Deploying Digitalisation and Artificial Intelligence in Sustainable Development Research

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Abstract: Many industrialised countries have benefited from 21st century technologies, especially automation, that have fundamentally changed manufacturing and industrial production processes. The next step in the evolution of automation is the development of artificial intelligence (AI), i.e., intelligence which is demonstrated by machines and systems, which cannot only perform tasks but also work synergistically with humans and nature. Intelligent systems that can see, analyse situations and respond sensitively to real-time cues, from human gestures and facial expressions to pedestrians crossing a busy street, will reshape transportation, precision agriculture, biodiversity conservation, environmental modelling, public health, construction and manufacturing, as well as initiatives designed to promote prosperity on Earth. This paper explores the connections between AI systems and sustainable development (SD) research. It addresses a perceived research gap seen in respect of investigations which examine the synergies among these topics. By means of a literature review, a world survey, and case studies, ways in which AI can support research on SD and, inter alia, contribute to a more sustainable and equitable world, are identified.

Keywords: artificial intelligence; digitalisation; sustainable development research; Sustainable Development Goals; world survey; case studies

1. Introduction to Digitalisation and Artificial Intelligence

Digitalisation and artificial intelligence (AI) technology have revolutionised life worldwide. Online reports showed that in 2019 the number of internet users worldwide reached 4.13 billion, which means that more than half of the global population is currently connected to the internet (Johnson, 2021). The internet has thus become increasingly more important for individual consumers as well as huge companies. Obviously, even though the number of internet users is visibly growing in numerous parts of the world, internet access and availability can differ significantly depending on the region. As a consequence of internet growth, globalisation, digitalisation and AI phenomena have seen a rather rapid development.

Oxford Learner's Dictionaries (2021b) defines digitalisation as the process of changing data into a digital form that can be easily read and processed by a computer. However, this term should be understood more widely, as the use of digital technologies to change a business model and to provide new revenue and value-producing opportunities. The European Commission (2021) enumerates the following technologies included in the digitalisation process: 3D Printing Cars; Mobile and Mobility; Internet of Things (IoT); AI; Blockchain; Augmented and Virtual Reality. Among those listed before, AI, i.e., the study and development of computer systems that can copy intelligent human behaviour (Oxford Learner's Dictionaries, 2021a), has gathered much attention recently (Kaplan & Haenlein, 2019). This idea was introduced in the middle of the twentieth century but needed a long time to turn it into reality, which was possible thanks to the increase in computation power and galloping miniaturisation. Currently, there are numerous applications of AI, including autonomous vehicles, cybersecurity, biometrics and many others (Choraś et al., 2019; Nowosielski et al., 2020; Orrù et al., 2020).

The progress of technology in sustainability research is summarised in Figure 1. In the beginning of 1980’s, technology options were rather constrained, researchers produced manuscripts with restricted distribution. Then, the microfiche aroused, allowing an acceleration of the availability of research results, and the word processors in the last four decades contributed to easy writing in research. Through progressive technological developments, research centres became increasingly connected, for example, at universities. The Advanced Research Projects Agency Network (ARPANET in US), together with the Transmission Control Protocol (TCP) and the Internet Protocol (IP), are considered as the Internet forerunners. The Internet and online browsers enabled to (re)search information all over the world. Digitalisation expanded at the beginning of the XXI century, from manuscripts to books, enabling academic libraries (and public as well) to provide wider access and ability to share resources. Currently, AI has become increasingly used in sustainability development research-and increasingly in the pursuit of the UN Sustainable Development Goals (Vinuesa & Sirmacek, 2021), mainly due to its analytical capacities, namely big data analyses, but also due to its ability to fine tune and make predictions in relation to biological mechanisms and processes, or ecological and environmental information management,. These features provide AI uses as potentially great benefits to the human and ecosystems health, as demonstrated though this study.

PLEASE INSERT FIGURE 1

Despite the evolution perspective of the adoption of technology in SD research, there is a paucity in the literature about how scholars are currently deploying AI and digitalisation as well as their opinions about using it in SD research. In this sense, this paper builds on the previous work in which is argued that the SDGs can benefit from the several applications of AI (Vinuesa et al., 2020) in several fields such as education, water management systems, agriculture and sanitation and health (Goralski & Tan, 2020), suggesting that understanding the extent to which AI is contributing to SD research is not only important, but essential to achieving the UN´s SDGs. To this purpose, the paper departs from the following research question: ow is AI being used to foster SD research and which elements influence this process?

The originality of this paper resides on the fact that it not only offers a comprehensive overview of the literature on the topic, but also combines it with a bibliometric analysis, the presentation of case studies and a survey, which has collected first-hand information from experts working with the topic. The combination of these three methods is believed to bring in depth answers to the previously formulated research question, generating theoretical and practical implications on how AI is being deployed by the scientific community and contributing to dealing with the SD challenges.

2. Artificial Intelligence and Sustainable Development Research

SD is a global, comprehensive initiative guided by the United Nations (UN). Its effective implementation needs intelligent research. Although there has been an increasing amount of SD research over the past few decades, scholarship on SD remains relatively emerging (Baumgartner, 2011). AI should, can and will play an increasingly supporting and coordinating role in SD research.

SD was initially defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations, 1987). It has evolved much since then. At present, SD objectives, such as those being currently pursued in the context of the UN-level Sustainable Development Goals (SDGs), address global challenges such as poverty, inequality, climate change, environmental degradation, peace and justice. SD is a comprehensive transformative vision. Its implementation has been emphasised by the pursuit of the UN 2030 Agenda for Sustainable Development (United Nations, 2015), which lists various goals, including some closely related to decarbonisation (Fuso Nerini et al., 2018), climate action (Fuso Nerini, Sovacool, et al., 2019), and other SD aspects.

AI is defined as the use of automated algorithms, robotics or automated machines that mimic cognitive functions of humans using the human brains to perform various tasks, such as learning, identifying, analysing and solving problems (Graham et al., 2020). The pace of advancement in developing and using AI has been accelerated by the expansion of artificial neural networks, cloud computing infrastructure, big data, research tools and datasets (Clark, 2015). The advances in AI technologies and algorithms, along with new AI techniques such as machine learning methods for structured data, modern deep learning, and natural language processing for unstructured data on the one hand, and the socioeconomic and environmental sustainability challenges that urgently need solutions on the other grant have granted AI significant momentum (Khakurel et al., 2018). Whereas developed countries led in the development of AI (Oxford Insights, 2020), China plays a leading role in the investment into AI technology (Gao et al., 2019). AI is fast becoming a component used in many fields including business, education and health. The use of machines and robots is pursued due to their deep learning abilities allowing for them to positively impact various sectors (Goralski & Tan, 2020).

Considering that both SD and SD research are extremely complex, AI holds the potential to play a transformative role in navigating and mitigating the difficulties inherent to pursuing both practical and academic tasks. For instance, AI-supported research can be used to help map, implement and report progress on individual SDGs and their related targets. AI systems, combined with augmented reality (AR) technology, can also play a leading role in coordinating the research of individual SDGs and targets in both vertical and horizontal manners. Vertically, AI can be used to intelligently guide and organise international, national, and local SD research efforts within various SDGs and SD targets. Horizontally, AI systems can be utilised to intelligently coordinate and enhance SD research efforts among various research groups on various SDGs and SD targets. AI is increasingly used to impact, map and support SD and the research on SD. AI has been found to have both positive and negative impacts on SD (Khakurel et al., 2018), and highlight the need for governance to achieve the UN SDGs (Truby, 2020). Earth observation data, for example, have an important contribution to make towards populating a wide diversity of the SDGs indicators (Andries et al., 2019). Machine learning and AI play an important role in supporting climate change research and preparedness (Huntingford et al., 2019). Case studies found digitalisation to support climate change adaptation and preparedness (Balogun et al., 2020). Comparison of AI algorithms for sustainability assessment (Bienvenido-Huertas et al., 2020), environmental evaluation (Liu et al., 2021), and text mining analysis (Sebestyén et al., 2020) all show the power of digitalisation for SD assessment and management. As earlier stated, AI can be used to achieve sustainability and the SDGs. Currently, AI is being used to address problems such as the water crisis. The design of smart water management systems allows for the replication of human learning in changing environments. AI powered systems maximise decisions and investments in water management infrastructure (Hill, 2018).

On top of that, the literature acknowledges that AI and digitalisation also have practical implications which could contribute to SD directly and indirectly, such as the effectiveness of policy-policy making in the public sector or even contributing to the organisational management and practices. From the public sector, for example, Di Vaio et al. (2022) identified through a bibliometric analysis that the human-AI, data intelligence and analytics interface could increase decision-making performance, which will lead to sustainable development (SD). On the other hand, from the companies´ perspective, there is evidence that AI-related technologies and digitalisation can also play an essential role in companies' innovation and contribute to sustainability-oriented strategies and practices (e.g. business model, supply chain, organisational culture), reducing the negative externalities and promoting positive ones towards the SDGs (Del Giudice et al., 2021; Isensee et al., 2020; Talwar et al., 2021).

In addition, AI can also be applied in the agricultural industry. A key example of AI in agriculture is the PlantVillage project that is aimed at small farmers who contribute largely to developing countries' food supply. PlantVillage was created to help in the diagnosis of plant diseases using a mobile app equipped with a database of images of different plant diseases (Brewster, 2016). Users can identify and classify plant disease by using a mobile phone camera. Due to farmers in developing countries lacking knowledge and technology, a decrease in productivity is observed. However, the use of inexpensive mobile technology can help in improving farming practice and thus increasing food security of countries (Goralski & Tan, 2020).

Providing clean water and sanitation falls under the SDGs set by the UN (Goralski & Tan, 2020). AI has been used to develop a Clean Water AI test system that can provide real time data about water quality. The system is able to identify contaminants swiftly and at low cost. The entire system set-up costs around $500, which is affordable for most organisations that are moving away from expensive traditional methods. Programmes are constantly upgraded with the goal of identifying all types of bacteria and viruses that are significantly smaller than bacteria. The creator Peter Ma would like to expand the technology to be used by municipal offices to monitor water contamination as well as individual consumers (Goralski & Tan, 2020; Lant, 2018).

AI has also been documented in aiding society to deal with different SDGs. SDGs 1, 4, 6 and 11 can be achieved by easier methods using AI that targets provision of food, water, education and energy (Vinuesa et al., 2020). Furthermore, it is well documented that AI is efficient in lowering carbon emissions. Thus it can be used in the development of smart cities that promotes the achievement of SD. The development of low carbon cities can be achieved through clean energy systems, electrical autonomous vehicles, and smart appliances that reduce fossil fuel usage (Fuso Nerini, Slob, et al., 2019; Vinuesa et al., 2020).

In terms of education, AI can be used to provide equality in education across the globe. It allows for targeting of marginalised groups such as the disabled or those who live in far-out communities. An example of this is the use of telepresence robotics which allows learners with special needs to attend school from home or hospitals (Reis et al., 2019). Furthermore, it allows for personalisation of learning and collaborative learning that has many benefits to students who have difficulty with learning (Pedro et al., 2019).

AR, which technologises human perception and experience of world through advanced personal and social AI agents in the form of digital avatars with improved AI-based natural language assistants, can be used to further enrich human existence, especially in the domains of training, exploration, data collection and knowledge dissemination. The scope of application of AR and lean culture in the area of SD management of enterprises is, for example, considered unlimited (Kościelniak et al., 2019).

In recent years, the deployment of AI for SD and SD research has been growing exponentially not only in sheer quantity, but also in disciplinary diversity and depth. The literature survey in the research database ScienceDirect found the deployment of AI for the R&D of smart grids and the intelligent management of renewable power over the last 11 years (2010-2021) to be an excellent example for this rapidly growing trend. While the total number of case studies on this topic in the first 6 years was only 155, the corresponding number in the more recent 6 years so far has already skyrocketed to 1982. Characteristic of bi-directional transmission of data and electricity among utility companies and power consumers, the digitisation of existing grid with smart meters and networked sensors has made the gird increasingly "smarter," i.e., more intelligent, efficient, effective and reliable by transmitting both power and data among power generating utilities, prosumers and organisations, and power consuming residents and businesses (Liang et al., 2020; Liu et al., 2021). Hybrid-cloud-based big data processing, IoT technologies, advanced analytics with AI algorithms such as Blockchain and deep machine learning, and abundant communication standards used to send data from one point to another, as well as digital twins in the digital transformation of utilities and in Industry 4.0 further accelerate the intelligent metamorphosis of the grid (Ahmad et al., 2020; Hasankhani et al., 2021; Talaat et al., 2020). The employment of Industrial IoT technologies allows asset optimisation, detection and predictive maintenance, self-healing to predict, isolate and fix grid operation issues (Khalid & Shobole, 2021; Kimani et al., 2019; Rivas & Abrão, 2020), restore grids or part of a grid when maintenance issues or external impacts such as cyberattacks take place, and correct and optimise renewable power quality (Gunduz & Das, 2020; Kotsiopoulos et al., 2021; Sakhnini et al., 2019; Sakhnini et al., 2021). The AI-supported smart grid using algorithms such as AccCap-DRL and machine learning was shown to be capable of decentralised modelling, monitoring, forecasting, detecting, integrating, managing and optimising renewable energy generation, transmission, and distribution (Hatti & Denai, 2020; Lin et al., 2020; Liu et al., 2020; Reddy et al., 2014; Sonnenschein et al., 2015) and connecting renewable smart grids with renewable power consumption, such as plug-in electric vehicles (Lee, 2020; Liu et al., 2015; Rahbari et al., 2017; Raza & Khosravi, 2015). Considering the need of tackling challenges posed by the intermittence and variability of renewable power generation on the one hand (Qadir et al., 2021) and the increasing complexity of the diverse renewable energy sources as the main players in the electric networks with energy storages on the other (F. Ahmad et al., 2021; Ahmad et al., 2019; T. Ahmad et al., 2021; Dreglea et al., 2021; Kalair et al., 2021; Lee & He, 2021), the crucial contribution of digitisation and AI to the R&D of the smart grid, the backbone of the SD of our decarbonised, 100% renewable energy future, is evident and paramount. At the same time, case studies also identified challenges the current grid with some smart grid components faces, such as insufficient data to meet high requirements on data, imbalanced learning, interpretability of AI, difficulties in transfer learning, the robustness of AI to communication quality, and the robustness against attack or adversarial events (Aly, 2020; Kempitiya et al., 2020; Schappert & von Hauff, 2020; Shi et al., 2020).

Despite these trends, there is a perceived literature gap in relation to how AI may support SD research and vice-versa. Consistent with the need to address this problem, the objective of this study is to investigate the transparency and reliability of AI systems for SD studies so that researchers may be able to better understand AI-based SD research outcomes and the challenges posed by the introduction of novel technologies. This means that the weaknesses, limitations and potential risks of AI systems must be identified and managed so that they can work in a robust, secure and safe way throughout their life cycles.

3. Materials and Methods

This paper examines the use of AI systems for SD research following the SDGs and respective targets and indicators associated; respecting the rule of law, human rights, and plurality in democratic values; and safeguarding human intervention and adjustment when and where necessary, so that the SD research consistently and proactively pursue the SDGs and related targets. To address the complexity inherent to SD, the AI systems deployed to SD research need to be continuously (re)examined, (re)designed, and/or (re)adapted, to ensure mutuality as drivers of justice and well-being, to effectively benefit both people and the planet. Although the increasing studies on AI for achieving SD, this is the first comprehensive reflection on the current status on the connection between AI systems and SD research targeting both directions in future research, application, and governance of AI. For these reasons, three methods were adopted to obtain relevant results further discussed against the current literature in the field: expert-driven literature review, bibliometric analysis and world survey.

The first method was based on an expert-driven literature review, which was adopted to unveil the connections between AI and SD research in a sample of countries known to be investing resources on AI for multiple purposes. A reputable reference source on those countries is *Government AI Readiness 2020* by Oxford Insights (2020), despite its acknowledged current weakness of merely focusing on readiness while ignoring implementation. The main sources of information evaluated for this study include peer-reviewed journal articles and reports from specialised organisations (e.g., research centres and societies, UN bodies, Organisation for Economic Co-operation and Development, International Monetary Fund, and Word Bank).

These sources are complemented by more than thirty recent relevant specific case studies on proven applications from companies and research centres (e.g., AI, machine learning techniques, forecasting algorithms, digitalisation, internet of things, and satellite image analysis in SD research), of a commercial or non-commercial basis nature, and which may be deployed in support of sustainability research efforts. The bibliometric analysis based on the co-occurrence of terms was the second method adopted. This technique is commonly used to reduce the complexity of a particular research field by understanding the possible research streams that researchers are exploring. In order to obtain the results, a broad-based search string was devised that includes terms such as AI, digitisation, SD, and SD research and used to search for indexed papers at Web of Science and Science Direct. The software used to conduct the data analysis was VOSviewer (version 1.6.16), a widely used text mining research tool for bibliometric analysis (Van Eck & Waltman, 2013). The results are displayed through a bibliometric network data graph in the results section.

The third method used to round up the study, consisted of a globally administered anonymised survey (participants were assured that all individual answers would be treated with confidentiality, and no personal data would be collected or stored) that seeks to determine the applications of digitalisation and AI in the context of SD research in general and the SDGs in particular. The instrument comprises 23 questions, including 11 multiple selection questions, 4 single response questions, 1 open-ended question, and 7 demographic questions. The full questionnaire applied in May 2021 is presented in Appendix A. The final version of the survey was implemented using Google Forms system and distributed by email, collecting responses for 9.5 weeks (From 13 March to 18 May 2021). Using a snowball sampling technique, the instrument was initially shared with the Inter-University Sustainable Development Research Programme (IUSDRP) (institution authorising the anonymised survey) and then disseminated through relevant academic list-serves. The resulting data obtained from the survey was organised to provide descriptive statistics regarding the frequency with which certain responses were selected by the participants.

4. Results and Discussion

4.1 Results from the bibliometric analysis

The initial search resulted in 2,432 journal papers, which indicated an exponential growth rate of 123% of the research on AI and digitisation and SD in the 25-year period from 1997 to 2021 and an average annual increase of 59% in the last 15 years (Figure 2).

PLEASE INSERT FIGURE 2

VOSviewer was used to screen titles and abstracts of these studies to conduct the aggregated bibliometric analysis of the research on AI/digitisation and SD. Major thematic areas were identified using the term co-occurrence analysis of the software. The visualised output is shown in Figure 3, where the node size is proportional to the occurrence frequency and the link width is proportional to the strength of the connection. Terms that are closely related to each other form thematic clusters.

While Figure 3 shows a full map of interconnected AI and digitisation and SD research topics in the entire body of 2432 journal papers on this main topic, the individual nodes in different sizes (AI, machine learning, sustainability/SD, renewable energy, internet of thing) show connections of related sub research topics on AI and digitisation and SD, such as cloud computing, cyber security, blockchain, industry 4.0, remote sensing, circular economy, innovation, wind energy, smart grid, smart city, fault diagnosis, monitoring, and optimisation.

PLEASE INSERT FIGURE 3

4.2 Survey Results

The global survey received a total of 175 responses from 48 countries (Table 1), illustrating the diversity of realities involved. Three of the responses were removed due to failure to finish the survey, resulting in 172 complete responses. Respondents were predominantly male (57%), located in urban areas (78%), living in developed countries (58%), aged 31-50 years old (53%), in possession of or pursuing a doctoral degree (63%), and working in academia (79%). See Figure 4.

PLEASE INSERT TABLE 1

PLEASE INSERT FIGURE 4

While nearly three-fourths of respondents address SD issues in their professions to a "great" extent or more (74%), a plurality of survey participants use AI and digitalisation only "sometimes" (32%). This gap between substantive research focus and use of AI or digitalisation is illustrated in Table 2.

PLEASE INSERT TABLE 2

The results of the survey convey many widely shared notions about the deployment of AI and digitalisation in the context of SD research. First, nearly three-fourths (74%) of participants held the view that AI can benefit SD research to a "great" extent or more. Specifically, two-thirds identified "analysis and response in real-time" as the main advantage conferred by AI. Similar proportions found that AI might prove most useful for "integrating variable renewables by enabling smart grids" (65%) and "enabling smart and low-carbon cities encompassing a range of interconnected technologies" (62%) in the context of SD more generally. These results are shown in Figure 5.

PLEASE INSERT FIGURE 5

The vast majority of respondents (73%) believed that, of the various fields within AI, machine learning is best positioned to contribute to research on SD. In addition, majorities believed that AI would strongly benefit a number of international organisations that deal with sustainability, including the United Nations (61%), World Health Organization (61%), UN Environment Programme (55%), World Bank (52%), and UN Development Programme (51%). However, over two-thirds (67%) of participants noted that the "lack of clear AI strategy and oversight" presented a barrier to adopting AI in SD research, followed by concerns about "data privacy and security" (64%). The greatest threat (shared by 65%) posed by AI was determined to be its lack of emotional intelligence, which may produce data-driven decisions that ignore the importance of context and impact. These results appear in Figure 6.

PLEASE INSERT FIGURE 6

Second, a strong majority (78%) held that digitalisation should be deployed in SD research to a "great" extent or more. Almost three-fourths (72%) found that the main benefit of deploying digitalisation in SD research lies in "expanding powerful means of acquiring data, verifying it, and manipulating it in search of patterns." The next most-cited benefit (64%) was "providing powerful tools for gleaning insights from massive data collections." Interestingly, two-thirds of respondents suggested that "efficiency, transparency, safety, and ethical standards" constituted the main challenge to utilising digitalisation. A slightly smaller proportion (64%) considered a replication of the digital divide among researchers as the most prominent negative impact of digitalisation. These results are reported in Figure 7.

PLEASE INSERT FIGURE 7

4.3 Case Studies

A total of thirty-eight case studies were extracted from the literature (Table 3) to illustrate how researchers are deploying AI and digitalisation methods and techniques in SD research. In addition, Figure 8 summarises all the case studies into the main objectives and benefits of adopting AI and digitalisation in tackling SD challenges and identifying the specific methods and techniques deployed. In general, it was possible to group the case studies into two categories regarding the SD challenges. The first group addresses the general and systemic challenges of SD, while the second entails studies that tackle a specific SDG.

The case studies that address the SD challenges in a broad sense aim to understand and show the role of AI modelling and digitalisation impacts on several domains of SD research (Baumgartner, 2011; Khakurel et al., 2018; Sebestyén et al., 2020; Truby, 2020), either by integrating biophysical processes and human dynamics (Steffen et al., 2020) or by considering SD from a systemic perspective (Gue et al., 2020; Sætra, 2021; Vinuesa et al., 2020). These case studies use AI algorithms, forecasting models and earth observation data (Andries et al., 2019) to support decision-making or policy-making processes for effective governance, helping actors work together to achieve SD (Gao et al., 2019).

Despite the attempts that try to tackle sustainability problems by adopting a more systemic and interdisciplinary perspective, several other studies address the AI and digitalisation related methods to advance specific SD challenges such as urban water management (Goralski & Tan, 2020; Xiang et al., 2021), disaster detection (Al Qundus et al., 2020; Alizadeh & Nikoo, 2018; Sublime & Kalinicheva, 2019), recycling and waste sorting (Bircanoğlu et al., 2018), poverty assessment and monitoring (Alsharkawi et al., 2021; Jean et al., 2016), food consumption and sustainability (Abdella et al., 2020), sustainable cities/urban ecosystems (Goddard et al., 2021; Ilieva & McPhearson, 2018; Majumdar et al., 2021; Vinuesa et al., 2020), threat to biodiversity (Jensen et al., 2020), health-related issues (Pirouz et al., 2020), smart sustainable agriculture (Alreshidi, 2019; Boev et al., 2020), climate action (Balogun et al., 2020; Fuso Nerini, Sovacool, et al., 2019; Huntingford et al., 2019), environmental evaluation (Liu et al., 2021)(Liu et al., 2021), and enterprise management for SD (Kościelniak et al., 2019).

In this context, it is possible to identify synergy between the lessons learned from the case studies and the opinions provided by the experts about the benefits of deploying AI and digitalisation in SD research (see Figures 5 and 7). Overall, the case studies confirm the experts´ general belief that SD research can benefit from real-time analysis and automated response by evaluating, managing, and modelling sustainability impacts on the earth systems (Bienvenido-Huertas et al., 2020; Steffen et al., 2020; Wiedmann et al., 2020), developing smart solutions for SD (Alreshidi, 2019; Bircanoğlu et al., 2018; Kościelniak et al., 2019), or even contributing to predicting natural disasters (Al Qundus et al., 2020; Alizadeh & Nikoo, 2018; Goralski & Tan, 2020; Sublime & Kalinicheva, 2019). Moreover, adopting AI and digitalisation could increase several stakeholders´ engagement (Fuso Nerini et al., 2018), such as the society (Irving & Hoffman, 2014; Mrówczyńska et al., 2019), supporting the scientific community to overcome the complexity of SD research (Gue et al., 2020; Sebestyén et al., 2020) or generating valuable information for policy-making (Gao et al., 2019; How et al., 2020; Jean et al., 2016; Mrówczyńska et al., 2019; Pirouz et al., 2020).

Finally, the case studies as much as the survey results also convey the importance of privacy and security issues in rolling out AI and digitalisation experimentations (see Figure 6). Specifically, 66% of the experts reported that the biggest challenges are transparency, safety, and ethical standards (Figure 7). Truby (2020) goes in the same direction, alerting about the danger of uncontrolled AI and automated decision-making algorithms that can compromise the achievement of the SDGs, urging about the need for regulatory oversight.

PLEASE INSERT TABLE 3

PLEASE INSERT FIGURE 8

From the same perspective, Vinuesa et al. (2020) point out that AI can cause on several sectors both positive and negative consequences to the SDGs, identifying that AI-based technologies can contribute positively to 134 targets but also hinder the achievement of 59 targets related to the SDGs, highlighting the need for regulatory insight and oversight.

5. Discussion

The results obtained in this study speak to the utility, benefits and obstacles presented by AI and digitalisation in the domain of SD research, leading to a few key observations. First, researchers focusing on SD recognise the potential impact of AI and digitalisation, but seldom make use of these technologies (at least for now). Second, respondents largely agreed that AI and digitalisation are likely to vastly improve the capacity to obtain and analyse large amounts of data pertaining to SD. Third, the experts diverged a bit when it came to assessing the challenges facing the deployment of AI and digitalisation, with concerns about overall strategy being deemed more central to the former while issues of efficiency, transparency, safety and ethics were more clearly associated with the latter.

In some ways, the expert opinions obtained through the survey reflect several key points identified in the relevant literature. First, of all systems associated with AI, machine learning tends to be one of the most promising in the context of SD research (Abdella et al., 2020; Alsharkawi et al., 2021; Huntingford et al., 2019; Jean et al., 2016; Jensen et al., 2020; Majumdar et al., 2021). Second, substantial agreement exists to suggest that AI and digitalisation have clear applications to the study of smart grids (Aly, 2020; Kotsiopoulos et al., 2021; Liang et al., 2020; Qadir et al., 2021; Shi et al., 2020; Talaat et al., 2020) and smart and low-carbon cities (Fuso Nerini, Slob, et al., 2019; Goddard et al., 2021; Ilieva & McPhearson, 2018; Majumdar et al., 2021). Third, concerns about the need for regulatory oversight and the effective enforcement of transparency, safety, and ethical standards resonated widely among both survey participants and authors of related scholarship (Vinuesa et al., 2020).

In terms of practical implications for SD, the survey results might be seen through the lens of the SDGs by connecting responses to the specific Global Goals to which they relate. This interpretive exercise can help to identify the kinds of effects and impacts AI and digitalisation might have with respect to the SDGs. Previous research has found that AI might positively enable achievement of 79% of the targets associated with the SDGs, while potentially resulting in negative impacts for 35% of the targets (Vinuesa et al., 2020). According to the framework proposed by Sætra (2021), the SDGs relevant to the responses represent a range of effects and impacts. AI is likely to have direct effects with medium impact in the case of SDGs 11 and 13, whereas it may produce indirect effects with minor impact for SDGs 7 and 17.

The responses obtained for the present study suggest that AI might be most profitably used to pursue research related to SDGs 7 (Affordable and Clean Energy), 11 (Sustainable Cities and Communities), 13 (Climate Action), and 17 (Partnerships for the Goals). For instance, SDG Target 7.2 requires increasing the share of renewable energy in the global energy mix, which would be assisted through the dissemination of best practices in implementing smart grid technology. As in the case of AI, survey participants similarly found digitalisation to be useful in research pertaining to SDG 17.

5. Conclusions

This paper explores the connections between AI systems and SD research. The methods deployed, namely a literature review, world survey, and case studies, illustrate some of the ways in which AI has been supporting research on SD.

The findings from the study reveal a number of trends, which guide the main conclusions from it. A first and conspicuous feature is related to the substantial growth rate in the literature addressing AI and digitisation and SD, with an average annual increase of 59% in the last 15 years. This illustrates how fast this field is developing. In addition, the research has identified the fact that within AI, machine learning is best positioned to contribute to research on SD.

The study also provides a warning, in the sense that over two-thirds of the participants indicated that the absence of clear AI strategy and misunderstanding posed a barrier to adopting AI in SD research, followed by concerns about data privacy. These are two important needs which should be met, so that a greater integration of AI in SD, especially SD research, may be achieved.

The study has also revealed that a main benefit of deploying digitalisation in SD research lies in increasing powerful means of acquiring information, analysing it and manipulating it, searching for patterns, allowing to model and predict scenarios in different contexts.

This paper has some limitations. The first one, connected with the review of the literature, is that the total of 2432 papers focused on the links between digitalisation and AI and SD, and did not took full account of non-technological issues. In addition, the survey and the resulting in 172 completed responses, although representing a significant number of countries, may not be enough to allow deep inferences from the study.

Despite these constraints, the paper, with data from 48 countries, offers a comprehensive reflection on the current status on the connection between AI systems and SD research, targeting both directions in future research, application, and governance of AI. It provides a comprehensive knowledge addition to the literature, based on the fact that it combines two robust methods, which add some weight to its results.

In respect of academic implications, what is really novel in this study, is that the analysis also discussed the significance of AI in the implementation of the SDGs. Some insights from the research, i.e., the fact that nearly three-fourths of the participants held the view that AI can benefit SD research to a “great” extent or more, may pave the way for further efforts in this field. There seems to be little doubt in relation to the fact that AI can contribute to a more sustainable and equitable world, and there is a great potential in respecting of supporting the achievement of the SDGs.

As a research agenda, it is suggested that further studies be performed on how AI can work to support the links between environmental and societal sustainability. A further research area is how AI may assist in measuring the impacts of SD technologies. In addition, research is needed on how to better capitalise from the potentials of AI as a tool to raise awareness on matters related to SD.

Since digitalisation and AI are already present in our lives, their use may represent good opportunities for improvements in efficiency and innovation in the context of SD, many of which were unthinkable just a few years ago. Provided due care is undertaken, a great use can be made from these technologies, without endangering human health and well-being.

Authors' statement

The manuscript has not been previously published, submitted or uploaded to any archive or pre-print server. We have not plagiarised or self-plagiarised any previous sources. All tables and figures displayed in the manuscript are of our own creation, and we hold the copyright for these materials. The authors have no relevant financial or non-financial interests to disclose.

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Appendix World Survey Questions

1. Country of residence/work

2. Name of your University

3. Place where you live

4. Gender

5. Age

6. Educational Level

7. Occupation

8. To what extent your work or research theme address sustainable development issues?

9. How often do you use AI and digitalisation solutions in your work or research

10. To which extent do you think digitalisation should be deployed to the sustainable development research?

11. What are the benefits of deploying digitalisation in sustainable development research? (multiple choice possible)

12. What could be the biggest challenges of deploying digitalisation in sustainable development research? (multiple choice possible)

13. What negative digitalisation impacts the sustainable development research could have? (multiple choice possible)

14. To which extent sustainable development research can benefit from artificial intelligence (AI)?

15. What are the main advantages deploying AI to sustainable development? (multiple choice possible)

16. What AI technological processes could be best applied to sustainable development research? (multiple choice possible)

17. Which do you believe to be the main advantages deploying AI to the sustainable development research? (multiple choice possible)

18. To maximise AI benefits to sustainable development research, which steps should be done? (multiple choice possible)

19. What role may AI play in sustainable development research? (multiple choice possible)

20. Which threats does AI bring to sustainability? (multiple choice possible)

21. What challenges and barriers are there to wider AI adoption to sustainable development research? (multiple choice possible)

22. Which worldwide scope organisations will strongly benefit from AI within sustainable fields? (multiple choice possible)

23. If you have specific examples of a case study or project involving digitalisation and AI in supporting sustainable development research, briefly describe the experience (objective, method, impact, and results, for exam

Table 1. Countries addressed in the survey

Countries included in the survey	
Austria	Malaysia
Brazil	Mali
Belgium	Mexico
Canada	Morocco
Cameroon	Nigeria
Chile	Puerto Rico
China	Romania
Costa Rica	Russia
Côte d'ivoire	Rwanda
Denmark	Senegal
Ethiopia	Serbia
Ecuador	Somalia
Finland	South Africa
France	Spain
Germany	Sweden
Ghana	Switzerland
Greece	The Netherlands
India	Turkey
Israel	Uganda
Italy	Ukraine
Federated States of Micronesia	United Kingdom
Kenya	United States
Japan	Tanzania
Latvia	Zimbabwe

Table 2. Gap between sustainable development research and the extent to which researchers use AI and digitalisation

Question	Answers	Frequency	Percentage
To what extent does your work or research theme address sustainable development issues?	Very Great Extent	83	48.0
	Great Extent	45	26.0
	Some Extent	33	19.0
	Little Extent	7	4.0
	Not at all	5	2.9
How often do you use AI and digitalisation solutions in your work or research?	Always	19	11.0
	Often	43	24.9
	Sometimes	56	32.4
	Rarely	34	19.7
	Never	21	12.1

Table 3. Case studies on artificial intelligence worldwide

Case	Title of the case study	Short description	Implications	References
1	Earth System-related measurements to support sustainability	Earth System-related measurements, and high spatial and temporal resolution Earth System model (ESM) to provide automated warnings and advice to society of approaching weather extremes	Better monitoring of climate dynamics and support to sustainability efforts	Huntingford et al. (2019)
2	Smart water management addressing SDGs 6, 12 and 14	Water input data is first correlated to knowns outputs allowing the algorithms to lean over time. AI acts to obtain patterns as new data is introduced, allowing constant adaption and processing of data in real time to manage water resources	Significant improvement of water productivity and cost-savings	Goralski and Tan (2020)
3	Wireless sensor network for AI-based flood disaster detection	System implementing some ML-based methods in order to predict the flood. The whole system was created and evaluated in Kuwait.	Flood detection, sustainable water level management	Al Qundus et al. (2020)
4	Fusion-based methodology for meteorological drought estimation using remote sensing data.	Drought estimation system using remotely sensing data placed in Iran, the province Fars. The presented results proved that AI models are often robust to grab some aspects of hydrological behaviour in drought analysis better than the other models.	Drought prediction, sustainable water level management	Alizadeh and Nikoo (2018)
5	Automatic post-disaster damage mapping using deep- learning techniques for change detection: case study of the Tohoku tsunami.	Satellite image analysis to evaluate whether the selected area was affected by the tsunami. The proposed solution was tested on the real data – the satellite images presenting the area affected by the Tohoku tsunami in November 2010.	Sustainable extreme phenomena damages management	Sublime and Kalinicheva (2019)
6	RecycleNet: intelligent waste sorting using deep neural networks	The RecycleNet is a carefully optimised deep convolutional neural network architecture to	AI-supported waste management	Bircanoğlu et al. (2018)

Case	Title of the case study	Short description	Implications	References
		classify selected recyclable object classes: glass, paper, cardboard, plastic, metal, and trash.		
7	Poverty classification using machine learning: the case of Jordan	Proposal of a machine learning approach to assess and monitor the poverty status of Jordanian households.	Better tracking and targeting poverty across the country. The work demonstrates how powerful and versatile machine learning can be, enabling its adoption across many private and government domains.	Alsharkawi et al. (2021)
8	Sustainability assessment and modelling based on supervised machine learning techniques: the case for food consumption	Presents a method for evaluating and modelling sustainability impacts of food consumption in the United States through the assessment of categories by (1) using high sector resolution input-output of the economy and (2) proposing an integrated sustainability modelling framework based on supervised machine-learning techniques.	The supervised machine-learning techniques allows to develop sustainability modelling and assessment method that deals with multiple decision-making units (food consumption categories) and sustainability indicators.	Abdella et al. (2020)
9	Combining satellite imagery and machine learning to predict poverty	Machine learning techniques and scalable method to predict poverty by estimating consumption expenditure and asset wealth from high-resolution satellite imagery and survey data;	The proposed method and machine learning techniques can foster research and policy	Jean et al. (2016)
10	Artificial intelligence-enhanced decision support for informing global sustainable development: a human-centric AI-thinking approach	Democratisation of AI via a user-friendly human-centric probabilistic reasoning approach and the application of AI-based predictive modelling techniques on Environmental Performance Index data, revealing tensions between (1) environmental health; and (2) ecosystem vitality.	Provide support to policy-making in sustainable development.	How et al. (2020)
11	Congestion prediction for smart sustainable cities using Internet of Things (IoT) and machine	Internet of Things and Machine learning approaches to develop long short-term memory networks to predict congestion propagation across a road network.	Smart congestion management, predicting congestion propagation on road networks and may form a key component of future traffic	Majumdar et al. (2021)

Case	Title of the case study	Short description	Implications	References
	learning approaches		modelling approaches for smart and sustainable cities around the world.	
12	Employing machine learning for detection of invasive species using sentinel-2 and AVIRIS Data: the case of Kudzu in the United States	Machine learning classifiers for detecting invasive plant species using remote sensing data.	Prevent invasive plants from causing massive economic and environmental troubles for societies worldwide.	Jensen et al. (2020)
13	Investigating a serious challenge in the sustainable development process: analysis of confirmed cases of COVID-19 (new type of coronavirus) through a binary classification using AI and regression analysis	Binary classification using AI and regression analysis in the classification of confirmed cases of COVID-19.	Artificial intelligence and regression analysis are essential methods to help researchers and policymakers deal with serious sustainable development challenges, such as a pandemic situation.	Pirouz et al. (2020)
14	Smart Sustainable Agriculture (SSA) solution underpinned by IoT and AI	IoT and AI technologies for SSA, the case also identifies IoT/AI technical architecture capable of underpinning the development of Smart Sustainable Platforms.	IoT and AI technologies can help monitor the agricultural environment to ensure high-quality products and improve performance in a sustainable development context.	Alreshidi (2019)
15	Urban water resource management for sustainable environment planning using artificial intelligence techniques	Adaptive Intelligent Dynamic Water Resource Planning (AIDWRP), based on AI, for management and to sustain the urban areas' water environment. The case also performed a simulative analysis to validate the accuracy in	AIDWRP can contribute to water management in urban areas, guaranteeing distribution, ecological, environmental, and hydrological integrity achievement.	Xiang et al. (2021)

Case	Title of the case study	Short description	Implications	References
		forecasting the energy demand for sustainable environmental planning and management.		
16	The use of AI as a tool for supporting sustainable development local policy	Non-linear support vector machine (SVM) networks were used to address the problem of noise in spa protection areas to properly manage space, in accordance with the idea of sustainable development, zones of environmental sensitivity (and their socio-environmental vulnerability).	Identification of exceedance of permissible noise levels; it allows to develop effective local policy tools to reduce noise infiltration and to define environmental priorities.	Mrówczyńska et al. (2019)
17	The role of AI in achieving SDGs	It reveals that current research overlook important aspects of AI. The fast development of AI needs to be supported by the necessary regulatory insight and oversight for AI-based technologies to enable sustainable development. Failure to do so could result in gaps in transparency, safety, and ethical standards.	It shows the constraints of the current AI systems for sustainable development research and emphasises the importance of best practices in this area.	Vinuesa et al. (2020)
18	Assessing the potentials of digitalisation as a tool for climate change adaptation and sustainable development in urban areas	It reveals the capabilities of digitalisation in supporting more effective early warning and emergency response systems, enhancing food and water security, improving power infrastructure performance, enabling citizen engagement.	Capabilities of digitalisation in supporting more effective early warning and emergency response systems	Balogun et al. (2020)
19	Translation of Earth observation data into sustainable development indicators: an analytical framework	The study found that the current preferable way for agriculture development lies on smart and precision farming based on the use of digital technologies, which contributes for the reduction of farming costs and the improvement of agricultural profitability.	It examines the digitalisation process in Russia	Boev et al. (2020)
20	Governing AI to benefit SDGs	It points out that Big Tech's unregulated rollout of experimental AI poses risks to the achievement of	It highlights the risks of unregulated AI causing harm to human interests,	Truby (2020)

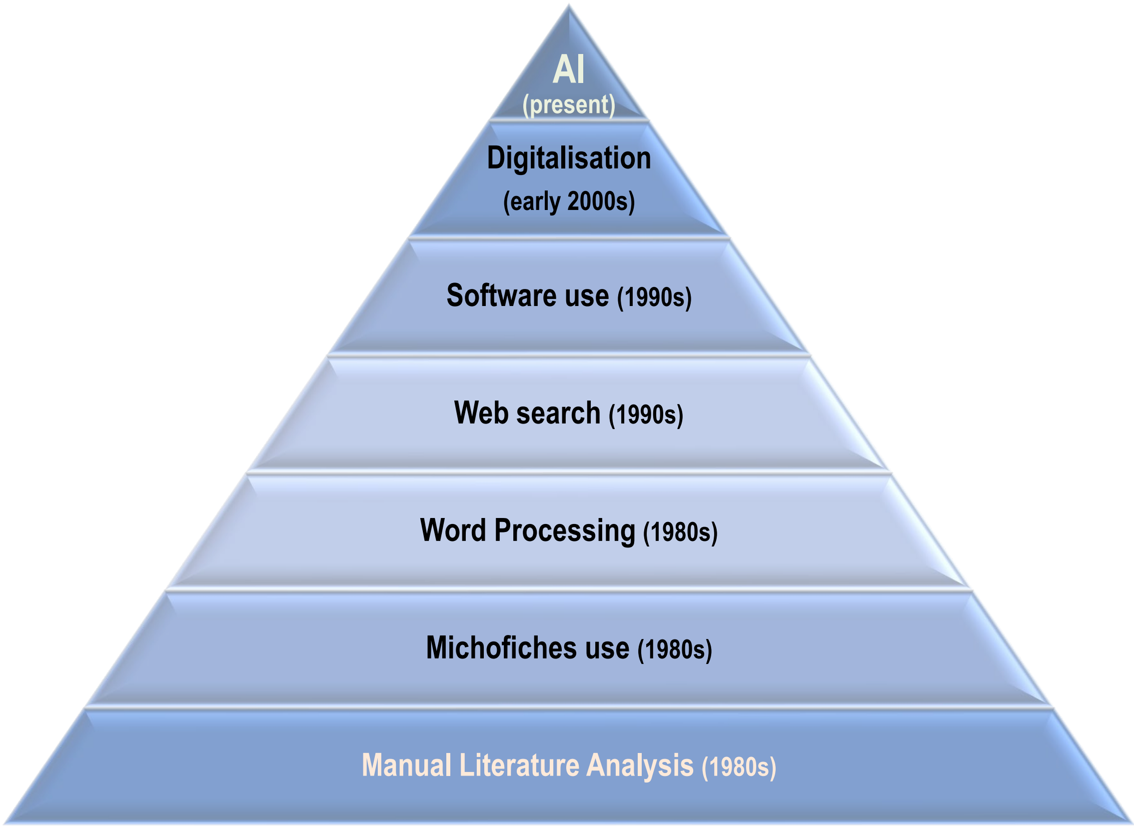
Case	Title of the case study	Short description	Implications	References
		SDGs, with particular vulnerability for developing countries.	where a public and regulatory backlash may result in over regulation that could damage the otherwise beneficial development of AI.	
21	Comparative analysis between international research hotspots and national-level policy keywords on AI in China from 2009 to 2018.	It reveals the development of AI in China and the interaction between academics and policy makers in the past ten years, which is of great significance for the sustainable development and effective governance of China's artificial intelligence.	AI in China	Gao et al. (2019)
22	Translation of Earth observation (EO) data into sustainable development indicators: an analytical framework	It demonstrates that although the applicability of EO derived data varies between the SDGs' indicators, EO has an important contribution towards populating a wide diversity of the SDGs indicators.	A case study on EO for SDR	Andries et al. (2019)
23	The rise of AI under the lens of sustainability	The study examined the impacts of AI on several domains of sustainable development.	Value, collaboration, sharing responsibilities; ethics will play a vital role in any future sustainable development of AI in society.	Khakurel et al. (2018)
24	Comparison of AI algorithms to estimate sustainability indicators	It reviewed estimations in the sustainability indicators of the C9Algarve region, compared four artificial intelligent algorithms: MLR, MLP, RF and M5P, and found C21M5P as the algorithm obtaining the best estimations in a greater number of indicators.	AI algorithms for SDR	Bienvenido-Huertas et al. (2020)
25	Intelligent, comprehensive evaluation system using	It reviewed the use of an advanced AI framework for environment development and protection.	It shows the experience of using AI for sustainable development research in China	Liu et al. (2021)

Case	Title of the case study	Short description	Implications	References
	AI for environmental evaluation			
26	The application of information technologies in consideration of augmented reality and lean management of enterprises in the light of sustainable development	It explores the problem associated with the use of modern information technologies that take into account extended reality and the lean management culture to achieve sustainable development by enterprises, which is part of the field of management science.	A sustainable approach to enterprise management should consider the assessment of augmented reality (AR) and instruments of lean culture in the area of management and consider the scope of application of augmented reality and lean culture in the area of sustainable development management of enterprises unlimited.	Kościelniak et al. (2019)
27	Nyungar place stories pilot: using augmented reality for Indigenous cultural sustainability	It examines the efficacy for the augmented reality app to present Indigenous narratives in a way that engages students in reflexive practice.	augmented reality app to present Indigenous narratives in a way that engages students in reflexive practice.	Irving and Hoffman (2014)
28	Mapping synergies and trade-offs between energy and SDGs	There is an urgent need to better organise, connect and extend this evidence, to help all actors work together to achieve sustainable development.	AI can help address this problem.	Fuso Nerini et al. (2018)
29	Connecting climate action with other SDGs	Understanding the relationships of SDR requires wider and deeper interdisciplinary collaboration.	AI systems can help overcome the complexity of sustainable development research.	Fuso Nerini, Sovacool, et al. (2019)
30	Critical perspectives of SDR and practice	It explored the impacts of AI on several domains. It finds that there is a significant impact on all five dimensions, with positive and negative impacts, and that value, collaboration, sharing responsibilities; ethics will play a vital role in any future sustainable development of AI within society.	It provides a foundation for in-depth discussions and future research.	Baumgartner (2011)

Case	Title of the case study	Short description	Implications	References
31	Focal points for sustainable development strategies - text mining - based comparative analysis of voluntary national review	The results of text mining-based analysis demonstrate that the proposed benchmark tool is capable of highlighting what kind of activities can make significant contribution.	it shows the power of digitalisation for SDR.	Sebestyén et al. (2020)
32	Artificial neural networks (ANN) for sustainable development: critical review	Identifies the current trends and limitations of ANN for SDGs and discusses its prominent applications and field of utilisation.	ANN is part of AI relevant to supporting the sustainable development research	Gue et al. (2020)
33	AI, SDGs and the limits of new technologies	Offers direct and indirect examples of how AI, considered part of the larger sociotechnical system, may be used in the context of the SDGs. Special attention is paid to non-universal access of AI.	Any effort to examine the utility of AI in sustainable development needs to account for the digital divide and the power that a few countries and large tech companies have to direct the development and deployment of new technologies.	Sætra (2021)
34	Social-media data (SMD) for urban sustainability	SMD for urban sustainability	Vast scale and near-real-time observation bring remarkable advantages of SMD	Ilieva and McPhearson (2018)
35	Structural transition in the collective behaviour of cognitive agents	Development of a minimal model of agents that explore the environment by means of sampling trajectories	Artificial systems like autonomous micro-robots, and swarm robotics able to mimic the collective behaviour of living organisms	Hornischer et al. (2019)
36	Scientists' warning on affluence	Resource use and pollutant emissions: transition towards sustainability	AI contributes to long-term and concurrent human and planetary wellbeing	Wiedmann et al. (2020)

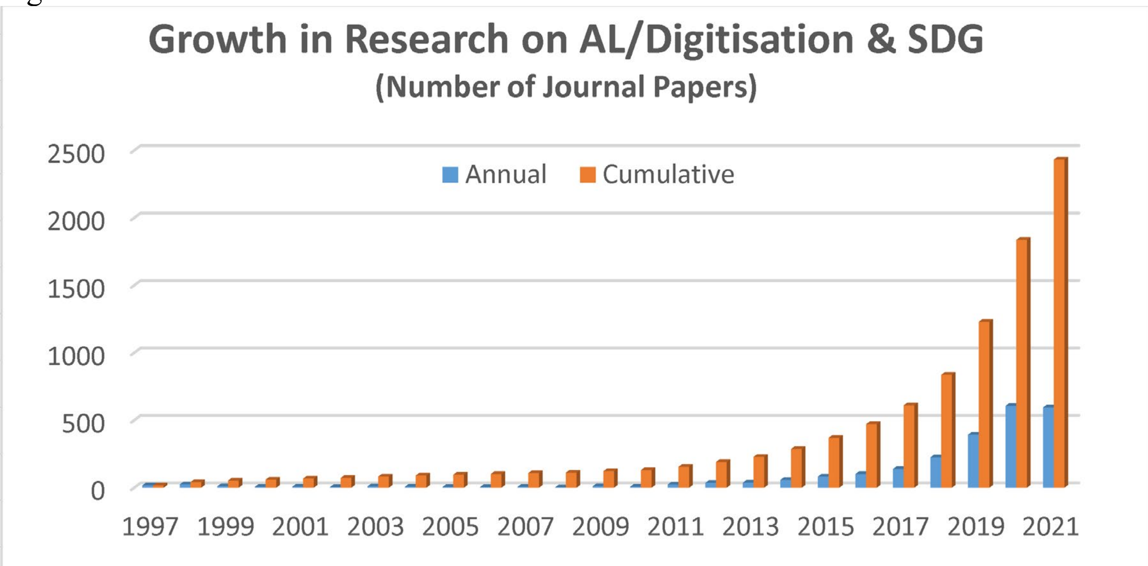
Case	Title of the case study	Short description	Implications	References
37	A global horizon scan of the future impacts of robotics and autonomous systems on urban ecosystems	Robotics and autonomous systems (RAS) transform land use, transport systems and human–nature interactions	Concerns, quality and interpretation of RAS-collected data	Goddard et al. (2021)
38	The emergence and evolution of Earth System Science	Earth System Science (ESS) concepts and frameworks	ESS and integration of biophysical processes and human dynamics	Steffen et al. (2020)

Figure 1



AI
(present)
Digitalisation
(early 2000s)
Software use (1990s)
Web search (1990s)
Word Processing (1980s)
Michofiches use (1980s)
Manual Literature Analysis (1980s)

Figure 2



Growth in Research on AL/Digitisation & SDG
(Number of Journal Papers)
Annual
Cumulative
2500
2000
1500
1000
500
0
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019
2021

Figure 3

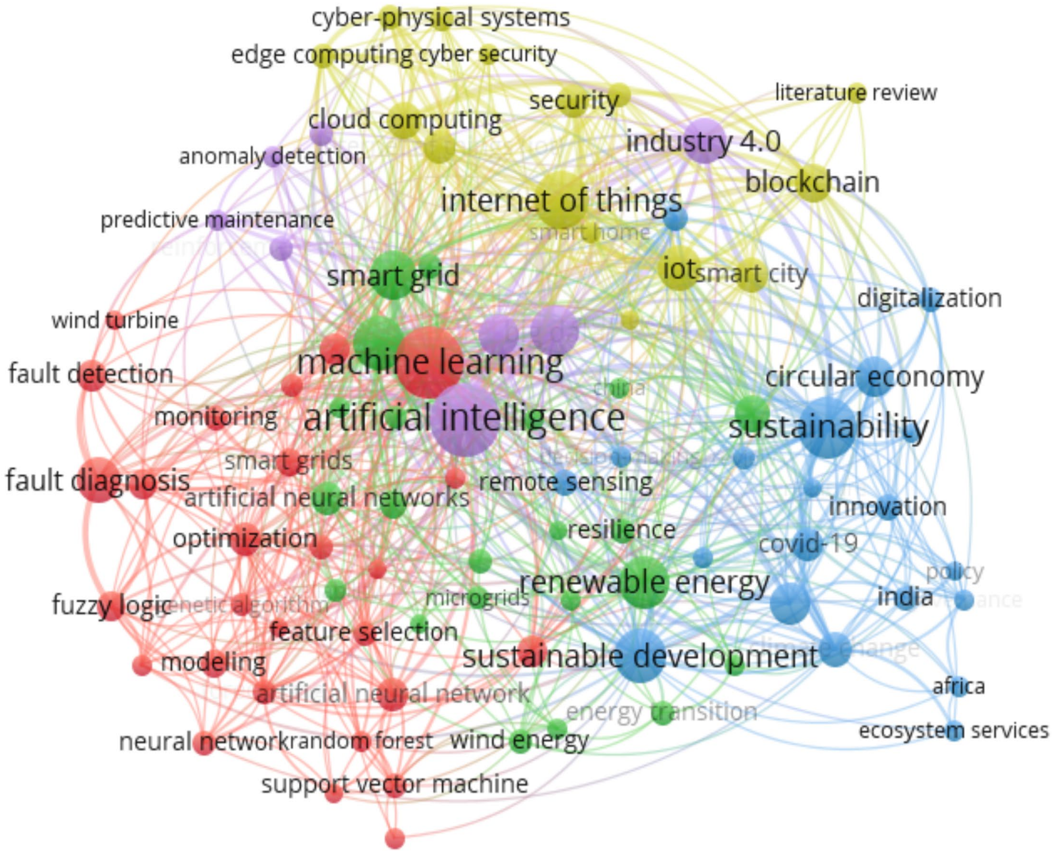

cyber-physical systems
edge computing
cyber security
literature review
security
cloud computing
industry 4.0
anomaly detection
blockchain
internet of things
predictive maintenance
smart home
iot
smart city
smart grid
digitalization
wind turbine
machine learning
circular economy
fault detection
china
monitoring
artificial intelligence
sustainability
smart grids
fault diagnosis
remote sensing
artificial neural networks
innovation
resilience
optimization
covid-19
policy
renewable energy
india
fuzzy logic
genetic algorithm
microgrids
feature selection
sustainable development
modeling
africa
artificial neural network
energy transition
ecosystem services
neural network
random forest
wind energy
support vector machine

Figure 4

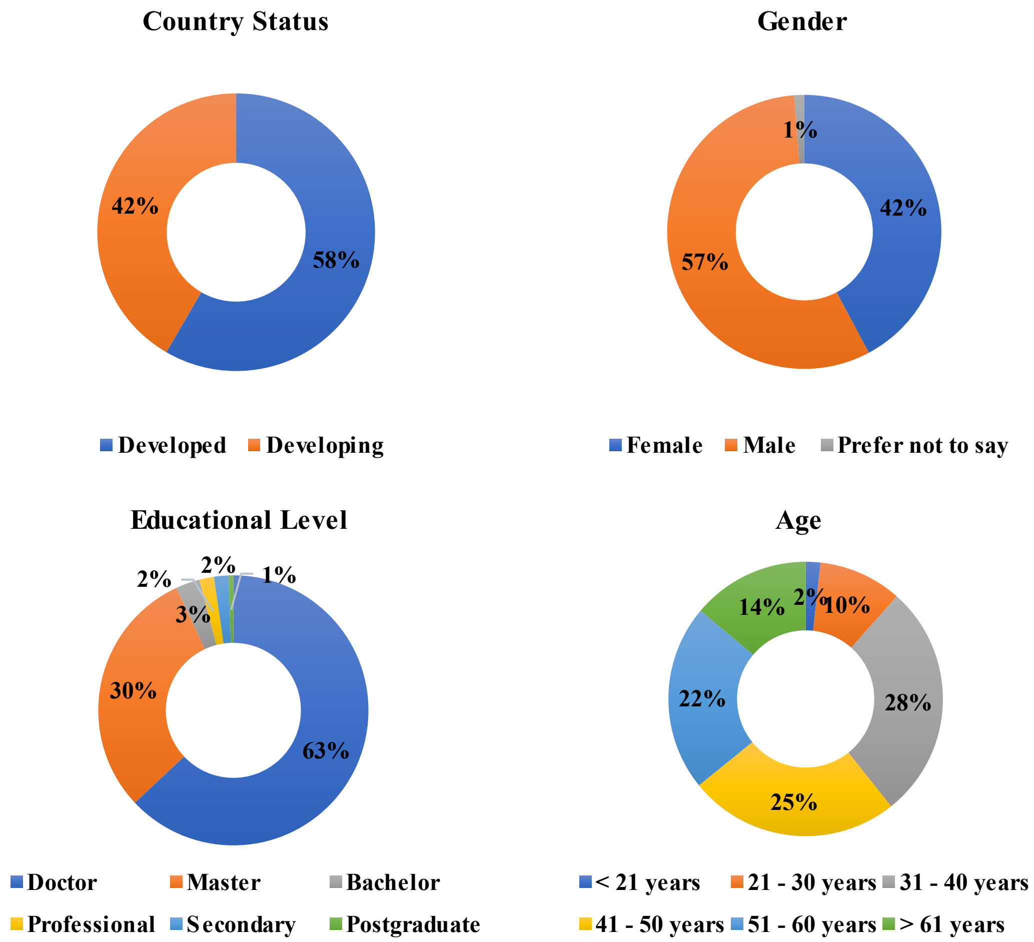
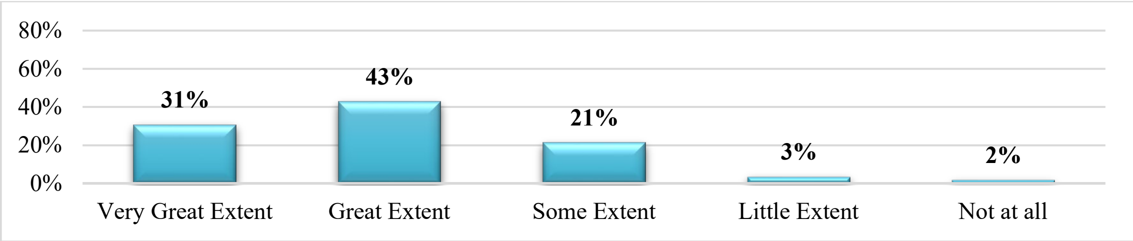
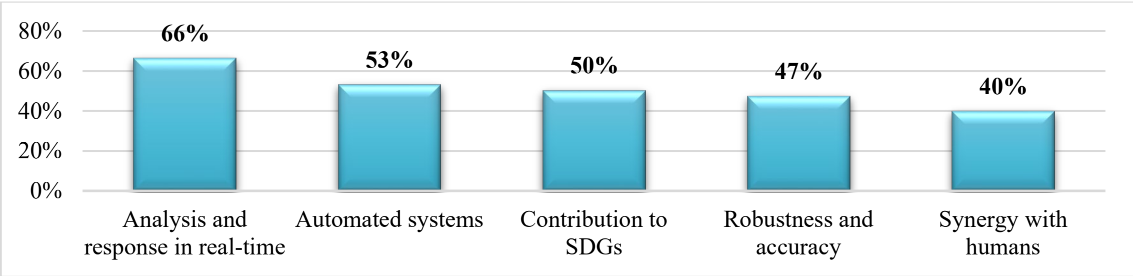

Country Status
42%
58%
Developed
Developing
Gender
1%
42%
57%
Female
Male
Prefer not to say
Educational Level
2%
2%
1%
3%
30%
63%
Doctor
Master
Bachelor
Professional
Secondary
Postgraduate
Age
14%
2%
10%
22%
28%
25%
< 21 years
21 - 30 years
31 - 40 years
41 - 50 years
51 - 60 years
> 61 years

Figure 5



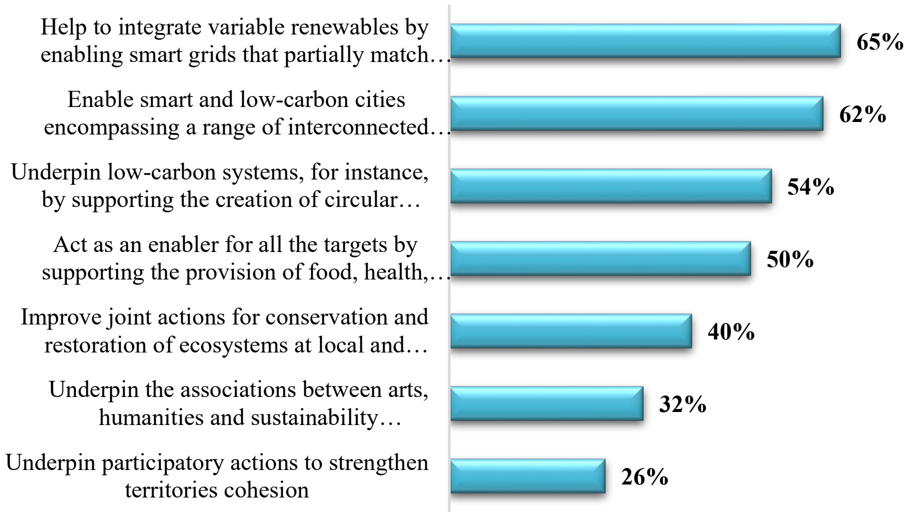
80%
60%
40%
20%
0%
31%
43%
21%
3%
2%
Very Great Extent
Great Extent
Some Extent
Little Extent
Not at all

a)



80%
60%
40%
20%
0%
66%
53%
50%
47%
40%
Analysis and response in real-time
Automated systems
Contribution to SDGs
Robustness and accuracy
Synergy with humans

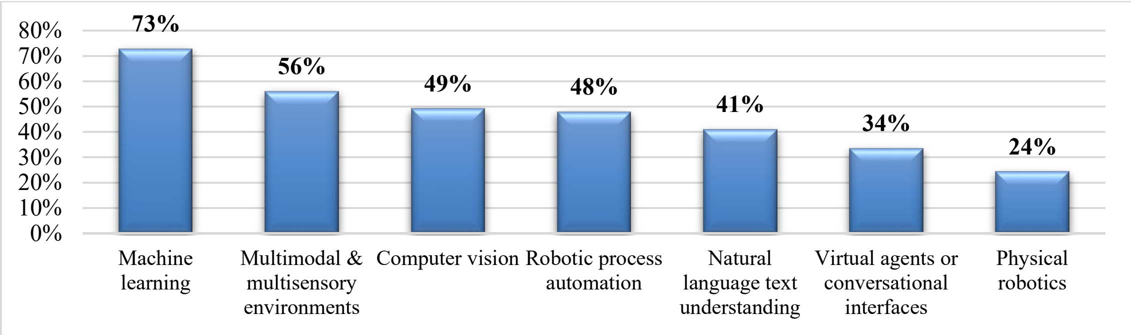
b)



Help to integrate variable renewables by enabling smart grids that partially match…
65%
Enable smart and low-carbon cities encompassing a range of interconnected…
62%
Underpin low-carbon systems, for instance, by supporting the creation of circular…
54%
Act as an enabler for all the targets by supporting the provision of food, health,…
50%
Improve joint actions for conservation and restoration of ecosystems at local and…
40%
Underpin the associations between arts, humanities and sustainability…
32%
Underpin participatory actions to strengthen territories cohesion
26%

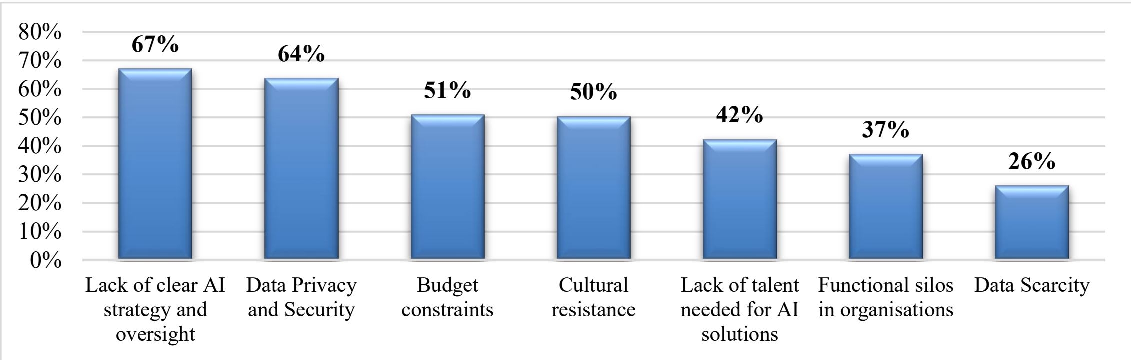
c)

Figure 6



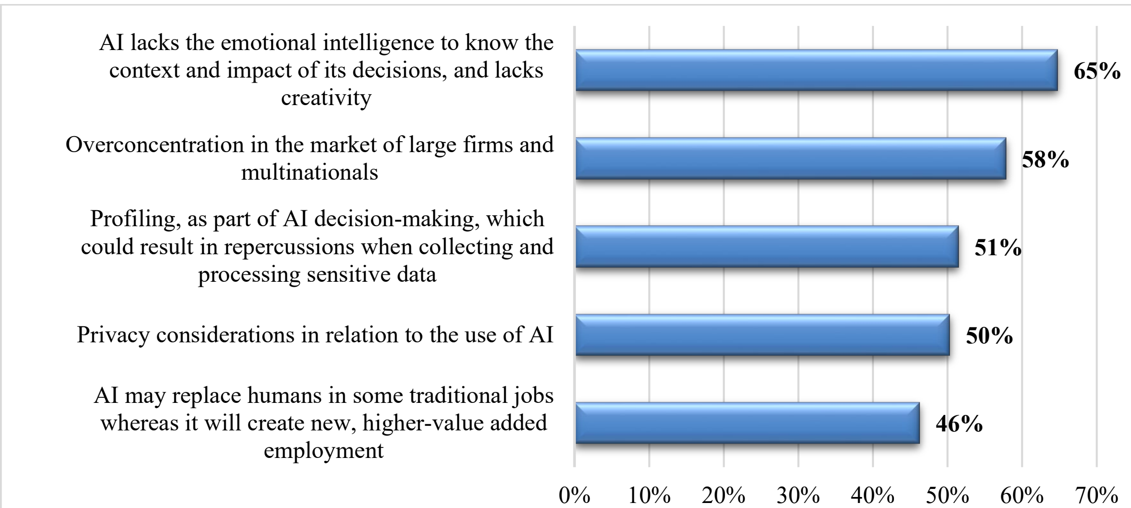
80%
70%
60%
50%
40%
30%
20%
10%
0%
73%
56%
49%
48%
41%
34%
24%
Machine learning
Multimodal & multisensory environments
Computer vision
Robotic process automation
Natural language text understanding
Virtual agents or conversational interfaces
Physical robotics

a)



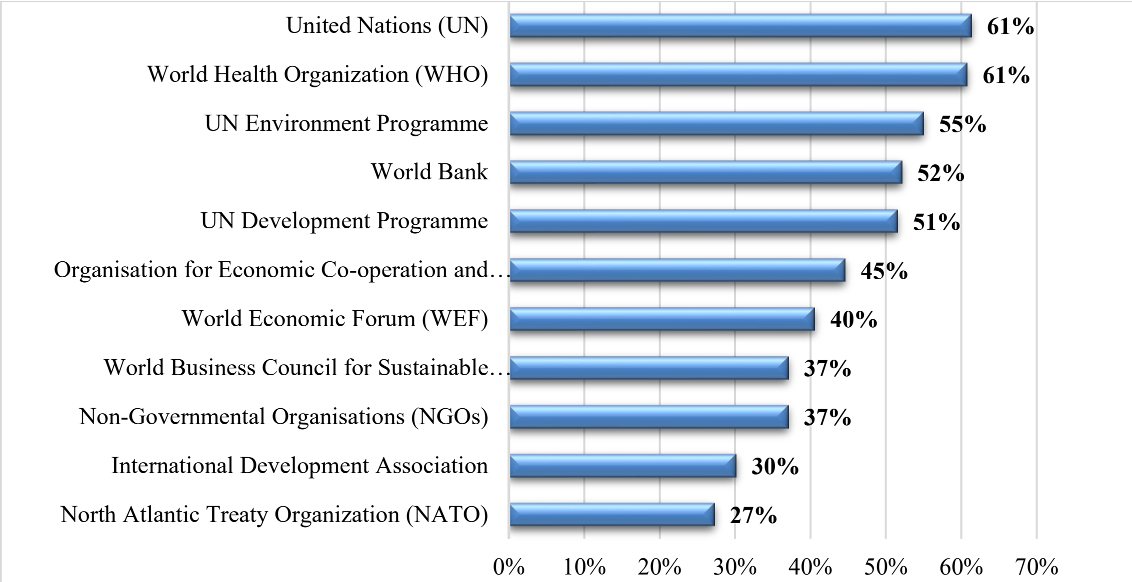
80%
70%
60%
50%
40%
30%
20%
10%
0%
67%
64%
51%
50%
42%
37%
26%
Lack of clear AI strategy and oversight
Data Privacy and Security
Budget constraints
Cultural resistance
Lack of talent needed for AI solutions
Functional silos in organisations
Data Scarcity

b)



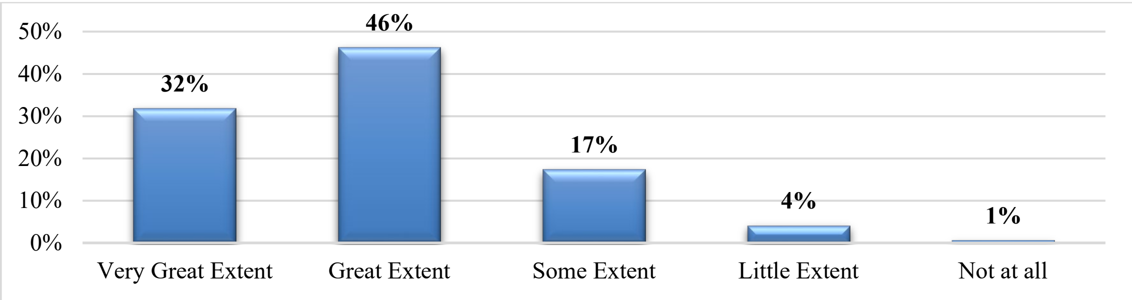
AI lacks the emotional intelligence to know the context and impact of its decisions, and lacks creativity
65%
Overconcentration in the market of large firms and multinationals
58%
Profiling, as part of AI decision-making, which could result in repercussions when collecting and processing sensitive data
51%
Privacy considerations in relation to the use of AI
50%
AI may replace humans in some traditional jobs whereas it will create new, higher-value added employment
46%
0%
10%
20%
30%
40%
50%
60%
70%

c)

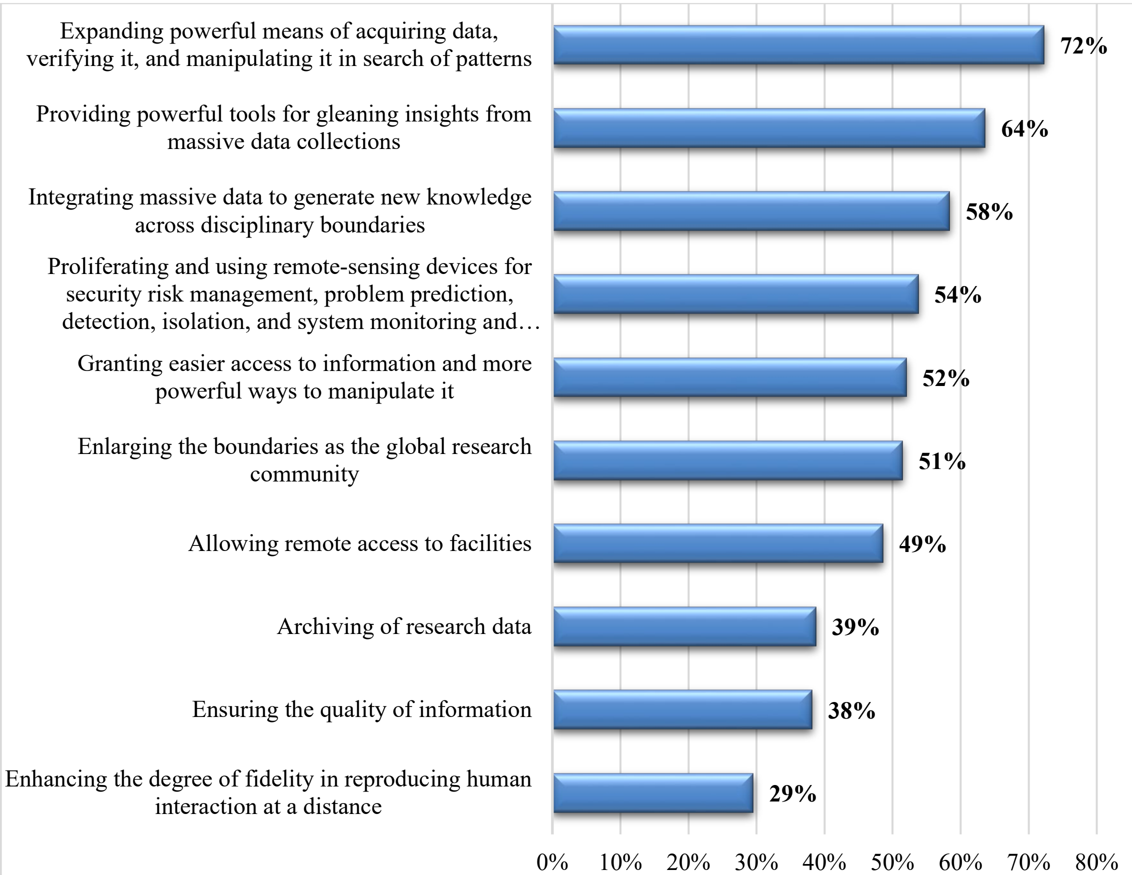

United Nations (UN)
61%
World Health Organization (WHO)
61%
UN Environment Programme
55%
World Bank
52%
UN Development Programme
51%
Organisation for Economic Co-operation and…
45%
World Economic Forum (WEF)
40%
World Business Council for Sustainable…
37%
Non-Governmental Organisations (NGOs)
37%
International Development Association
30%
North Atlantic Treaty Organization (NATO)
27%
0%
10%
20%
30%
40%
50%
60%
70%

d)

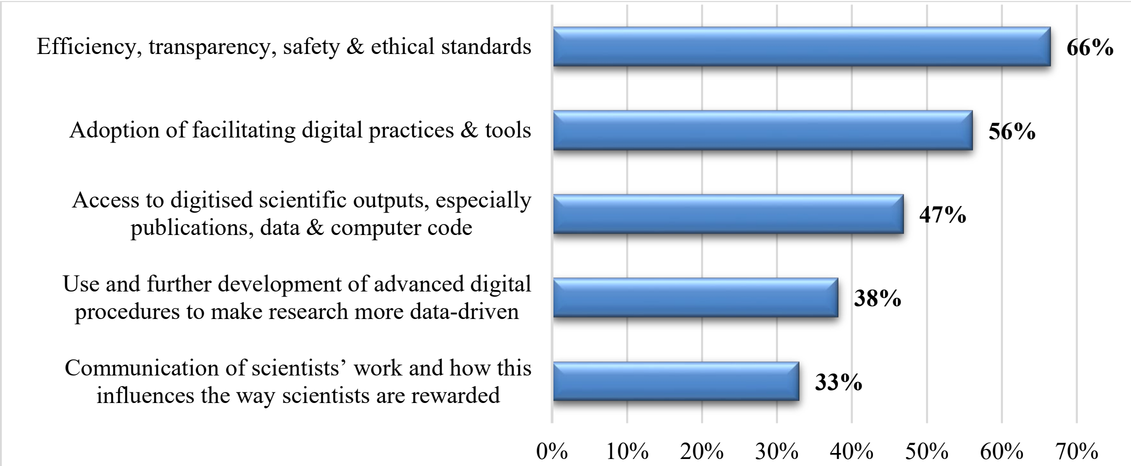
Figure 7


50%
40%
30%
20%
10%
0%
32%
46%
17%
4%
1%
Very Great Extent
Great Extent
Some Extent
Little Extent
Not at all

a)

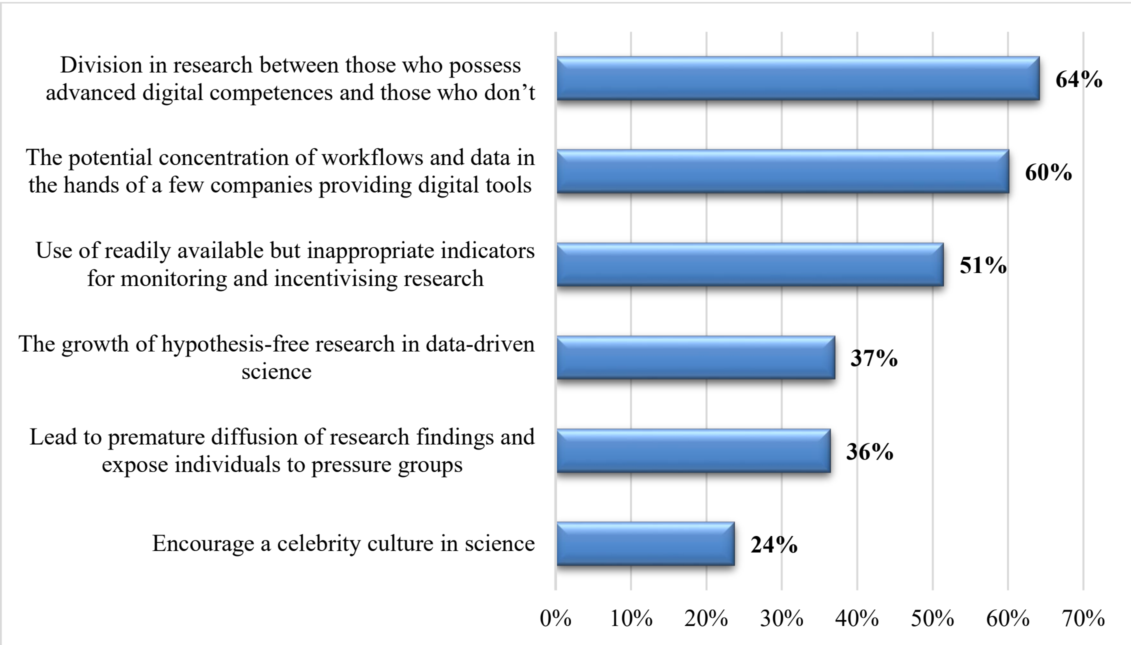

Expanding powerful means of acquiring data, verifying it, and manipulating it in search of patterns
72%
Providing powerful tools for gleaning insights from massive data collections
64%
Integrating massive data to generate new knowledge across disciplinary boundaries
58%
Proliferating and using remote-sensing devices for security risk management, problem prediction, detection, isolation, and system monitoring and…
54%
Granting easier access to information and more powerful ways to manipulate it
52%
Enlarging the boundaries as the global research community
51%
Allowing remote access to facilities
49%
Archiving of research data
39%
Ensuring the quality of information
38%
Enhancing the degree of fidelity in reproducing human interaction at a distance
29%
0%
10%
20%
30%
40%
50%
60%
70%
80%

b)



Efficiency, transparency, safety & ethical standards
66%
Adoption of facilitating digital practices & tools
56%
Access to digitised scientific outputs, especially publications, data & computer code
47%
Use and further development of advanced digital procedures to make research more data-driven
38%
Communication of scientists' work and how this influences the way scientists are rewarded
33%
0%
10%
20%
30%
40%
50%
60%
70%

c)



Division in research between those who possess advanced digital competences and those who don't
64%
The potential concentration of workflows and data in the hands of a few companies providing digital tools
60%
Use of readily available but inappropriate indicators for monitoring and incentivising research
51%
The growth of hypothesis-free research in data-driven science
37%
Lead to premature diffusion of research findings and expose individuals to pressure groups
36%
Encourage a celebrity culture in science
24%
0%
10%
20%
30%
40%
50%
60%
70%

d)

Figure 8

Sustainable Development Challenges

- Sustainable development research
- Sustainability indicators
- Weather extremes
- Climate dynamics/climate change
- Water (security, management, etc.)
- Sustainable water level management
- Hydrological behaviour in drought analysis
- Flood detection
- Hydrological integrity
- Catastrophes / natural disasters prediction.
- Waste sorting /waste management
- Food (security, consumption, etc.)
- Prediction, tracking and targeting poverty
- Sustainable cities
- Smart congestion management
- Detecting invasive plant species
- Pandemic situations
- Smart and sustainable agriculture
- Urban Sustainability
- Pollutant Emissions
- Exceedance of noise levels
- Indigenous cultural sustainability

Benefits of Deploying AI and Digitalisation

- Assessing, Monitoring and Managing several types of systems related to the SDGs
- Predicting natural disasters
- Warning and emergency response systems
- Automating data collection, processes or decisions
- Evaluating and modelling sustainability impacts
- Policy-making support
- Increasing stakeholder´s engagement
- Supporting and overcoming the complexity of sustainable development research.
- Developing smart solutions for sustainable development (platforms, machines, autonomous production systems)

Main Methods and Techniques Deployed

- Earth System-related measurements, satellite imagery, remote sensing data
- Earth observation (EO) data
- Wireless sensor network for AI
- Algorithms - Data pattern and predictive modelling techniques
- Neural networks
- Machine learning
- Augmented reality
- Internet of Things (IoT)
- Support Vector Machine (SVM)
- Vast scale and near real-time observation of social media data
- Artificial Systems (micro-robots and swarm robotics)
- Autonomous systems

Figure captions

Figure 1. Evolution in the use of technology in sustainability research
Figure 2. Growth of research on artificial intelligence and digitalisation and sustainable development since 1997 (sum: 2432 journal papers)
Figure 3. Bibliometric nodes and networks of research on artificial intelligence/digitalisation & sustainable development
Figure 4. Sample demographic details (country status, gender, age, and education level)
Figure 5. Responses to survey items regarding (a) sustainable development research benefits from artificial intelligence (b) specific advantages of artificial intelligence in the context of sustainable development research and c) sustainable development in general
Figure 6. Responses to survey items regarding a) specific artificial intelligence technologies, b) challenges and barriers to the application of artificial intelligence in sustainable development research, c) threats artificial intelligence poses to sustainability and d) international organisations that would benefit from artificial intelligence
Figure 7. Responses to survey items regarding the a) deployment, b) benefits, c) challenges and d) negative impacts of digitalisation in sustainable development research
Figure 8. Case studies on artificial intelligence and digitalisation in sustainable development research