Digital Technologies for Sustainability

Climate change and AI: A research agenda for sustainable intelligence

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Abstract: Artificial intelligence (AI) represents one of the most powerful technologies currently available to humanity, offering immense potential for transformative change. It has the potential to assist us in addressing our most pressing climate change concerns. It can also enhance our ability to promote and lead the transition to sustainability. However, it is also important to acknowledge that AI is a technology that requires significant resources. It is estimated that by 2025–2026, the daily training costs for the large AI models will exceed the global computing capacity. This chapter presents the latest developments in AI for sustainability transformation and sustainable AI, with a particular focus on reducing resource consumption. It introduces the concept of sustainable intelligence and discusses a research agenda featuring a multidisciplinary, transformative approach to the design and development of AI technologies and AI-based systems, with the objective of ensuring their development in an environmentally friendly and socially responsible manner, and with the aim of investigating their impact on the natural, technical and societal environment.

Keywords: digital transformation, information and communication technologies, artificial intelligence, sustainable AI, AI for sustainability, sustainable intelligence

1. Technologies and societal progress – demystifying technical progress

In the context of climate change and the potential of artificial intelligence (AI) to develop solutions to mitigate its effects, this section begins with a discussion of key concepts of technology, technological progress, and technical infrastructures in societies. Building on this, Section 2 discusses information and communication technologies and the dual transition for digital transformation and sustainable transformation in line with the United Nations Sustainable Development Goals. Finally, Section 3 focuses on AI as an emerging powerful technology and its relationship to the transformation towards sustainability. Based on this discussion and a review of related research, the concept of sustainable intelligence and a research agenda for sustainable intelligence are presented and discussed.

This section introduces key concepts of engineering in the construction of the technical infrastructures on which modern societies depend, such as energy supply, transport and mobility services, or information distribution. A basic understanding of engineering is important to place the social science debate on contextualised dichotomies in digital transformation; on the relationship between society, resources, and pollution; or on power relations into a broader, multidisciplinary perspective that includes technical sciences and engineering.

In his book on the 'technological society', Ellul (2021, p. XXV) states:

> The term technique, as I use it, does not mean machines, technology, or this or that procedure for attaining an end. In our technological society, technique is the totality of methods rationally arrived at and having absolute efficiency (for a given stage of development) in every field of human activity. Its characteristics are new; the technique of the present has no common measure with that of the past.

And Ellul (2021, p. 427):

> The human race is confusedly beginning to understand at last that it is living in a new and unfamiliar universe. The new order was meant to be a buffer between man and nature. Unfortunately, it has evolved autonomously in such a way that man has lost all contact with his natural framework … Enclosed within his artificial creation, man finds that there is no 'exit' … The new milieu has its own specific laws which are not the laws of organic or inorganic matter. Man is still ignorant of these laws.

Sixty years later, we are still struggling to realise that in the Anthropocene the human-centred view must be replaced by or, at least, combined with a planet-centred view, where humans are just one of the species on this planet. If the well-being of the majority of humanity is to prevail, then the well-being of the whole planet must be the top priority towards which all available resources and efforts must be directed.

Another obstacle is that this artificial technological universe, as the source of climate change, is also the foundation for the solution to the transformation towards sustainability and climate resilience (see section 2). However, the initial theory of technocracy has proved inadequate in addressing the challenges that emerged in the context of political and industrial crises. Technocracy gave rise to expectations that were not fully aligned with the capabilities of the technocratic approach, which was also perceived as a means of declining ideologies and even politics in a knowledgeable society. Boorstin (1978, frontmatter) posits that the converging powers of technology will ultimately prevail, overcoming the barriers posed by '[i]deology, tribalism, nationalism, the crusading spirit in religion, bigotry, censorship, racism, persecution, immigration and emigration restriction, tariffs, and chauvinism'.

In a subsequent statement, Gunnell (1982, p. 9) asserts that:

> The precise nature of the impact of technology on politics is sometimes ambiguous, but it seems to involve three distinct – though not mutually exclusive – theories, dimensions, or levels of analysis:
> 1. In circumstances in which political decisions necessarily involve speciali[s]ed knowledge and the exercise of technical skills, political power tends to gravitate toward technological elites.
> 2. Technology has become autonomous, hence politics has become a function of systemic structural determinants over which it has little or no control.
> 3. Technology (and science) constitute a new legitimating ideology that subtly masks certain forms of social domination.
> In each level of analysis, there is a concern about the depreciation of the political realm, the subversion of traditional bases of authority, and the ascendancy of instrumental over political rationality.

Gunnell's evaluation provides a more accurate depiction of the interrelationship between technique (and technologies) and politics (and society). In the context of the technocratic paradigm, however, the contributions of technologies and engineers are frequently excluded from social and political discourse on the grounds that they would be unable to offer meaningful solutions to the challenges societies face. This attitude is particularly noteworthy in light of the fact that, as a consequence of technological advancement, global well-being, satisfaction, and happiness are on a steady upward trajectory (Azuh et al., 2020; Hausken & Moxnes, 2019; Kowal & Paliwoda-Pekosz, 2017).

Myths about technical progress include:

- We would have been overrun by technology.
- Technology would be harmful.
- Technology would be accountable.

Notably, technology is a science and the study of engineering. It is concerned with the ways in which (raw) materials and components can be transformed into technical systems, including digital products, services, and information/data. These transformation processes use scientific knowledge and tools. The results of engineering are technical systems that are deployed, operated, maintained, and used, and the sum of these technical systems constitutes the technical infrastructure of a society. Its modernity and availability are directly related to a society's ability to be innovative and resilient: 'in the longer view a secure society involves innovation in strong infrastructure and social systems' (Allenby & Fink, 2005, p. 1034).

Moreover, because technologies, technical systems, and infrastructures have no agency, they cannot be held accountable, but stakeholders such as clients, contractors, developers, operators, consumers, regulators, researchers, entrepreneurs, or firms can. Technologies, actors, and infrastructures (technical, institutional, and operational) constitute technological systems:

> A technological system may be defined as a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utili[s]ation of technology. Technological systems are defined in terms of knowledge/competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks. In the presence of an entrepreneur and sufficient critical mass, such networks can be transformed into development blocks, i.e. synergistic clusters of firms and technologies within an industry or a group of industries. (Carlsson & Stankiewicz, 1991, p. 111)

Such technological systems are sources of innovation (Blatter 2004). They can be regional, such as the microelectronics core in Saxony, or cross-border, such as Silicon Valley and the Baja California region between the United States and Mexico, or the Øresund region between Denmark and Sweden.

In addition, technologies, technical systems, infrastructures, technological systems, and innovations are human-made. The actors involved in their development decide on the objectives, the values pursued, and the final impact on society. The closer developers get to the final artefacts, the smaller the set of choices available. Along the development processes – whether it is a concrete product, a technical infrastructure, or an innovation region – more and more values are hard-coded. Therefore, it is essential to address value sets from the outset of analysis and design. The speed and scale of today's information and communication technologies (ICTs) used in digital transformation make it particularly important to ensure respect for democratic values. Important fields include privacy, data security, and decision-making powers (Subirats, 2002), sustainability goals like the United Nations' Sustainability Development Goals (UN SDGs; see Pedersen, 2018), and business values that include corporate social responsibility (CSR; Ali et al., 2017) and environmental, social, and governance performance (ESG; Huang, 2021).

Finally, Esmark (2020, p.79) 'clears up the considerable confusion surrounding the relationship between technocracy, bureaucracy and democracy, which provides the foundation for the empirical analysis of the anti-bureaucratic and pro-democratic nature of contemporary technocracy', leading me to conclude that there is no dichotomy between technology and sustainability and no dichotomy between technology and prosperity, but that there may be an imbalance between the technical, environmental, and political environment, as will be discussed in the following sections.

Before discussing this further, the paper presents a brief overview of the components of the ICTs that provide the fundamental capabilities for digital transformation (Figure 1). Hardware and software are used to build the devices, which are interconnected by networks for telecommunications and mobile communications. The devices essentially store, compute, interpret, and present data that can be stored in databases. (Cyber) security is important to ensure the integrity of systems and services, to protect sensitive data, to prevent cybercrime, to protect privacy, and to build and maintain trust in digital solutions. More and more IT services are being virtualised and delivered via cloud platforms as infrastructure as a service (IaaS), platform as a service (PaaS), software as a service (SaaS), and data as a service (DaaS) – in short, everything as a service (XaaS). Emerging technologies for ICT include:

- Internet of Things (IoT) for connecting the physical and cyber worlds, where IoT refers to a network of interconnected physical devices that can collect, exchange, and act on data over the Internet

- Cloud computing for the delivery of computing services such as storage, processing, and software over the Internet, allowing users to access and use these resources on demand from anywhere
- Edge computing focuses on processing data closer to where it is generated or needed, reducing latency and bandwidth consumption by processing data locally on devices or close to the data source
- Distributed ledger technologies to improve security, immutability, and/or transparency through decentralised systems where multiple participants maintain and validate a synchronised, immutable record of transactions across a network
- Computer vision to analyse, understand, and interpret visual information from digital images, video, or 3D models to make decisions or to perform specific tasks to interpret and make decisions based on visual data from the world
- Virtual reality (VR) immerses the user in a fully artificial digital environment, and augmented reality (AR) overlays digital information onto the real world to enhance the user's perception of their surroundings
- AI essentially simulates human intelligence processes by computer systems, enabling them to perform tasks such as learning, reasoning, problem-solving, perception, and language understanding
- Next generation software engineering improves the efficiency, scalability, and quality of software development and maintenance processes by applying new methods such as AI, DevOps, or microservices

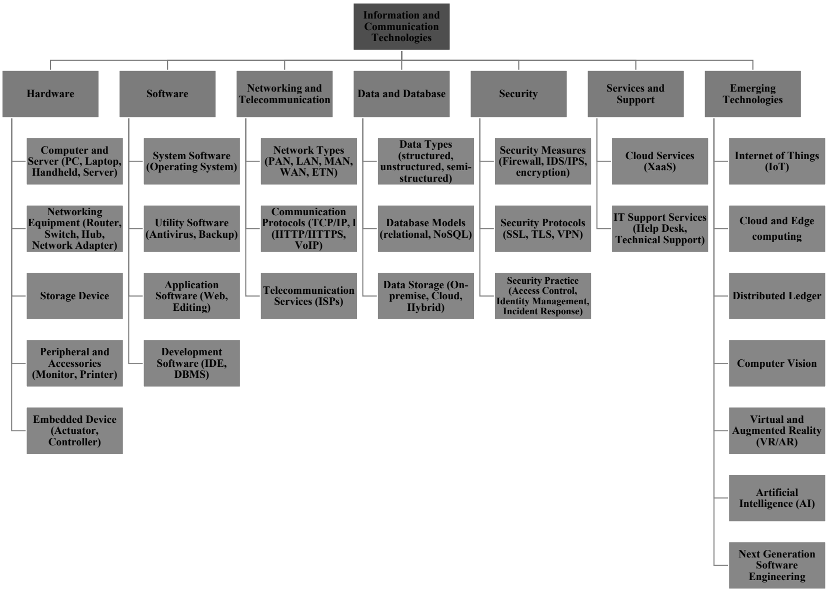

Figure 1. Overview of information and communication technologies (ICTs)

ICTs provide the basis for digital socio-technical systems, e.g. in Industry 4.0 (Aceto et al., 2019). The term socio-technical system was coined in the 1960s and refers to the

> joint optimization of the social and technical systems. The technical and social systems are independent of each other in the sense that the former follows the law of natural science while the latter follow the laws of the human sciences and is a purposeful system. Yet they are correlative in that one requires the other for the transformation of an input to an output, which comprise the functional task of a work system. Their relationship represents a coupling of dissimilars which can only be jointly optimized. (Trist, 1981, p. 24)

More recent publications define digital transformation (DT) as 'the process of organizational or societal changes driven by innovations and developments of ICT. DT includes the ability to adopt technologies rapidly and affects social as well as technical elements of business models, processes, products and the organizational structure' (Bockshecker et al., 2018, p. 9).

ICT has led to the development and evolution of the Internet 2 (Leiner et al., 2009; Ryan, 2010), which began as an Internet of Information for the exchange of data and documents through hypertexts. With the commercialisation of the Internet after the 1990s, it has evolved into the Internet of Services, where different services are seamlessly connected and delivered. The Internet of Services focuses on the provision of a wide range of services offered, such as infrastructure, platform, and business process services, enabling greater accessibility, efficiency, and automation. It aims to create a service-oriented ecosystem where services can be dynamically discovered, provisioned, managed and consumed. Since the 2000s, the Internet of Things has also added connections to the physical world through smart sensors and actuators. Currently, the Internet is evolving into the Internet of Collaboration by providing unified platforms, enhanced connectivity and real-time collaboration for instant interaction and synchronised workflows. It enables remote working, education, and participation at a new scale, as well as inclusive participation.

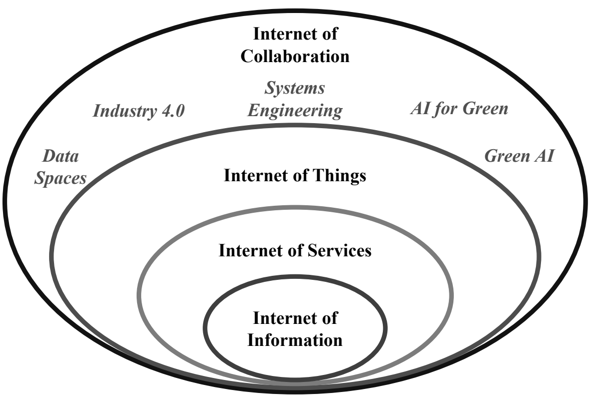

Figure 2. The evolution of the Internet

The Internet has become a technique that has transformed the way individuals, businesses, and societies interact. It has become a central part of the technical infrastructures of societies to the extent that the ability to use the Internet as a means of consuming and providing information is being discussed as a fundamental human right – for the freedom of expression through the free access to the Internet (Reglitz, 2020). Its emergence also led to the term Digital Age (Messner et al., 2019), originally called the

Information Age (Toffler, 1982). While the Internet fundamentally changed the exchange of information and services in societies, AI will fundamentally change their production and consumption, including their exchange (see also section 3).

2. Sustainability and digitalisation

Before discussing the implications of AI further, this section briefly reviews aspects of sustainability and digitalisation in general: At the UN Conference on Sustainable Development in Rio de Janeiro in 2012, the "The Future We Want" document on sustainable development and a green economy was adopted. This document set the stage for the development of the UN Sustainable Development Goals (UN SDGs). The UN SDGs (Saxena et al., 2021) are a globally adopted canon of values to combat climate change with balanced means for environmental, social, and economic progress. They consist of 17 goals and 169 targets to advance societies economically and politically, reducing poverty and increasing prosperity in a world with mitigated climate change. The SDGs address environmental, social, and economic sustainability for a coordinated approach to climate change (see Figure 3).

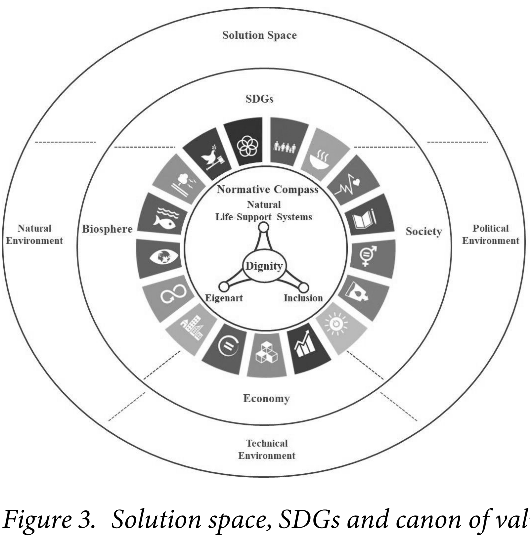

Figure 3. Solution space, SDGs and canon of values for sustainability

The transformation towards sustainability in the Digital Age is based on a normative compass. Its starting point is human dignity, i.e. its inviolability, respect, and protection. In addition, the normative compass has three dimensions (Messner et al., 2019, p. 3; for further reading, see Chowdhary, 2020; Enholm et al., 2022; Zhang & Lu, 2021):

- 'Sustaining the natural life-support systems': Comply with planetary guardrails and avoid or solve local environmental problems.
- 'Inclusion': Ensure universal minimum standards for substantive, political and economic inclusion.
- 'Eigenart': Recognise the value of diversity as a resource for successful transformation and as a condition for well-being and quality of life.

As an aside, it is important to note that researchers question (Stober, 2019; Tarcan et al., 2022) whether the normative compass for the transformation towards sustainability should remain human-centred, as it is today, or shift to a more-than-human-centred or nature-centred leadership, which has been debated often and remains an ongoing discussion. However, this topic does not directly contribute to the essence of this chapter and, therefore, will not be discussed further here.

The solution space for sustainability transformation in the Digital Age consists of solutions that target the natural, technical, or political environment. All three environments are interconnected, and a solution in one environment rarely works without taking into account the others, also referred to as dimensions. Most solutions for the transformation towards sustainability will have to be socio-technical-ecological solutions, going far beyond the conventional concept of purely socio-technical systems (Ahlborg et al., 2019; Smith & Stirling, 2010).

Due to the complexity of the SDGs, this chapter focuses on the environmental aspects of sustainability in view of digitalisation in general; later sections centre on AI. Because ICTs and digitalisation, like the SDGs, are very complex (see section 1), the chapter below focuses on the specific implications of AI for environmental sustainability in view of the natural, technical, and political environment.

There are a number of surveys on environmental sustainability and digitalisation:

- Chen et al. (2020) investigate whether digital applications in manufacturing positively or negatively impact the environment by looking at improved resource efficiency in product design, production, transport, and customer service. They also examine the environmental impacts of resource and energy use, including waste and emissions from the manufacture, use, and disposal of digital systems. The authors propose a lifecycle perspective on the environmental impacts of a product and the technology lifecycle. Such a lifecycle perspective is supported by the ecological footprint, which should also include the footprint of the digital services used.

- Broccardo et al. (2023, p.15) review how companies have built sustainable business models through the use of digitalisation. They identify the benefits of digitalisation in helping to 'i) share resources, ii) improve relationships and collaboration, iii) reuse, and iv) recycle. All these actions have a positive impact on the cost structure, efficiency, and the creation of new revenue flows'.
- Lange et al. (2020, frontmatter) investigate the relationship between digitalisation, ICT usage, and energy consumption. They conclude that 'ICT decreases energy demand via energy efficiency and sectoral change. ICT increases energy demand via a growing ICT sector, rebounds and economic growth'. Since digitalisation cannot decouple economic growth from energy consumption, it finally leads to a rise in energy consumption.
- Guandalini (2022, p. 466) analyses the relationship between digital transformation and sustainability improvements, calling for 'the development of a new stream of literature' dubbed 'digital sustainability'. The author claims that the 'identified research gaps are expected to foster future investigations with more focused outputs from management scholars to the practical community' and highlights selected research questions.

All this suggests that if ICT-based solutions for sustainability are resource-efficient and socially acceptable, they can make a real contribution to tackling climate change and improving climate resilience (Santarius et al., 2023; Rome, 2019). This view is also shared by the European Green Deal's policy objective of a digital and environmental 'twin transition', in which the two dynamics of digital and sustainable transformation reinforce each other (Salvi et al., 2022). For further reading on the digital revolution for sustainable development, see Fouquet and Hippe (2022), Mäkitie et al. (2023), and Sachs et al. (2019).

3. The impact of AI on environmental sustainability

Before discussing the implications of AI on the natural environment, this section provides a brief overview of AI as a key technology (see Figure 4) applied in almost every application domain of digitalisation. While there is no widely accepted definition of AI (Monett & Lewis, 2018), according to (Union, 2024, Article 3), an

> 'AI system' means a machine-based system that is designed to operate with varying levels of autonomy and that may exhibit adaptiveness after deployment, and that, for explicit or implicit objectives, infers, from the input it receives, how to generate outputs such as predictions, content, recommendations, or decisions that can influence physical or virtual environments.

Thus, AI systems are generally defined as cyber-physical systems that exhibit adaptability, however defined. Cyber-physical systems are

> [o]pen, networked systems ... that use sensors to capture data about what is going on in the physical world, interpret these data and make them available to network-based services, whilst also using actuators to directly affect processes in the physical world and control the behaviour of devices, objects and services. (Geisberger & Broy, 2015, p. 13)

Wang (2019, p. 1) defines (artificial) intelligence as capabilities for 'adaptation with insufficient knowledge and resources'. These capabilities include knowledge acquisition, language processing, search and pattern recognition, reasoning and learning, decision-making, and problem-solving (see Figure 4). On several benchmarks, AI-based systems have surpassed some human capabilities, such as image classification, visual reasoning, and language understanding, but not yet the capabilities needed for more complex problem-solving in mathematics, visual reasoning, or planning, to name a few (Perrault & Clark, 2024).

Nevertheless, AI capabilities are used in a wide variety of applications, including expert systems, natural language processing, computer vision, multi-agent systems, autonomous systems, and robotics and motion control. A wide variety of methods can be used to build AI-based systems. These can be divided into symbolic, statistical, and sub-symbolic methods, each of which has a number of subcategories (e.g. Chowdhary, 2020; Enholm et al., 2022; Zhang & Lu, 2021).

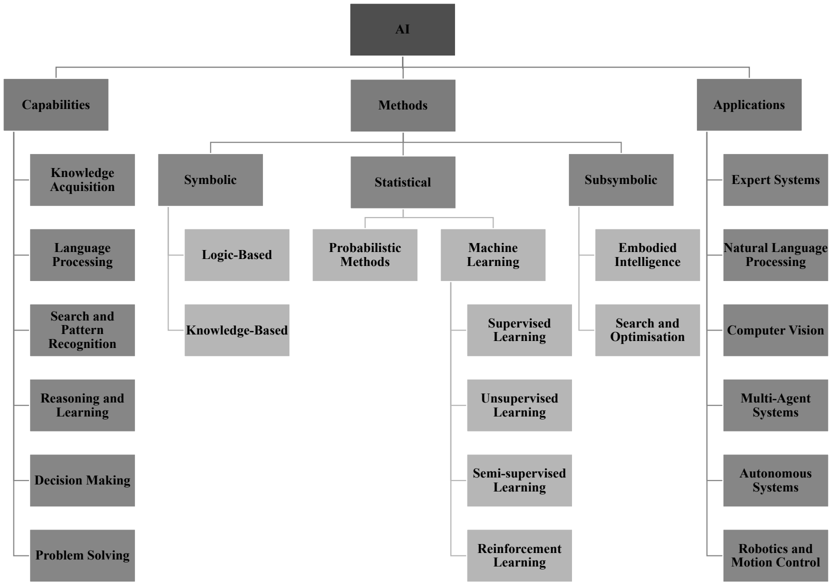

Figure 4. Overview of artificial intelligence

Digital systems (Belkhir & Elmeligi, 2018) and AI-based systems (Luccioni et al., 2024) have several orders of magnitude of impact on the environment and society (Bohnsack et al., 2022):

- 1st order: The use of resources and energy in the development, production, construction, operation and maintenance of AI-based technical infrastructures (Luccioni et al., 2024).
- 2nd order: Consumption effects through differently organised AI-based processes and through new processes such as in industry, administration, or smart cities (Bibri et al., 2024).
- 3rd order: Consumption and lifestyle effects through AI-based digital systems like online marketplaces (Bai, 2022).

The first, second, and third-order impacts of AI add up to the total impact, which can be positive or negative in terms of CO_2 emissions or resource use, impacting environmental sustainability. Currently, the first-order impacts are already very large in terms of energy consumption and carbon release, for example, for AI training and the use of AI systems such as ChatGPT or Llama (Luccioni et al., 2024):

> For instance, Meta's Llama2 70B model released approximately 291.2 tonnes of carbon, which is nearly 291 times more than the emissions released by one traveler on a round-trip flight from New York to San Francisco, and roughly 16 times the amount of annual carbon emitted by an average American in one year. (Perrault & Clark, 2024, p. 154)

The calculation of second and third-order effects is challenging due to the rapid pace of change in AI. No concrete figures are available. Nevertheless, research (Vinuesa et al., 2020) suggests that sustainable AI-based systems will make a significant contribution to tackling climate change. Some evidence indicates that AI can enable 134 targets across all SDGs, i.e. it can have a positive impact on 79% of the SDG targets, while it can inhibit 59 targets, i.e. it can have a negative impact on 34%. Further, the positive impact can only be achieved if there is 'regulatory insight and oversight for AI-based technologies to enable sustainable development' (Vinuesa et al., 2020, p. 1).

The potential second and third-order effects of AI have been investigated in numerous comprehensive and supplementary studies:

- Nishant et al. (2020, p. 1) argue that 'AI can support the derivation of culturally appropriate organizational processes and individual practices to reduce the natural resource and energy intensity of human activities. The true value of AI will not be in how it enables society to reduce its energy, water, and land use intensities, but rather, at a higher level, how it facilitates and fosters environmental governance'.
- Uriarte-Gallastegi et al. (2023, p. 662) demonstrate that 'Artificial Intelligence can significantly impact resource efficiency and provide a competitive edge to organizations, primarily by reducing energy and material consumption'.
- Regarding the potential impact of AI on the SDGs, Gupta et al. (2021, p. 2) state that 'the Environment category entails the highest potential with 93% of the targets being positively affected' and that 'when taking into account the type of evidence indicating the connection with AI, we observed that the positive effects on the Environment ... were quite robust'.
- Bibri et al. (2024) present the concept of smarter eco-cities as the convergence of AI and the Internet of Things (AIoT), which has significant potential to address complex environmental challenges by improving the performance and efficiency of smart cities.

Despite the existence of a multitude of research agendas pertaining to AI as a general-purpose technology, there is a notable absence of an integrated research agenda that encompasses both sustainable AI and AI for sustainability. To date, publications have focused on either sustainable AI or AI for sustainability. However, this separation of concerns carries the risk of overlooking important aspects, framework conditions, or side effects of AI. To illustrate, Vinuesa et al. (2020), Nishant et al. (2020), and Dwivedi et al. (2021) provide comprehensive accounts of AI for sustainability, but they do not address the specific issue of sustainable AI. More specifically, they fail to address the necessity of making AI more resource-efficient, including the issue of reducing its energy and data consumption. Another example is Mumtaz et al. (2022), who address potential unintended consequences, threats, and hazards of AI, including, for example, the performance threat. However, the article fails to consider the carbon footprint of AI. This omission is somewhat surprising given that Hilty and Aebischer (2015) had already identified the necessity for a new research field in the field of ICT for sustainability, highlighting the importance of reducing ICT-induced energy and material flows. However, the article by Hilty and Aebischer (2015) was somewhat lacking in its consideration of the societal need for trustworthy AI, although it also discussed ethical aspects of ICT. Verdecchia et al. (2021) present a technological landscape for the development of energy-efficient digital infrastructure. The paper's focus on the technical environment for sustainable transformation precludes any consideration of the natural and societal environments. While the authors identify the need for paradigm shifts and environmental and social solutions within the technical context, these are viewed exclusively from a technical perspective.

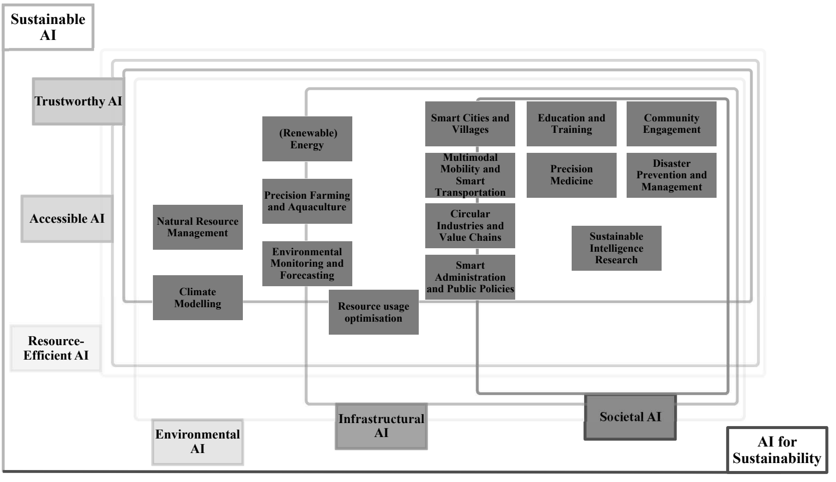

Figure 5. Research agenda for sustainable intelligence

It is time to coin a new concept: **sustainable intelligence** refers to the comprehensive approach of integrating sustainability principles into the development, deployment, and application of AI technologies. This concept has two primary dimensions:

1. Sustainable AI will address the sustainable development of AI by considering the environmental, technical, and societal impacts of AI in its design and implementation.

- Sustainable AI minimises carbon footprints, energy consumption, and resource use by optimising AI methods for data and energy efficiency, adopting the reduce, reuse, repair, and recycle principles for AI-based solutions, and using renewable energy to power them.
- Sustainable AI is to be made accessible through appropriate AI infrastructures, tools, and licences, including open access to AI and open-source AI methods, algorithms, models, and training and validation data for the public.
- Sustainable AI needs to be made trustworthy by making AI-based systems reliable, robust, and performant; more transparent through explanation, documentation, and disclosure; fairer through inclusivity and bias mitigation; accountable through explicit responsibilities and recourse mechanisms; secure by security design and secure operation

and through data, privacy, and security protection; and ethically aligned with the normative compass of society through value alignment.

By addressing these issues, sustainable AI can build and maintain trust among users and stakeholders, fostering greater acceptance and the responsible adoption of AI.

2. AI for sustainability to accelerate sustainability in society through AI-based solutions for a society's natural, infrastructural, and political environment.

- AI-based solutions for the natural environment involve the application of artificial intelligence technologies to monitor, manage, and protect natural ecosystems through remote sensing and (extra-)terrestrial and satellite imagery; image, sound, and pattern recognition; monitoring, modelling, simulation, and forecasting; and optimisation of resource use.
- AI-based solutions for the technical environment include the intelligent digitalisation of society's infrastructure, making it more robust, reliable, resilient, and secure through AI-based methods. These solutions also encompass the development and operation of AI infrastructures for industry, government, and the public, including data, computing, and storage centres.
- AI-based solutions at the societal level include enhancing public welfare and improving the quality of life in communities, using machine learning, data analytics, natural language processing, and other AI methods to address issues related to education, healthcare, public safety, governance, and more.

By applying AI technologies in these areas, we can develop innovative and effective solutions to further develop our democratic societies while protecting nature and biodiversity for future generations by reducing the impact of human activities on nature. Sustainable intelligence aims to create a symbiotic relationship between AI and sustainability, ensuring that technological advances contribute positively to the environmental, social, and economic dimensions of sustainability, while making AI development processes themselves more sustainable.

The research agenda for sustainable intelligence is shown in Figure 5, which highlights the highest-priority applications of AI and positions them in relation to the three-by-three dimensions of sustainable intelligence. It also highlights the fact that any AI-based solution in the public interest should be resource-efficient and accessible to relevant stakeholders. The majority of AI-based solutions must also be trustworthy, especially those that are societal AI solutions, as they interact within society with individuals, stakeholders, and interest groups. For simplicity's sake, the various AI-based solutions will not be detailed here. Instead, reference is made to the research mentioned above for further reading. The added value of the Research Agenda for Sustainable Intelligence lies in its multidimensional, multidisciplinary, and transformative approach, which is important to avoid siloed approaches to AI.

4. Conclusion

AI has and will continue to surpass human capabilities, enables novel solutions, and can be a socio-technical game changer in the transition towards sustainability. As climate change is the most pressing grand challenge facing humanity, and as digital solutions, especially AI-based systems, are at the same time the fastest-growing large energy consumers worldwide, it is important to engage in multidisciplinary, transformative research into the wide range of concepts, approaches, and empirical evidence of sustainable AI and AI for sustainability.

The concepts of sustainable AI and AI for sustainability collectively constitute sustainable intelligence. This term reflects the necessity to develop AI in a manner that is both resource-efficient and accessible while also ensuring that it is trustworthy. Furthermore, it encompasses the objective of utilising AI to address environmental, infrastructural and societal sustainability challenges.

In order to facilitate the successful development of sustainable artificial intelligence, it is essential that focused research adopts a multidisciplinary and transformative approach, investigating the enablers, inhibitors, power structures, and socio-technical basis for successful change towards sustainability. It is imperative that research be conducted to develop a comprehensive and well-founded knowledge base regarding the most appropriate technologies, designs, processes, and empirical models for facilitating a sustainable transformation. Furthermore, research should be conducted to gain a deeper understanding of the societal dynamics involved, including an analysis of the potential barriers and conditions for success.

Acknowledgements

This article has been made possible by the work and discussions with my colleagues and friends at the Weizenbaum Institute for the Networked Society, the Weizenbaum Conference on Uncertain Journeys into Digital Futures, and the German Advisory Council on Global Change. Thanks to all of you.

Disclosure of Interests

Ina Schieferdecker was a co-founding director of the Weizenbaum Institute. She is now an independent researcher with no connection to the Weizenbaum Institute other than as an alumna.

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