and human-centered AI, focusing on concrete AI embeddings, explicitly reference sustainability in a broader sense (e.g., the triple bottom line). Consequently, the human-centered AI development process should undergo a systematic extension of sustainable AI development. As a result, AI development should be understood as a multi-level process, where work processes (collaboration and tasks) will be redesigned with the help of AI, in which human, technical and organizational aspects (HTO) take place within an economic, social, and environmental context.

² „Goldman Sachs employed six hundred traders in 2000, the corporation was able to reduce their number of human traders to two by 2017 because of advances in narrow AI” [8.]

4 AI Development in Industry – A Sustainable Approach

On the one side, sustainable AI development in manufacturing/industries needs to be aware of the changes and impacts on micro-level (e.g., concrete humans, material flows, emissions by work tasks), meso-level (e.g., processes, organization, and collaboration, pollution) and on macro-level (e.g., industries/economy, society, eco(logical)-system), which comes along with AI implementation. On the other side, there are driving and regulating forces from the macro-level, which are highly relevant for the sustainable AI development process. Therefore, we suggest a conceptual model (figure 1) for the development of sustainable AI, which includes a selection of the major perspectives that are displayed in the contemporary scientific debate. The model represents the forces at the level described below.

There are mainly four forces spanning from macro-level through meso-level to micro-level. (1) The **industry** or sector pushes the organization to be competitive, in two major directions: First to be competitive on market by AI-driven rationalization or product/service enrichment and second to be competitive in the war for talents, having an attractive and future-oriented work environment. (2) In addition, there is a growing demand for **sustainability**, e.g., offering eco-friendly solutions, pushing the organization to explore the potentials of AI development (e.g., in material loss or emission reduction). (3) From the **political side**, a lot of initiatives to regulate the operation of AI are ongoing. (4) Those regulations are built on works about the **ethics** of AI and AI usage – which is broader and less formalized than the law, regulations and standards [21] – but is also a driving force in AI development. Both ethics and politics targeting on the humanization of AI-based collaboration and work. Its three levels resp. perspectives are explained in the following:

Micro-level of sustainable AI Development

While human-centered AI approaches place humans at the center of AI development, the Human-Technologies-Organization (HTO) approach complements this approach by analyzing and developing socio-technical systems and emphasizing the importance of the work task which bridges the comprehensive intertwining of humans, technology, and organization [22]. This also includes the role of the machine, as a novel actor in tasks (see definition above). Finally, AI developments are creating novel technical actors (see AI definition) and thus novel collaboration schema on the micro-level. Consequently, in order to analyze the impact and design of the use of AI technologies on a micro-level in a sustainable way, one needs to be aware of the strong links between humans and their tasks, the collaborations, incl. to autonomous tasks taken by AI, within the organization.

The idea of sustainable AI development is to enhance the flexibility, resilience, autonomy, and efficiency of organizational processes (economical value) and reduce the ecological impact (e.g., emissions) while keeping the independence of human decisions within the tasks or processes (social sustainability). All targets may be contradictory. Therefore, the development process needs to be multi-disciplinarity (e.g., HTO, human-centered approaches, sustainability measures), including different measures to analyze and develop novel organizational, technical as well as human capabilities, and participative, involving stakeholders and maximize the values in a sustainable way. Collaboration among the various stakeholders is particularly

important, both in terms of external influences and within the organization (e.g., inclusion of different employee groups). Aspects of team design, task design, and work practices are related to human-centered collaboration - e.g., how to incorporate machine team members into existing collaborative processes [23]. This requires bringing together expert knowledge from science (e.g., industrial psychology) and practical use cases from companies. Finally, sustainable AI development is a pathway of finding measures to minimize negative impacts and maximize values for all.

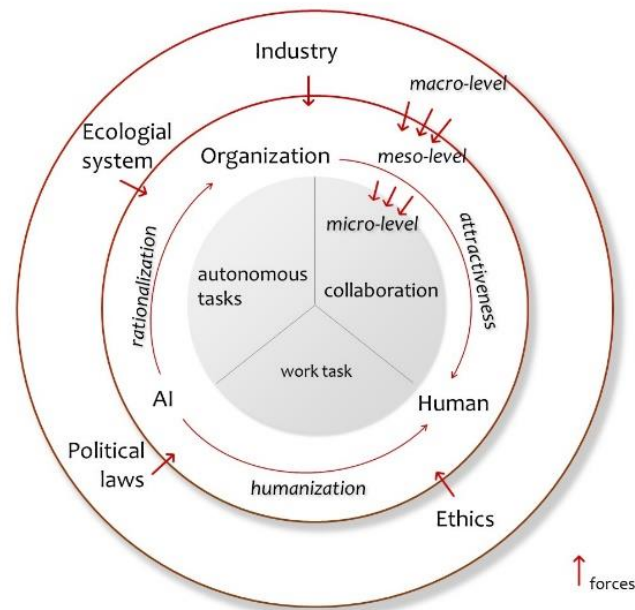


Figure 1 Conceptualization of the levels of sustainable AI development

Meso-level of sustainable AI Development

On the meso-level, analytically, AI development has two directions. While AI development is on the one hand, a rationalization process toward automation and autonomization of processes within an organization or in collaborative networks, it is on the other hand, a mechanism that can foster the humanization of work (fostering well-being), focusing on the human-oriented design of work systems. While the first aspect (rationalization) is mainly driven by economic factors of the organization, the second (humanization) is primarily driven by social demands and requirements (e.g., law or culture). On the meso-level, the above described four main forces are getting operand. AI development can act like a catalysator for realizing aspects of sustainability on the macro-level (e.g., reducing material loss in manufacturing, which goes along with economic factors and helps to support SDG 12 [24]).

Macro-level of sustainable AI Development

SDG has been adapted in several ways in the European Union, e.g., by the Green Deal [25] or the Annual Sustainable Growth Strategy 2020 [26]. A combination of reports, regulations, and recommendations of the EU high-level expert group [27] as

well as the presented political frame for sustainability builds the backbone of the macro-level. Eurostat has developed several indicators to measure the sustainable impact [28]. Besides the ethical and political dimension, the macro-level also includes the societal and economical forces on the market described above.

To assess sustainable AI development at different levels, the interplay needs to be considered. The identification of trade-offs between the indicators is always important for the analysis and development. As an example: AI-enabled eco-efficient production lines (less material as well as input and costs per product) may foster, on the macro-level, unemployment (meso-level also loss of capability and knowledge) or repetitive, non-creative work and therefore violate the decision-making autonomy of employees and increase psychological strain (micro-level) [29]. It also may lead to a higher production rate (more products and more material input and respectively more waste) – thus, the end-of-life and business models came into focus. Table 1 presents some quintessential examples of measures for the levels of sustainable AI development and depicts the interlinkage among them.

Table 1: Exemplary methods for measuring sustainable AI

Methods (examples)		Impact and value perspective
To identify and measure concrete values for all stakeholders, value mapping tools [30] can be used to describe created, destroyed, and not-realized values. Also, the human-centered design of work systems with digital work equipment approaches can be used (see also DIN EN ISO 6385 2016; DIN EN ISO 9241-11 2018).	Micro-level	AI developments have an impact on work tasks and concrete collaborations. There are concrete values and effects on the ecological and economical side, as well as consequences for direct or indirect involved actors that need to be analyzed. Design and development include measures to maximize stakeholder values and avoid one-sided misuse.
Lifecycle costing and assessments are common tools for sustainable developments [31]. To assess the value for this triple-bottom-line of sustainability, a 3D vector may be used [32], but a multidimensional vector with industrial and case-specific indicators is also possible. Further a sustainable value mapping or similar approaches can be employed [33].	Meso-level	The organizations and collaborative networks are the binding links between task level and multi-national sustainability goals. Indicators need to summarize the micro-level impacts in a proper way all over the product lifecycle and the supply network.

In addition to the SDG and its European realization mentioned above, several works/methods with specific indicators, like the GRI (Global Report Initiative), ISO 26000, EMAS (Eco-Management and Audit Scheme) can be used.	Macro-level	AI developments all over the product lifecycle and supply network will have an impact on economic growth, ecological and social aspects. Here, sustainable AI development needs to link the indicators on the meso-level with the indicator developments on the macro-level.
------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	-------------	------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

AI will cause changes within the whole product lifecycle – from cradle to cradle – and the supply network. Consequently, sustainable AI development must be aware of its prerequisites (e.g., data acquisition and data sovereignty of all stakeholders), consequences (e.g., on workforces and competencies), and (if predictable) rebound effects (more products without end-of-life integration) within the product lifecycle [34] also shown in [24].

5 Conclusion and Outlook

Due to the potential negative impacts of AI, the application of AI encounters ethical, political, and organizational resistance. For example, there is currently a lack of uniform, European-level recommendations with a focus on human-centered and ethical AI [6]. To counteract these, the possible values, as well as the potential value destruction, on all levels need to be understood. The approach developed here provides a conceptual framework that places sustainable and human-centered AI in the focus of design research. This combines approaches from different domains (see e.g., [7]). Due to its rapid development, AI has a decisive influence on the achievement of the 2030 Agenda, and in this context, can influence the goals both positively and negatively [15]. Its sustainability considerations and interdisciplinarity, the presented concept may serve as a starting point to using AI as a positive driver for the achievement of the Sustainable Development Goals and for creating relevant contexts.

However, at this stage, the concept has its limitations, e.g., effectiveness in practical applications. In this context, the concept needs to be implemented and evaluated in practice [9]. Therefore, the long-term goal must be to apply and adapt the concept to various practical use cases. Due to different legal regulations, cultural values, and organizational structures, there are also certain differences between countries and regions in terms to the practical problems in the introduction of AI [15].

Furthermore, the paper focuses on the impact of AI in processes/value chains/networks within the industries and not on AI development for products or services. Maybe the approach is also adaptable, but we focus on the organizational value chain at this point. In summary, the presented approach provides a basis for combining the factors of technology, human, and organization when using AI. In the future, the concept needs to be expanded based on ongoing research projects as well as practical evaluations. Therefore, further work will e.g., require to administer standardized interviews and the assessment of an AI-readiness questionnaire to evaluate the concept in a practical environment.

Acknowledgments. This research and development project is funded under the funding measure "Future of Work: Regional Competence Centers for Work Research - Artificial Intelligence" in the program "Innovations for Tomorrow's Production, Services and Work" of the Federal Ministry of Education and Research (BMBF) and supervised by the Project Management Agency Karlsruhe (PTKA). Fund. No.: 02L19C500.

References

1. Camarinha-Matos LM, Fornasiero R, Ramezani J et al. (2019) Collaborative Networks: A Pillar of Digital Transformation. *Applied Sciences* 9:5431. <https://doi.org/10.3390/app9245431>
2. Makridakis S (2017) The forthcoming Artificial Intelligence (AI) revolution: Its impact on society and firms. *Futures* 90:46–60. <https://doi.org/10.1016/j.futures.2017.03.006>
3. EC (2018) Coordinated Plan on AI. <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52018DC0795&rid=3#:~:text=Artificial%20Intelligence%20refers%20to%20systems,or%20speak%20with%20digital%20assistants.> Accessed 05 Apr 2022
4. Cioffi R, Travagliani M, Piscitelli G et al. (2020) Artificial Intelligence and Machine Learning Applications in Smart Production: Progress, Trends, and Directions. *Sustainability* 12:492. <https://doi.org/10.3390/su12020492>
5. Hong Z, Guo X (2019) Green product supply chain contracts considering environmental responsibilities. *Omega* 83:155–166. <https://doi.org/10.1016/j.omega.2018.02.010>
6. Floridi L, Cows J, Beltrametti M et al. (2018) AI4People-An Ethical Framework for a Good AI Society: Opportunities, Risks, Principles, and Recommendations. *Minds Mach (Dordr)* 28:689–707. <https://doi.org/10.1007/s11023-018-9482-5>
7. Auernhammer J (2020) Human-centered AI: The role of Human-centered Design Research in the development of AI. In: *DRS2020: Synergy*. Design Research Society
8. Goralski MA, Tan TK (2020) Artificial intelligence and sustainable development. *The International Journal of Management Education* 18:100330. <https://doi.org/10.1016/j.ijme.2019.100330>
9. Hevner, March, Park et al. (2004) Design Science in Information Systems Research. *MIS Quarterly* 28:75. <https://doi.org/10.2307/25148625>
10. Gregor S, Hevner AR (2013) Positioning and Presenting Design Science Research for Maximum Impact. *MIS Quarterly* 37:337–355. <https://doi.org/10.25300/MISQ/2013/37.2.01>
11. Bjørlo L, Moen Ø, Pasquine M (2021) The Role of Consumer Autonomy in Developing Sustainable AI: A Conceptual Framework. *Sustainability* 13:2332. <https://doi.org/10.3390/su13042332>
12. Halsband A (2022) Sustainable AI and Intergenerational Justice. *Sustainability* 14:3922. <https://doi.org/10.3390/su14073922>
13. Wilson C, van der Velden M (2022) Sustainable AI: An integrated model to guide public sector decision-making. *Technology in Society* 68:101926. <https://doi.org/10.1016/j.techsoc.2022.101926>
14. Shevlin H, Vold K, Crosby M et al. (2019) The limits of machine intelligence: Despite progress in machine intelligence, artificial general intelligence is still a major challenge. *EMBO Rep* 20:e49177. <https://doi.org/10.15252/embr.201949177>

15. Vinuesa R, Azizpour H, Leite I et al. (2020) The role of artificial intelligence in achieving the Sustainable Development Goals. *Nat Commun* 11:233. <https://doi.org/10.1038/s41467-019-14108-y>
16. Frank MR, Autor D, Bessen JE et al. (2019) Toward understanding the impact of artificial intelligence on labor. *Proc Natl Acad Sci U S A* 116:6531–6539. <https://doi.org/10.1073/pnas.1900949116>
17. Dörr S (2021) *Corporate Digital Responsibility*. Springer Berlin Heidelberg, Berlin, Heidelberg
18. Shneiderman B (2020) Human-Centered Artificial Intelligence: Three Fresh Ideas. *THCI*:109–124. <https://doi.org/10.17705/1thci.00131>
19. Shneiderman B (2020) Human-Centered Artificial Intelligence: Reliable, Safe & Trustworthy. *International Journal of Human–Computer Interaction* 36:495–504. <https://doi.org/10.1080/10447318.2020.1741118>
20. Floridi L, Cowls J (2021) A Unified Framework of Five Principles for AI in Society. In: Floridi L (ed) *Ethics, Governance, and Policies in Artificial Intelligence*, vol 144. Springer International Publishing, Cham, pp 5–17
21. ISO ISO/IEC DIS 23894: Information technology - Artificial intelligence - Guidance on risk management(1). <https://www.iso.org/standard/77304.html>. Accessed 17 Jun 2022
22. Paulsen H, Zorn V, Inkermann D et al. (2020) Soziotechnische Analyse und Gestaltung von Virtualisierungsprozessen. *Gr Interakt Org* 51:81–93. <https://doi.org/10.1007/s11612-020-00507-z>
23. Seeber I, Bittner E, Briggs RO et al. (2020) Machines as teammates: A research agenda on AI in team collaboration. *Information & Management* 57:103174. <https://doi.org/10.1016/j.im.2019.103174>
24. Mancini L, Vidal Legaz B, Vizzarri M et al. (2019) Mapping the role of raw materials in sustainable development goals: A preliminary analysis of links, monitoring indicators and related policy initiatives. EUR, Scientific and technical research series, vol 29595. Publications Office of the European Union, Luxembourg
25. EC (2019) The European Green Deal. https://ec.europa.eu/info/sites/default/files/european-green-deal-communication_en.pdf. Accessed 05 May 2022
26. EU (2019) Annual Sustainable Growth Strategy. <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0575&from=en>. Accessed 05 May 2022
27. AI H (2019) High-level expert group on artificial intelligence. Ethics guidelines for trustworthy AI
28. eurostats (2020) Indikatoren: Indikatoren für nachhaltige Entwicklung. <https://ec.europa.eu/eurostat/de/web/sdi/indicators>. Accessed 05 May 2022
29. Hacker W (2022) Arbeitsgestaltung bei Digitalisierung. *Z Arb Wiss* 76:90–98. <https://doi.org/10.1007/s41449-022-00302-0>
30. Bocken N, Short S, Rana P et al. (2013) A value mapping tool for sustainable business modelling. *Corporate Governance* 13:482–497. <https://doi.org/10.1108/CG-06-2013-0078>
31. Hunkeler D, Lichtenvort K, Rebitzer G (2008) *Environmental life cycle costing*. Crc press
32. Aliabadi MM, Huang Y (2016) Vector-Based Sustainability Analytics: A Methodological Study on System Transition toward Sustainability. *Ind Eng Chem Res* 55:3239–3252. <https://doi.org/10.1021/acs.iecr.5b03391>
33. Winans K, Dlott F, Harris E et al. (2021) Sustainable value mapping and analysis methodology: Enabling stakeholder participation to develop localized indicators mapped to broader sustainable development goals. *Journal of Cleaner Production* 291:125797. <https://doi.org/10.1016/j.jclepro.2021.125797>
34. Terzi S, Bouras A, Dutta D et al. (2010) Product lifecycle management – from its history to its new role. *IJPLM* 4:360. <https://doi.org/10.1504/IJPLM.2010.036489>