
Research article

Artificial Intelligence and the Sustainable Development Goals: Opportunities, Trade-offs, and Governance Challenges

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ABSTRACT

The rapid rise of Artificial Intelligence (AI) and its increasing influence on many industries mean that its implications for achieving the Sustainable Development Goals (SDGs) must be considered carefully. Using a consensus-based expert elicitation method, we discover that AI could support the attainment of 134 targets across all 17 SDGs, while potentially hindering 59 targets. But present research agendas neglect key pieces of this link. Unfortunately, the rapid pace of AI research is not matched by enough regulatory understanding and control to ensure that AI-powered technology will be a force for good in sustainable development. Not doing so could leave us with serious holes in transparency, safety, and ethical norms that would defeat the whole purpose AI is there to serve.

1. Introduction

The emergence of artificial intelligence (AI) is increasingly shaping a diverse range of sectors, with profound implications for global productivity, equality, environmental outcomes, and numerous other domains in both the short and long term. Reported potential impacts of AI indicate both positive and negative consequences for sustainable development. However, to date, no published study has systematically assessed the extent to which AI might influence all dimensions of sustainable development defined in this study as the 17 Sustainable Development Goals (SDGs) and their 169 associated targets, as internationally agreed upon in the 2030 Agenda for Sustainable Development[1, 2]. This gap in the literature is critical, as our findings indicate that AI may significantly affect the ability to meet all SDGs.

This paper presents and discusses the implications of AI's ability to enable or inhibit the delivery of all 17 goals and 169 targets recognized in the 2030 Agenda. The relationships were characterized through a consensus-based expert elicitation process[3, 4], informed by previous studies that mapped SDG interlinkages[4]. A summary of the results is presented in Fig. 1, with Supplementary Data 1 providing a comprehensive list of all SDGs and targets alongside the detailed findings of this work. Although there is no internationally agreed-upon definition of AI, for this study we considered any software technology with at least one of the following capabilities: perception

(including audio, visual, textual, and tactile processing, e.g., facial recognition), decision-making (e.g., medical diagnosis systems), prediction (e.g., weather forecasting), automatic knowledge extraction and pattern recognition from data (e.g., identification of fake news networks in social media), interactive communication (e.g., social robots or chatbots), and logical reasoning (e.g., theory development from premises). This broad conception encompasses a wide variety of subfields, including machine learning[3, 5].

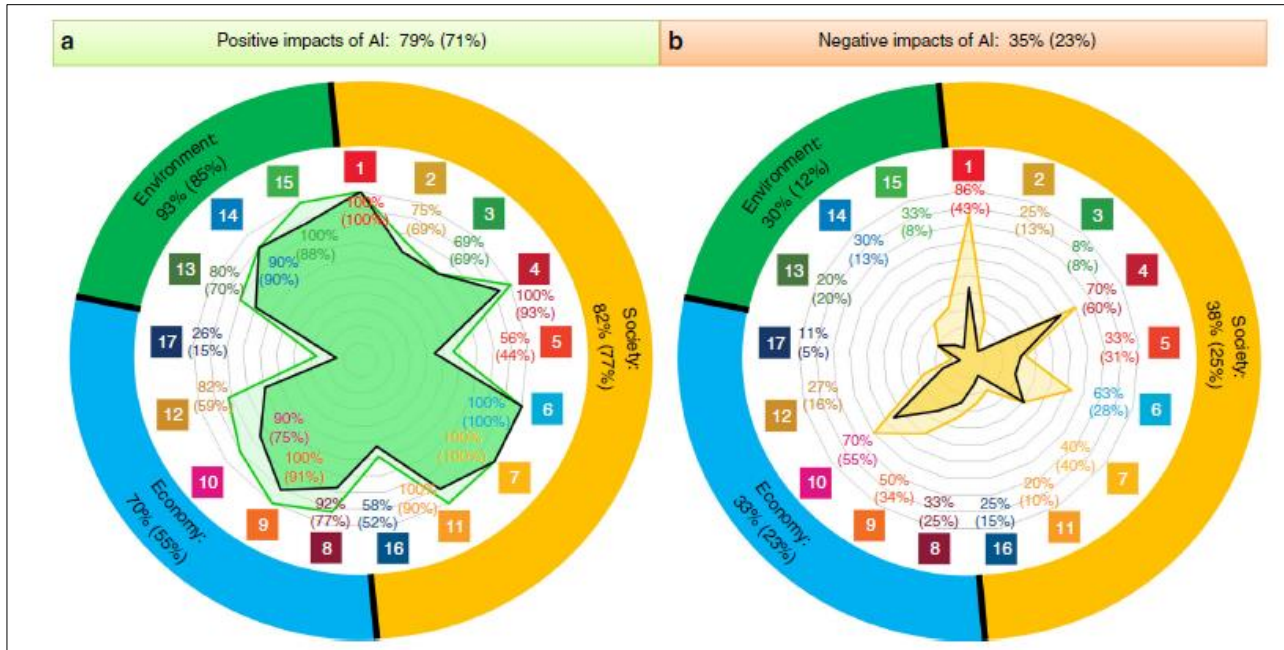


Figure1: Summary of positive and negative impact of AI on the various SDGs. Documented evidence of the potential of AI acting as (a) an enabler or (b) an inhibitor on each of the SDGs. The numbers inside the colored squares represent each of the SDGs (see Supplementary Data 1). The percentages on the top indicate the proportion of all targets potentially affected by AI, and the ones in the inner circle of the figure correspond to proportions within each SDG. The results corresponding to the three main groups, namely Society, Economy, and Environment, are also shown in the outer circle of the figure. The results obtained when the type of evidence is taken into account are shown by the inner shaded area and the values in brackets[6].

2. Documented Connections between AI and the SDGs

Our review of relevant evidence demonstrates that AI may serve as an enabler for 134 targets (79%) across all SDGs, generally through technological improvements that may overcome existing limitations. However, 59 targets (35%) across all SDGs may experience negative impacts from the development and deployment of AI. For this study, we have categorized the SDGs into three groups according to the three pillars of sustainable development: Society, Economy, and Environment[7, 8]. This classification enables us to provide an overview of the general areas of AI influence. In Fig. 1, we also present results obtained when weighting the appropriateness of the evidence presented in each reference to assess an interlinkage, as discussed in the Methods section. A detailed assessment of the Society, Economy, and Environment groups, accompanied by illustrative examples, is provided below.

2.1 AI and Societal Outcomes

Sixty-seven targets (82%) within the Society group could potentially benefit from AI-based technologies (Fig. 2). For instance, in SDG 1 (No Poverty), SDG 4 (Quality Education), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 11 (Sustainable Cities and Communities), AI may act as an enabler for all targets by supporting the provision of food, health, water, and energy services to populations. It can also underpin low-carbon systems, for example, by facilitating the creation of circular economies and smart cities that efficiently utilize their resources[9, 10]. Specifically, AI can enable smart and low-carbon cities encompassing interconnected technologies such as electric autonomous vehicles and smart appliances that enable demand response in the

electricity sector, yielding benefits across SDGs 7, 11, and 13 (Climate Action). AI can also assist in integrating variable renewable energy sources by enabling smart grids that partially match electrical demand to periods of peak solar and wind availability[11]. Fewer targets in the Society group can be negatively impacted by AI (31 targets, 38%) compared to those with positive impacts. Nevertheless, their consideration is crucial. Many of these negative impacts relate to how technological improvements enabled by AI may be implemented in countries with different cultural values and levels of wealth. Advanced AI technology, research, and product design often require massive computational resources available only through large computing centers. These facilities have substantial energy requirements and carbon footprints[12]. For instance, cryptocurrency applications such as Bitcoin currently consume as much electricity as some nations' total electrical demand[13], compromising outcomes in SDG 7 and SDG 13. Some estimates suggest that the total electricity demand of information and communications technologies (ICTs) could reach up to 20% of global electricity demand by 2030, up from approximately 1% today. Green growth of ICT technology is therefore essential[14, 15]. More efficient cooling systems for data centers, broader energy efficiency measures, and increased renewable energy usage in ICTs will all play important roles in containing electricity demand growth[16]. In addition to more efficient and renewable-energy-based data centers, it is essential to embed human knowledge in the development of AI models. The human brain consumes considerably less energy than is required to train AI models, and available knowledge introduced into models—for instance, through physics-informed deep learning[17] does not need to be learned through data-intensive training, potentially significantly reducing associated energy consumption. Although AI-enabled technology can act as a catalyst for achieving the 2030 Agenda, it may also trigger inequalities that act as inhibitors on SDGs 1, 4, and 5. This duality is reflected in target 1.1: while AI can help identify areas of poverty and foster international action using satellite imagery, it may also lead to additional qualification requirements for jobs, consequently increasing inherent inequalities [18] and acting as an inhibitor toward the achievement of this target. Another significant drawback of AI-based developments is that they are traditionally based on the needs and values of nations where AI is being developed. If AI technology and big data are used in regions lacking ethical scrutiny, transparency, and democratic control, AI might enable nationalism, hatred toward minorities, and biased election outcomes [19]. The term "big nudging" has emerged to describe the use of big data and AI to exploit psychological weaknesses to steer decisions—creating problems such as damaging social cohesion, democratic principles, and even human rights[19]. AI has recently been utilized to develop citizen scores, which are used to control social behavior a clear example of a threat to human rights due to AI misuse, with one of its most significant problems being the lack of information provided to citizens regarding the types of data analyzed and the consequences this may have on their lives. It is also important to note that AI technology is unevenly distributed. For example, complex AI-enhanced agricultural equipment may not be accessible to small farmers, potentially increasing the gap with respect to larger producers in more developed economies, thereby inhibiting the achievement of some targets of SDG 2. Another important shortcoming of AI in the context of SDG 5 (Gender Equality) is the insufficient research assessing the potential impact of technologies such as smart algorithms, image recognition, or reinforced learning on discrimination against women and minorities. Machine-learning algorithms uncritically trained on regular news articles will inadvertently learn and reproduce societal biases against women and girls embedded in current languages. Word embeddings, a popular technique in natural language processing, have been found to exacerbate existing gender stereotypes. In addition to the lack of diversity in datasets, another main issue is the lack of gender, racial, and ethnic diversity in the AI workforce. Diversity is one of the main principles supporting innovation and societal resilience, which will become essential in a society exposed to changes associated with AI development. Societal resilience is also promoted by decentralization—that is, by the implementation of AI technologies adapted to the cultural background and particular needs of different regions.



Figure 2: Detailed assessment of the impact of AI on the SDGs within the Society group. Documented evidence of positive or negative impact of AI on the achievement of each of the targets from SDGs 1, 2, 3, 4, 5, 6, 7, 11, and 16 (<https://www.un.org/sustainabledevelopment/>). Each block in the diagram represents a target (see the Supplementary Data 1 for additional details on the targets). For targets highlighted in green or orange, we found published evidence that AI could potentially enable or inhibit such a target, respectively. The absence of highlighting indicates the absence of identified evidence. It is noteworthy that this does not necessarily imply the absence of a relationship. (The content of this figure has not been reviewed by the United Nations and does not reflect its views).

2.2 AI and Economic Outcomes

The technological advantages provided by AI may also have a positive impact on the achievement of several SDGs within the Economy group. We have identified benefits from AI on 42 targets (70%) within this group, whereas negative impacts are reported in 20 targets (33%), as shown in Fig. 1. Although Acemoglu and Restrepo [1] report a net positive impact of AI-enabled technologies associated with increased productivity, the literature also reflects potential negative impacts mainly related to increased inequalities. In the context of the Economy group of SDGs, if future markets rely heavily on data analysis and these resources are not equally available in low- and middle-income countries, the economic gap may be significantly increased due to newly introduced inequalities, significantly impacting SDGs 8 (Decent Work and Economic Growth), 9 (Industry, Innovation and Infrastructure), and 10 (Reduced Inequalities). Brynjolfsson and McAfee argue that AI can exacerbate inequality also within nations. By replacing old jobs with ones requiring more skills, technology disproportionately rewards the educated. Since the mid-1970s, salaries in the United States have risen approximately 25% for those with graduate degrees, while the average high-school dropout experienced a 30% pay cut. Moreover, automation shifts corporate income to those who own companies from those who work there. Such transfer of revenue from workers to investors helps explain why, even though the combined revenues of Detroit's "Big 3" (GM, Ford, and Chrysler) in 1990 were almost identical to those of Silicon Valley's "Big 3" (Google, Apple, and Facebook) in 2014, the latter had nine times fewer employees and were worth thirty times more on the stock market. Figure 3 presents an assessment of the documented positive and negative effects on various targets within the SDGs in the Economy group. Although the identified linkages in the Economy group are mainly positive, trade-offs cannot be neglected. For instance, AI can have a negative effect

on social media usage by showing users content specifically suited to their preconceived ideas, potentially leading to political polarization and affecting social cohesion [21], with consequences in the context of SDG 10 on reduced inequalities. On the other hand, AI can help identify sources of inequality and conflict and thereby potentially reduce inequalities—for example, by using simulations to assess how virtual societies may respond to changes. However, there is an underlying risk when using AI to evaluate and predict human behavior, which is the inherent bias in the data. It has been reported that a number of discriminatory challenges are faced in the automated targeting of online job advertising using AI, essentially related to previous biases in selection processes conducted by human recruiters. The work by Dalenberg highlights the need to modify data preparation processes and explicitly adapt AI-based algorithms used for selection processes to avoid such biases.



Figure 3: Detailed assessment of the impact of AI on the SDGs within the Economy group. Documented evidence of positive or negative impact of AI on the achievement of each of the targets from SDGs 8, 9, 10, 12, and 17 (<https://www.un.org/sustainabledevelopment/>). The interpretation of the blocks and colors is as in Fig. 2. (The content of this figure has not been reviewed by the United Nations and does not reflect its views).

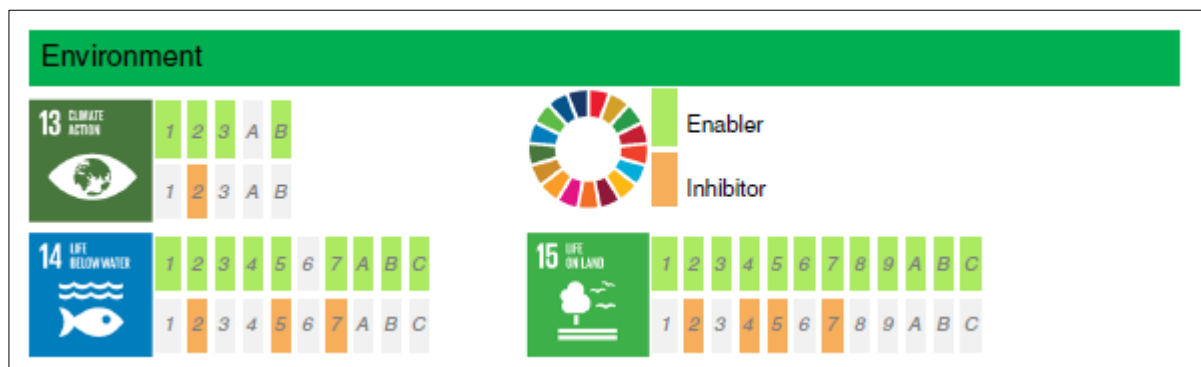


Figure 4: Detailed assessment of the impact of AI on the SDGs within the Environment group. Documented evidence of positive or negative impact of AI on the achievement of each of the targets from SDGs 13, 14, and 15 (<https://www.un.org/sustainabledevelopment/>). The interpretation of the blocks and colors is as in Fig. 2. (The content of this figure has not been reviewed by the United Nations and does not reflect its views).

2.3 AI and Environmental Outcomes

The final group of SDGs relates to the Environment, analyzed in Fig. 4. The three SDGs in this group pertain to climate action, life below water, and life on land (SDGs 13, 14, and 15). For the Environment group, we identified 25 targets (93%) for which AI could act as an enabler. Benefits from AI could be derived from the possibility of analyzing large-scale interconnected databases to develop joint actions aimed at preserving the environment. Looking at SDG 13 on climate action, there is evidence that AI advances will support the understanding of climate change and the modeling of its possible impacts. Furthermore, AI will support low-carbon energy systems with

high integration of renewable energy and energy efficiency, all of which are needed to address climate change. AI can also help improve ecosystem health. The achievement of target 14.1, calling for preventing and significantly reducing marine pollution of all kinds, can benefit from AI through algorithms for automatic identification of possible oil spills. Another example is target 15.3, which calls for combating desertification and restoring degraded land and soil. These AI techniques can help identify desertification trends over large areas, providing information relevant for environmental planning, decision-making, and management to avoid further desertification or help reverse trends by identifying major drivers. However, as noted above, efforts to achieve SDG 13 on climate action could be undermined by the high energy needs of AI applications, especially if non-carbon-neutral energy sources are used. Furthermore, despite the many examples of how AI is increasingly applied to improve biodiversity monitoring and conservation, it can be conjectured that increased access to AI-related information about ecosystems may drive overexploitation of resources, although such misuse has so far not been sufficiently documented. This aspect is further discussed below, where currently identified gaps in AI research are considered.

3. An Assessment of the Collected Evidence on the Interlinkages

A deeper analysis of the gathered evidence was undertaken as shown in Fig. 1. In practice, each interlinkage was weighted based on the applicability and appropriateness of each reference to assess a specific interlinkage—and possibly identify research gaps. Although accounting for the type of evidence has a relatively small effect on the positive impacts (we observe a reduction of positively affected targets from 79% to 71%), we observe a more significant reduction (from 35% to 23%) in targets with negative impacts of AI. This can be partly attributed to the fact that AI research typically employs quantitative methods that may bias results toward positive effects. However, there are some differences across the Society, Economy, and Environment spheres. In the Society sphere, when weighting the appropriateness of evidence, positively affected targets diminish by 5 percentage points (p.p.) and negatively affected targets by 13 p.p. In particular, weighting the appropriateness of evidence on negative impacts on SDG 1 (No Poverty) and SDG 6 (Clean Water and Sanitation) reduces the fraction of affected targets by 43 p.p. and 35 p.p., respectively. In the Economy group, positive impacts are reduced more (15 p.p.) than negative ones (10 p.p.) when taking into account the appropriateness of the found evidence to address these issues. This may be related to the extensive study in the literature assessing the displacement of jobs due to AI (because of clear policy and societal concerns), but overall the longer-term benefits of AI on the economy are perhaps not so extensively characterized by currently available methods. Finally, although the weighting of evidence decreases the positive impacts of AI on the Environment group only, the negative impacts see the largest average reduction. This is explained by the fact that, although there are some indications of the potential negative impact of AI on this SDG, there is no strong evidence (in any of the targets) supporting this claim, making this a relevant area for future research. In general, the fact that the evidence on interlinkages between AI and the large majority of targets is not based on tailored analyses and tools to address each particular issue provides a strong rationale for addressing several research gaps, which are identified and listed below.

4. Research Gaps on the Role of AI in Sustainable Development

The more we enable SDGs by deploying AI applications from autonomous vehicles to AI-powered healthcare solutions and smart electrical grids, the more important it becomes to invest in the AI safety research needed to keep these systems robust and beneficial, to prevent them from malfunctioning or being hacked. A crucial research avenue for safe AI integration involves understanding catastrophes that can be enabled by systemic faults in AI technology. For instance, a recent World Economic Forum (WEF) report raised concerns due to the integration of AI in the financial sector. It is therefore very important to raise awareness of the risks associated with possible failures of AI systems in a society progressively more dependent on this technology. Furthermore, although we were able to find

numerous studies suggesting that AI can potentially serve as an enabler for many SDG targets and indicators, a significant fraction of these studies have been conducted in controlled laboratory environments, based on limited datasets or using prototypes. Hence, extrapolating this information to evaluate real-world effects often remains a challenge. This is particularly true when measuring the impact of AI across broader scales, both temporally and spatially. We acknowledge that conducting controlled experimental trials for evaluating real-world impacts of AI can result in depicting a snapshot situation, where AI tools are tailored toward that specific environment. However, as society is constantly changing (also due to factors including non-AI-based technological advances), the requirements for AI are changing as well, resulting in a feedback loop with interactions between society and AI. Another underemphasized aspect in existing literature is the resilience of society toward AI-enabled changes. Therefore, novel methodologies are required to ensure that the impact of new technologies is assessed from the perspectives of efficiency, ethics, and sustainability before launching large-scale AI deployments. In this sense, research aimed at obtaining insight into the reasons for failure of AI systems, introducing combined human-machine analysis tools is an essential step toward accountable AI technology, given the substantial risk associated with such failures. Although we found more published evidence of AI serving as an enabler than as an inhibitor on the SDGs, there are at least two important aspects that should be considered. First, self-interest can be expected to bias the AI research community and industry toward publishing positive results. Second, discovering detrimental aspects of AI may require longer-term studies and, as mentioned above, there are not many established evaluation methodologies available to do so. Bias toward publishing positive results is particularly apparent in the SDGs corresponding to the Environment group. A good example of this bias is target 14.5 on conserving coastal and marine areas, where machine-learning algorithms can provide optimum solutions given a wide range of parameters regarding the best choice of areas to include in conservation networks. However, even if the solutions are optimal from a mathematical point of view (given a certain range of selected parameters), additional research would be needed to assess the long-term impact of such algorithms on equity and fairness, precisely because of the unknown factors that may come into play. Regarding the second point stated above, it is likely that the AI projects with the highest potential for maximizing profit will receive funding. Without oversight, research on AI is expected to be directed toward applications where funding and commercial interests lie. This may result in increased inequality. Consequently, there is a risk that AI-based technologies with potential to achieve certain SDGs may not be prioritized if their expected economic impact is not high. Furthermore, it is essential to promote the development of initiatives to assess the societal, ethical, legal, and environmental implications of new AI technologies. Substantive research and application of AI technologies to SDGs is concerned with the development of better data-mining and machine-learning techniques for the prediction of certain events. This is the case for applications such as forecasting extreme weather conditions or predicting recidivist offender behavior. The expectation with this research is to enable preparation and response for a wide range of events. However, there is a research gap in real-world applications of such systems, e.g., by governments. Institutions face a number of barriers to adopting AI systems as part of their decision-making processes, including the need to establish cybersecurity measures and protect the privacy of citizens and their data. Both aspects have implications for human rights regarding surveillance, tracking, communication, data storage, and automation of processes without rigorous ethical standards. Targeting these gaps would be essential to ensure the usability and practicality of AI technologies for governments. This would also be a prerequisite for understanding long-term impacts of AI regarding its potential, while regulating its use to reduce the possible bias that can be inherent to AI. Furthermore, our research suggests that AI applications are currently biased toward SDG issues that are mainly relevant to those nations where most AI researchers live and work. For instance, many systems applying AI technologies to agriculture—e.g., to automate harvesting or optimize its timing—are located within wealthy nations. Our literature search resulted in only a handful of examples where AI technologies are applied to SDG-related issues

in nations without strong AI research. Moreover, if AI technologies are designed and developed for technologically advanced environments, they have the potential to exacerbate problems in less wealthy nations (e.g., when it comes to food production). This finding leads to a substantial concern that developments in AI technologies could increase inequalities both between and within countries, in ways that counteract the overall purpose of the SDGs. We encourage researchers and funders to focus more on designing and developing AI solutions that respond to localized problems in less wealthy nations and regions. Projects undertaking such work should ensure that solutions are not simply transferred from technology-intensive nations. Instead, they should be developed based on a deep understanding of the respective region or culture to increase the likelihood of adoption and success.

5. Towards Sustainable AI

The great wealth that AI-powered technology has the potential to create may flow mainly to those already well-off and educated, while job displacement leaves others worse off. Globally, the growing economic importance of AI may result in increased inequalities due to unevenly distributed educational and computing resources throughout the world. Furthermore, existing biases in the data used to train AI algorithms may result in exacerbation of those biases, eventually leading to increased discrimination. Another related problem is the use of AI to produce computational (commercial, political) propaganda based on big data (also defined as "big nudging"), which is spread through social media by independent AI agents with the goals of manipulating public opinion and producing political polarization. Despite the fact that current scientific evidence refutes technological determinism of such fake news, long-term impacts of AI are possible (although unstudied) due to a lack of robust research methods. A change of paradigm is therefore needed to promote cooperation and to limit the possibilities for control of citizen behavior through AI. The concept of Finance 4.0 has been proposed as a multi-currency financial system promoting a circular economy aligned with societal goals and values. Informational self-determination (in which the individual takes an active role in how their data are handled by AI systems) would be an essential aspect of such a paradigm. The data intensiveness of AI applications creates another problem: the need for more and more detailed information to improve AI algorithms, which is in conflict with the need for more transparent handling and protection of personal data. One area where this conflict is particularly important is healthcare. Panch et al. [54] argue that although the vast amount of personal healthcare data could lead to the development of very powerful tools for diagnosis and treatment, the numerous problems associated with data ownership and privacy call for careful policy intervention. This is also an area where more research is needed to assess possible long-term negative consequences. All the challenges mentioned above culminate in the academic discourse about the legal personality of robots [55], which may lead to alarming narratives of technological totalitarianism. Many of these aspects result from the interplay between technological developments on one side and the requests of individuals, responses from governments, and environmental resources and dynamics on the other. Figure 5 shows a schematic representation of these dynamics, emphasizing the role of technology. Based on the evidence discussed above, these interactions are not currently balanced, and the advent of AI has exacerbated the process. A wide range of new technologies are being developed very rapidly, significantly affecting the way individuals live and the impacts on the environment, requiring new piloting procedures from governments. The problem is that neither individuals nor governments seem to be able to keep pace with these technological developments. This fact is illustrated by the lack of appropriate legislation to ensure the long-term viability of these new technologies. We argue that it is essential to reverse this trend. A first step in this direction is to establish adequate policy and legislation frameworks to help direct the vast potential of AI toward the highest benefit for individuals and the environment, as well as toward the achievement of the SDGs. Regulatory oversight should be preceded by regulatory insight, where policymakers have sufficient understanding of AI challenges to be able to formulate sound policy. Developing such insight is even more urgent than oversight, as policy formulated without understanding is likely to be ineffective at best and counterproductive at worst. Although strong and connected

institutions (covered by SDG 16) are needed to regulate the future of AI, we find that there is limited understanding of the potential impact of AI on institutions. Examples of positive impacts include AI algorithms aimed at improving fraud detection or assessing the possible effects of certain legislation. A concern is that data-driven approaches for policing may hinder equal access to justice because of algorithm bias, particularly toward minorities. Consequently, we believe that it is imperative to develop legislation regarding transparency and accountability of AI, as well as to decide the ethical standards to which AI-based technology should be subjected. This debate is being pushed forward by initiatives such as the IEEE (Institute of Electrical and Electronics Engineers) Ethical Aligned Design [60] and the new EU (European Union) Ethical Guidelines for Trustworthy AI. It is noteworthy that despite the importance of an ethical, responsible, and trustworthy approach to AI development and use, this issue is independent of the aims of this article. In other words, one can envision AI applications that improve SDG outcomes while not being fully aligned with AI ethics guidelines. We therefore recommend that AI applications targeting SDGs are open and explicit about guiding ethical principles, also by indicating explicitly how they align with existing guidelines. On the other hand, the lack of interpretability of AI, which is currently one of the challenges of AI research, adds additional complication to the enforcement of such regulatory actions. Note that this implies that AI algorithms (which are trained with data consisting of previous regulations and decisions) may act as a "mirror" reflecting biases and unfair policy. This presents an opportunity to possibly identify and correct certain errors in existing procedures. The friction between the uptake of data-driven AI applications and the need to protect the privacy and security of individuals is stark. When not properly regulated, the vast amount of data produced by citizens might potentially be used to influence consumer opinion toward a certain product or political cause.

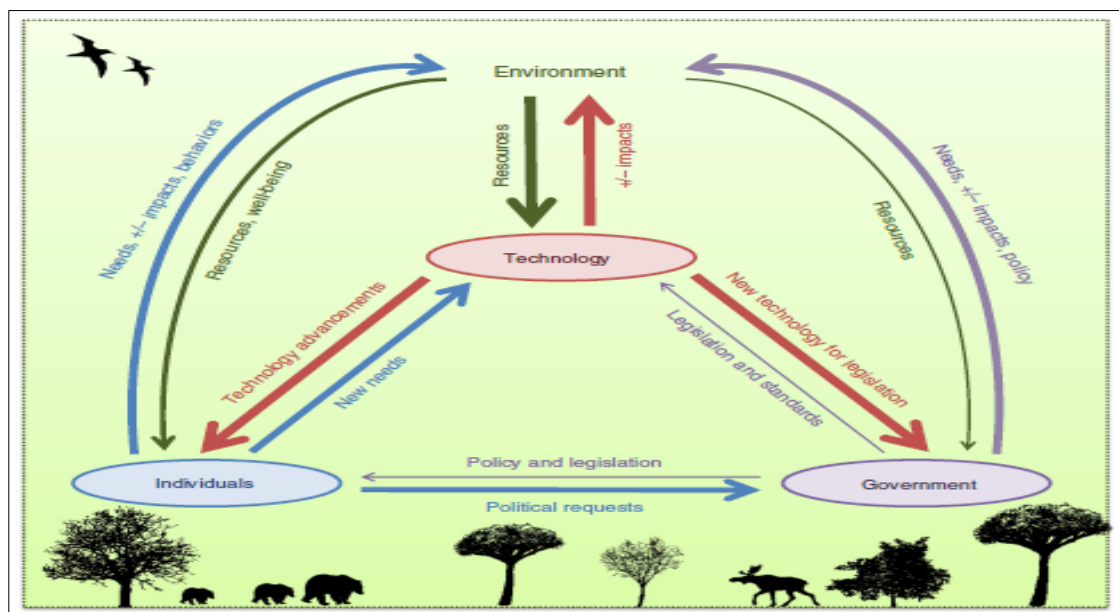


Figure 5 Interaction of AI and society. Schematic representation showing the identified agents and their roles towards the development of AI. Thicker arrows indicate faster change. In this representation, technology affects individuals through technical developments, which change the way people work and interact with each other and with the environment, whereas individuals would interact with technology through new needs to be satisfied. Technology (including technology itself and its developers) affects governments through new developments that need appropriate piloting and testing. Also, technology developers affect government through lobbying and influencing decision-makers. Governments provide legislation and standards to technology. Governments affect individuals through policy and legislation, and individuals would require new legislation consistent with the changing circumstances from the governments. The environment interacts with technology by providing the resources needed for technological development and is affected by the environmental impact of technology. Furthermore, the environment is affected either negatively or positively by the needs, impacts, and choices of individuals and governments, which in turn require environmental resources. Finally, the environment is also an underlying layer that provides the “planetary boundaries” to the

mentioned interactions.

AI applications that have positive societal welfare implications may not always benefit each individual separately. This inherent dilemma of collective vs. individual benefit is relevant in the scope of AI applications but is not one that should be solved by the application of AI itself. This has always been an issue affecting humankind and cannot be solved in a simple way, since such a solution requires participation of all involved stakeholders. The dynamism of context and the level of abstraction at which human values are described imply that there is not a single ethical theory that holds all the time in all situations. Consequently, a single set of utilitarian ethical principles with AI would not be recommendable due to the high complexity of our societies. It is also essential to be aware of the potential complexity in the interaction between human and AI agents, and of the increasing need for ethics-driven legislation and certification mechanisms for AI systems. This is true for all AI applications, but especially those that, if uncontrolled, could have catastrophic effects on humanity, such as autonomous weapons. Regarding the latter, associations of AI and robotics experts are already getting together to call for legislation and limitations on their use. Furthermore, associations such as the Future of Life Institute are reviewing and collecting policy actions and shared principles around the world to monitor progress toward sustainable-development-friendly AI. To deal with the ethical dilemmas raised above, it is important that all applications provide openness about the choices and decisions made during design, development, and use, including information about the provenance and governance of the data used for training algorithms, and about whether and how they align with existing AI guidelines. It is therefore important to adopt decentralized AI approaches for a more equitable development of AI [66]. We are at a critical turning point for the future of AI. A global and science-driven debate to develop shared principles and legislation among nations and cultures is necessary to shape a future in which AI positively contributes to the achievement of all SDGs. The current choices to develop a sustainable-development-friendly AI will determine whether AI becomes a powerful enabler of the 2030 Agenda or a major obstacle to it. With the right regulatory insight, oversight, and ethical frameworks, we can harness the transformative potential of AI to build a more sustainable, equitable, and prosperous future for all.

6. Methods

This section outlines the methodological approach employed to generate the findings presented in this study and detailed in Supplementary Data 1. The central research question guiding this investigation was: "Is there published evidence of artificial intelligence (AI) acting as an enabler or an inhibitor for each of the 169 targets across the 17 Sustainable Development Goals (SDGs)?" To address this question, we conducted a consensus-based expert elicitation process, building upon prior studies that mapped SDG interlinkages and following established methodological frameworks. The authorship team comprised academics representing a broad spectrum of disciplines, including engineering, natural sciences, and social sciences, who collectively served as experts throughout the elicitation process. These authors undertook an expert-driven literature review to substantiate the identified connections between AI and the various SDG targets. The following sources were considered acceptable forms of evidence: peer-reviewed publications on real-world applications (with quality assurance based on publication venue and rigor); peer-reviewed evidence from controlled or laboratory-based studies (similarly vetted for quality); reports from accredited organizations (e.g., United Nations agencies or governmental bodies); and documented commercial-stage applications. Conversely, the following were excluded from consideration: educated conjectures or speculative assertions; real-world applications lacking peer-reviewed research validation; media reports; public opinion; and other non-verifiable sources. The expert elicitation proceeded according to the following protocol. Each SDG was allocated to one or more primary contributors, with additional contributors assigned in certain cases, as summarized in Supplementary Data 1 (where author initials correspond to individual contributors). Primary contributors

conducted an initial literature review for their assigned SDG, after which additional contributors completed the primary analysis. A single published study documenting a synergy or trade-off between a target and AI was deemed sufficient to establish an interlinkage; however, for the vast majority of targets, multiple references were provided. Upon completion of the analysis for a given SDG, an independent reviewer—who had not participated in the initial analysis—was appointed to critically evaluate the connections and reasoning presented. Wherever possible, we assigned primary contributors and reviewers with complementary expertise for each SDG. The reviewer's role was to introduce additional perspectives and considerations while critically appraising the analysis. Subsequently, primary contributors and reviewers engaged in iterative discussion to refine the results for each SDG until consensus was achieved and the analysis was sufficiently robust. Following the attainment of consensus on the assessments presented in Supplementary Data 1, we analyzed the results by enumerating the targets for which AI may act as an enabler or an inhibitor, and calculated the percentage of targets with positive and negative impacts for each of the 17 goals, as illustrated in Fig. 1. Additionally, we categorized the SDGs into three groups consistent with the three pillars of sustainable development: Society, Economy, and Environment, following the classification discussed in references[20]. The assignment of SDGs to each category is presented in Fig. 6, with the detailed results for each group depicted in Figs. 2–4. These figures indicate, for each target within each SDG, whether published evidence of positive or negative impact was identified[2].

6.1 Weighting of Evidence Types

In the methodology described above, a connection between AI and a particular target is established if at least one reference documenting such a link is identified. However, given that the analyzed studies rely on substantially different types of evidence, it is essential to classify the references according to the methodological rigor employed to support their conclusions. Accordingly, all references included in Supplementary Data 1 are assigned a classification from (A) to (D), based on the following criteria:

- Type (A): References utilizing sophisticated analytical tools and comprehensive datasets to address the specific issue, with findings that are generalizable beyond the immediate context.
- Type (B): Studies based on empirical data relevant to the issue, but with limited generalizability due to contextual or methodological constraints.
- Type (C): Anecdotal qualitative studies and methods that provide illustrative but not necessarily representative evidence.
- Type (D): Purely theoretical or speculative references lacking empirical substantiation.

These classifications were assigned through the same expert elicitation process described above. To account for variations in evidentiary quality, the references were weighted according to their classification: Type (A) received a weight of 1.0; Type (B), 0.75; Type (C), 0.5; and Type (D), 0.25. It is important to acknowledge that, given the vast scope of research across all SDG areas, our literature search was not exhaustive; consequently, some targets are associated with more references than others in our study. To mitigate any bias arising from differential reference counts across targets, we considered the largest positive and negative weight when establishing a connection with each target. To illustrate this approach, consider the following example: for a particular target, one Type (B) reference documents a positive connection, while two references of Types (A) and (D) respectively document negative connections with AI. In this scenario, the potential positive impact of AI on that target would be assessed with a weight of 0.75, while the potential negative impact would receive a weight of 1.0.

7. Limitations of the Research

The analysis presented herein reflects the perspective of the authors. It is possible that some relevant literature on how AI might affect certain SDGs was inadvertently overlooked, or that published evidence on such interlinkages

does not yet exist. Nevertheless, the methodological approach employed sought to minimize the subjectivity inherent in such assessments. The evaluation of how AI might affect the delivery of each SDG was assessed and reviewed by multiple authors, with numerous studies examined for each interlinkage. Furthermore, as discussed above, each interlinkage was deliberated among a subset of authors until consensus was reached regarding its nature. Finally, this study relies on the analytical framework provided by the SDGs. The SDGs offer a powerful lens for examining internationally agreed sustainable development objectives and represent a significant advancement over the Millennium Development Goals in their comprehensive coverage of all dimensions of sustainable development, encompassing human rights, social sustainability, environmental outcomes, and economic development. However, the SDGs are inherently a political compromise and may be limited in their capacity to represent the full complexity of cross-interactions and dynamic relationships among targets. Therefore, the SDGs should be considered in conjunction with prior and ongoing international agreements and frameworks [21]. For instance, as highlighted in a recent report by the UN Human Rights Office, human rights considerations are substantially embedded within the SDGs. Nonetheless, the SDGs should be viewed as a complement to, rather than a replacement for, the United Nations Universal Declaration of Human Rights[0].

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