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Using artificial intelligence to implement the UN sustainable development goals at higher education institutions

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ABSTRACT

Artificial intelligence (AI) can significantly contribute to the implementation of the United Nations Sustainable Development Goals (SDGs) by offering innovative solutions and enhancing the efficiency of processes aimed at achieving these goals. There is a perceived need for studies which may look at these connections. Against this background, this paper reports on a study that investigated the connections between artificial intelligence and the implementation of the UN Sustainable Development Goals (SDGs) at higher education institutions. The paper deployed a multi-methods approach. The first one was a bibliometric analysis of publications in the topic. The second method used was an assessment of a set of case studies, that illustrate how artificial intelligence is being deployed among a sample of universities in support of efforts to implement the SDGs and a survey aimed at identifying current and future trends. The data gathered allow some trends to be identified. For instance, that there is a wide range of applications of AI to sustainability in High Education Institutions (HEI), to be chosen in terms of campus operations and greening, outreach and community engagement, research, teaching and learning, and university management. Also, the paper has identified successful examples of the deployment of AI in various sustainability contexts, illustrating what are the success factors for them. Moreover, the survey identified the fact that the use of AI is quite widely spread, and is likely to increase in coming years, due to a greater demand. Finally, AI also poses several challenges, such as authenticity and ethics in assessment (case studies), 'lack of access to software/materials', and 'lack of information technology training for myself/my colleagues' (survey). Overall, AI offers a powerful toolset to accelerate and enhance the implementation of the UN SDGs. By analysing vast datasets, predicting outcomes, optimising processes, and providing new insights, AI has the potential to address complex sustainability challenges across various sectors.

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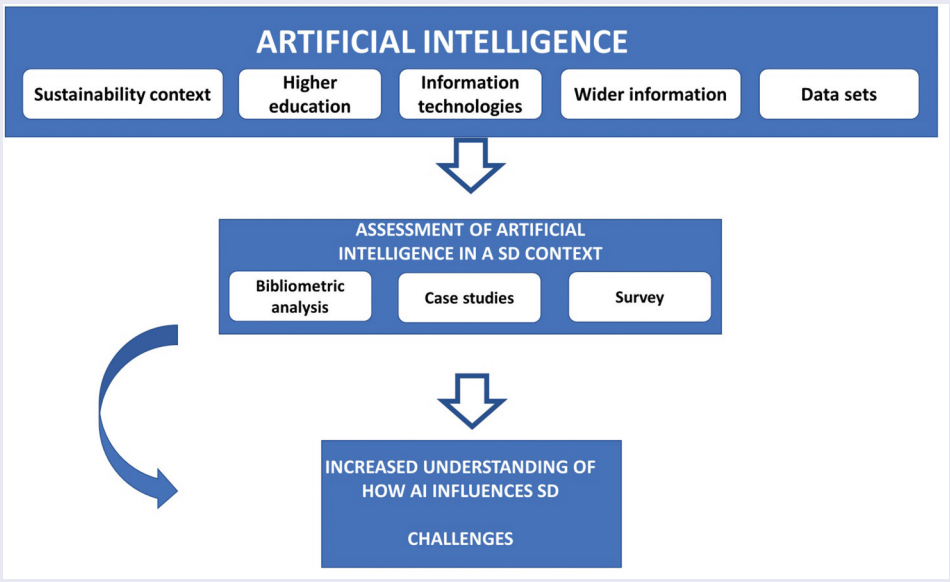

HIGHLIGHTS

Artificial intelligence (AI) is fast becoming a component of modern life, being used in many areas.

AI has a growing impact on achieving the Sustainable Development Goals.

It can catalyse innovations in areas as varied as circular economy and smart cities.

AI offers a vital nexus between sustainable development and effective climate change adaptation.

1. Introduction

Considering the complexity of Sustainable Development (SD), the UN Sustainable Development Goals (SDGs), and research about SD and the SDGs, AI can offer valuable support to their implementation, especially in helping to overcome the difficulties seen in pursuing both practical and academic tasks (Leal Filho et al. 2022). Some studies showed that AI contribute to achieving the 17 SDGs, making information more reliable, supporting better-informed decision-making, implementing data-based policies, prioritizing actions, and optimizing the allocation of resources (Bachmman et al. 2022; Shenkoya and Kim 2023). Singh et al. (2023) found SDGs 3 and 7 as the areas with the most applications of AI in the SDG context. Besides, the authors presented trends in these applications such as Precision/Genomic Medicine (SDG 3) and Energy Efficient Houses (Smart Grids), Energy Generation, and Optimisation (SDG 7). The other applications are in Online Education and Software Development (SDG 4), Renewable Energy and Grid Management (SDG 13), Remote Sensing (Computer Vision) (SDG 11), and Behaviour Forecasting and Mental Health (SDG 16). Related to the benefits of AI for SDGs, a study by Fosso Wamba et al. (2024) suggests a connection among AI capability strategies on SDGs such as SDG 9 (industry, innovation, and infrastructure) and SDG 12 (responsible consumption and production). Ulussever et al. (2023) applied Machine Learning and compares it with econometric models to estimate CO_2 emissions.

The adoption of AI in the learning process can produce notable results, such as less learning anxiety, a willingness to use those technologies, knowledge access, and assistance in the development of student profiles and learning materials that are tailored to each student's abilities and learning preferences (King et al. 2021; Laine et al. 2022; Hu et al. 2023; Tunjera and Chigona 2023; Alhumaid et al. 2023). For universities to become vectors of development, they must commit to their core activities – teaching, researching, and extension programs – but also to non-core ones, such as internal policies aiming to strive for sustainability (Leal Filho et al. 2023, 2023).

The benefits of AI related to the SDG in education (SDG 4) are the reduction of the digital breach across professional sectors, the employability driven by innovation, enhancement of professional mobility, and economic prosperity, underlined across sectors of the population that have historically had more difficulties in accessing education (Leal Filho et al. 2023). Despite its value for learning experiences, AI adoption faces some challenges. The perceptions of teaching staff related to AI and robotics are usually based on a general understanding of these technologies. They have either optimistic and positive expectations towards these technologies, or are accepting them as part of inevitable progress and teaching practice without a conscious desire to foster well-being of individuals and groups (Grossi et al. 2020; Leoste et al. 2021; Shenkoya and Kim 2023).

According to Shenkoya and Kim (2023), there are not many studies about the impacts of digital transformation in the higher education system and on its impacts on sustainability. This impression was confirmed after a search for articles in Scopus and Web of Science, two subscription-based databases with a selective approach to document indexing (i.e documents from a pre-selected list of publications) (Martín-Martín et al. 2021). To check the innovative characteristics of this study, the authors searched for the string 'artificial intelligence and sustainable development goals and high education institutions' without any filters in these two databases. In Scopus, three articles were found, but none of them discussed the three themes, while in the Web of Science database, there were 27 articles, and 3 articles presented content about AI, SDGs, and HEIs. Although the themes discussed in these articles are the same and close to this paper, their aims are different in comparison with this study's objective. Jokhan et al. (2022) connected the three themes, but they used an AI-based analytics tool for student performance prediction in the first year of an Information Technology literacy course in one HEI. Shenkoya and Kim (2023) published an article where the combination of a systematic literature review and a bibliometric analysis shows that the digital transformation of the higher education sector is leading to the development of sustainable curriculums and other results related to innovation and the performance of students, which are not the core of this study. Zhu and Rich (2023) proposed the use of AI for translation tasks and for developing this skill among the students in one HEI, improving their employability in the market and in professions related to sustainability. To contribute to this debate and move beyond the state of the art, the present study focuses on the following research question: What are the connections between artificial intelligence and the implementation of the UN SDGs at HEIs? This research question can be understood by addressing the following specific objectives of the paper:

- Identify AI techniques applied in specific SDGs (bibliometric analysis);
- Identify examples of AI techniques implemented by HEIs to support the SDGs (case studies);
- Identify and analyse the problems and challenges of AI implementation in HEIs (case studies and the survey);
- Identify current and future trends in AI used for the UN SDGs implementation in HEI (survey).

To provide a context for the study, the authors first conducted a comprehensive literature review. In addition, a bibliometric analysis was conducted in the main databases (Scopus and Web of Science), using some strings with keywords related to the themes of this discussion. To highlight the key themes, the study used the VOSviewer software and bibliometric analysis techniques, such as the 'co-occurrence analysis' deployed by Depren et al. (2022) in another study on fossil fuel and renewable energy consumption. Case studies in the literature on the application of AI by HEIs to support the SDGs were also used. For the results and discussion, thematic analysis techniques were employed. Finally, a survey representing a large number of HEIs around the world, sheds light on the research question and identifies current and future trends in the use of AI by HEIs to support the SDGs. A snowball sampling was used to distribute a questionnaire with 16 questions among 101 respondents in the research community on sustainability, Information and Communication Technology (ICT), and AI.

The results showed that a variety of AI technologies (e.g. Machine Learning, Big Data, Blockchain, and IoT) supported the HEIs investigated in the case studies and in the survey to implement most of the SDGs (1, 2, 3, 4, 8, 11, 12, 13, 15, and 17). Even though AI supports activities at HEIs, it also presents some challenges related educational quality and equity.

The article is structured as follows: following this first section which presents the justification and the contribution of the research to the field, the second section dwells on the topic of AI and the SDGs, followed by the third section's discussion of the relationships between artificial intelligence and sustainable development. The fourth section describes the research Methods used, and the fifth section presents the results and discussion from the bibliometric review, case studies and survey. This is followed by the conclusions. The Appendix contains a table with the acronyms which are used in this article and their descriptions.

2. Artificial intelligence and the UN SDGs

2.1. The use of artificial intelligence in research

AI category-2 encompasses four varieties of AI systems based on their functionalities, specifically, their similarity to the human mind and their ability to emulate human-like 'thinking' or 'feeling' (Hassani et al. 2020). Reactive machines use a limited set or combination of inputs that can be applied for generating automatic responses. Limited memory machines expand the capacity of reactive machines by learning from historical information to improve future actions. Theory of mind refers to concepts or work-in-progress AI-driven systems that could enhance their understanding of individuals they interact with by recognising their requirements, emotions, beliefs, and cognitive processes. Self-aware AI represents a theoretical phase in AI advancement where AI systems would have progressed to a point resembling the self-awareness capabilities of the human brain. Figure 1 shows a classification of AI branches, their current development status, and some examples of applications.

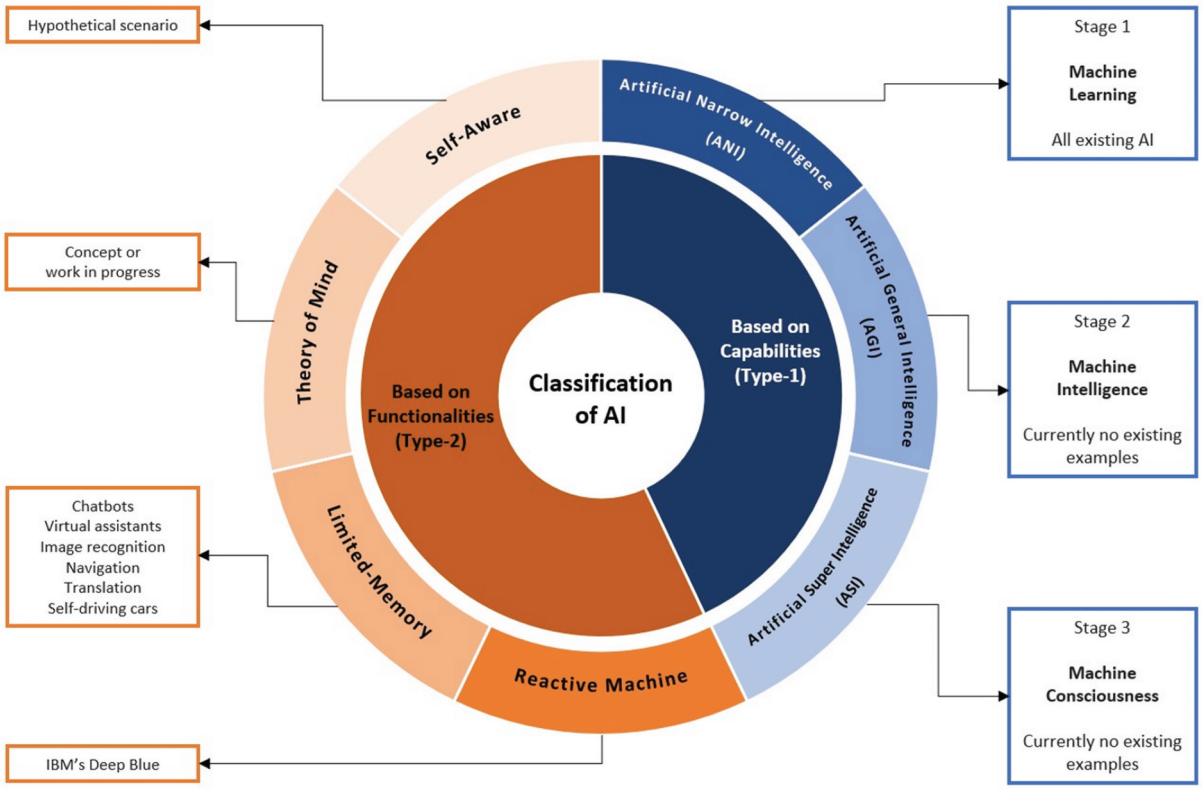

Figure 1. Classification of AI.

At present, AI plays a central role in many activity sectors that have incorporated new information technologies. In this regard, the potential of machines to learn, reason, and adapt makes AI-based systems a centrepiece for the future development of human society (Barredo Arrieta et al. 2020). In this context, there is a wide range of applications of AI for research purposes in areas such as engineering (Attaran 2023), education (Rudolph et al. 2023), transport (Consilvio et al. 2024), medicine (Kwekha-Rashid et al. 2023), environment (Hafeez et al. 2023), public management (Gao et al. 2023), and business (Rusch et al. 2023).

Some specific examples of AI applications include: the use of robotics to foster the effectiveness and efficiency of surgical interventions; the use of unmanned aerial vehicles for the monitoring and supervision of environmental deterioration; the application of machine learning (ML) to improve education; applying ML to optimise medical diagnosis; developing ML-based strategies to enhance crop production; defining and understanding biotechnological patterns and trends; the identification of animal and plant species to enhance their correct preservation; fostering astronomy investigation and space exploration; monitoring and preventing climate-related risks such as floods and fires; improving the process to distinguish between benign and malignant tumors; analysing Big Data results to better understand historical health information; and detecting and analysing complex mixtures of gases with potential environmental risks (Musib et al. 2017).

With regard to the specific applications of AI for enhancing sustainability, there are examples of how it could be used for optimising decarbonization strategies in the waste management sector (Kurniawan et al. 2023) or improving energy efficiency using biomass (Khan et al. 2023). AI is also being increasingly used for companies to improve business operations by optimizing internal process and circular economy strategies (Wang et al. 2023; Schöggl et al. 2023). In addition to this, its applications in sectors such as fishing (Rowan 2023), farming (Akkem et al. 2023) or meat production (Kumar et al. 2023), has also proved to be highly successful.

2.2. Artificial intelligence and sustainable development

Artificial intelligence (AI) has a broad and growing impact on achieving the Sustainable Development Goals (SDGs). AI can constructively contribute to reaching many of the 169 targets across all 17 of the Sustainable Development Goals that were globally agreed upon in the 2030 Agenda for Sustainable Development (United Nations 2016; Vinuesa et al. 2020). Moreover, AI is anticipated to have key short- and long-term impacts on global production, environmental outcomes, equality and inclusion, and other different areas (Bolukbasi et al. 2016; Acemoglu and Restrepo 2018; Norouzzadeh et al. 2018). In short, the impacts of AI are likely to comprehensively impinge on

all three sustainable development pillars of society, the environment, and the economy (Stockholm 2017; United Nations Economic Council Social 2019; Luetz and Walid 2019). The next section of this paper describes the Methods used in this study.

3. Methods

In order to study the connections between AI and sustainability, this study used a mixed-method approach that considered quantitative methods applied for the bibliometric analysis and for the conduction of the exploratory research (with a survey) and qualitative Methods used in the analysis of the case studies. These will now be described in turn.

3.1. Bibliometric analysis

The bibliometric analysis was conducted using Web of Science and Scopus as the database, considering the quality of peer-reviewed publications. The search string was informed by existing literature reviews related to artificial intelligence (Contreras and Vehi 2018; Zawacki-Richter et al. 2019; Chen et al. 2020).

The final search string was as follows ((‘artificial intelligence’ OR ‘machine intelligence’ OR ‘intelligent support’ OR ‘intelligent virtual reality’ OR ‘chat bot*’ OR ‘machine learning’ OR ‘automated tutor’ OR ‘personal tutor*’ OR ‘intelligent agent*’ OR ‘expert system’ OR ‘neural network*’ OR ‘natural language processing’ OR ‘Deep learning’ OR ‘Ensemble learning’ OR ‘Ensemble algorithm*’ OR ‘regression algorithm*’ OR ‘decision tree*’ OR ‘Gradient boosting’ OR ‘Gradient boosted tree*’ OR ‘random forest’ OR ‘Support- vector machine’ OR ‘knowledge inference’ OR ‘Reinforcement learning’ OR ‘computer vision’ OR ‘natural language processing’) AND (‘sustainable development goal*’ OR ‘SDG*’)).

The search considered the literature that contained the search strings in the ‘Title, Abstract, and Keywords’ fields of the ‘Web of Science Core Collection’. The bibliometric search was conducted on 27 September 2022, and returned 448 articles. As SDGs were officially introduced in 2015, any articles published in the previous years were excluded. We have adopted this exclusion criterion as the paper is specifically focused on using AI to implement the UN SDGs at higher education institutions. In other words, SDG issues are not reflected in studies published before 2015. In total, 431 articles were retained in the database for analysis purposes. Most of these articles have been published in the past two years, indicating that this is a nascent area of research. Different tools exist for bibliometric analysis. Among various bibliometric analysis tools available, the VOSviewer was used due to its user-friendly interface. Also, it is relatively more suitable for highlighting key thematic areas (Van Eck and Waltman 2017; Sharifi 2021). Among different types of bibliometric analysis techniques, the ‘term co-occurrence analysis’ was used, which helps to identify major themes and connections between them. The results of the term co-occurrence analysis can be visualised as a network diagram. In this diagram, each node represents a key term, and its size reflects the frequency of its co-occurrence with other terms. The width of the links between two nodes indicates the strength of their connection. Terms that co-occur frequently form clusters that indicate thematic focus areas.

For more details on the mathematical background of the term co-occurrence analysis, readers can check the VOSviewer Manual (Van Eck and Waltman 2022).

3.2. Analysis of case studies

The case study method facilitates a comprehensive understanding of a phenomenon while reinforcing the analytical conclusions of the study. When the evidence is accumulated from similar research interests, the theory becomes grounded in a broader array of studies and applications (Yin 2009). Research based on different case studies can encompass various data sources and methodologies, proving to be an effective technique for compiling a substantial amount of data (Miles and Huberman 1994; Yin 2009).

In this regard, in this study we selected multiple case studies based on the relevance of each HEI in the implementation of AI towards the UN SDGs, drawing from secondary data available online and studies published in peer-reviewed journals. In an effort to cover different approaches addressed by HEIs on a global scale, the search terms ‘artificial intelligence’, ‘higher education’, and ‘Sustainable Development Goals’ were used in different databases, such as Scopus, Web of Science, and Google Scholar. Then the publications were selected based on their relevance to the topic and the diversification of the method, the university activity, and the study region. To analyse the case studies, a table was created (Table 1), containing specific information: key themes on the role of HEIs in SD and the SDGs, university name and country, AI method used, purpose, expected outputs related to the SDGs, and source. This table facilitates the crosschecking of information and allows readers to obtain additional details. Thus, the publications were analysed based on thematic analysis, summarised in a table and presented in the results section.

In this study multiple case studies were selected based on their relevance for the implementation of AI by HEIs towards achievement of the UN SDGs, drawing from secondary data available online and studies published in peer-reviewed journals. In an effort to cover different approaches addressed by HEIs on a global scale, the search terms ‘artificial intelligence’, ‘higher education’, and ‘Sustainable Development Goals’ were

Table 1. Case studies on the implementation of AI towards the UN SDGs in HEIs.

Themes (HEI and the SDGs)	Institution and Country	AI method used	Purpose	Expected outputs related to the SDGs	Source
Campus operations and greening	University Malaysia Perlis (Malaysia)	IoT	To detect discarded electronic scraps correctly in e-waste, assisting the administration to monitor the status of e-waste bin levels, detection of e-waste objects, and the e-waste count	To enhance e-waste data management efficiency (SDG 12)	Rani et al. (2021)
	University of Extremadura (Spain)	Cyber-physical system	To monitor the water consumption of campus buildings	To reduce water consumption (SDGs 12 and 13)	Barroso et al. (2022)
	Osaka City University Sugimoto Campus (Japan)	Artificial neural network model	Using AI to inform planning of campus operations	Managing and reducing electricity consumption by university campuses (SDG 7)	Yuan et al. (2018)
	University of Bologna (Italy)	Data visualisation dashboard	To measure classroom/labs capacity and visualise room occupancy	To ensure social distancing and safety, and to reduce energy consumption (SDGs 3, 4, 12 and 13)	Ceccarini et al. (2021)
	Universiti Malaysia Sabah (Malaysia)	IoT	To provide a bus tracking system on campus	To give campus users information regarding bus operations (SDGs 3 and 13)	Khamis and Li (2021)
Outreach and community engagement	Federal University of Uberlândia (Brazil)	NLP	To map the alignment between community outreach projects and SDGs	To understand the SDGs regarding underdeveloped community development outreach projects	Borsatto et al. (2024)
	Federal University of Santa Maria (Brazil)	Data visualisation dashboard	To keep track of all community outreach projects	A dashboard with community outreach projects in each SDG	Burmann et al. (2021)
	Federal University of Paraíba (Brazil)	Data visualisation dashboard	SDG-PB Platform is a tool to monitor the SDGs and verify the global result in the territories of Paraíba	Creation of the sustainable development index (SDI-PB)	Federal University of Paraíba (2022)
	Nnamdi Azikiwe University, Nigeria	Internet of things (IoT)	Wireless sensor network and IoT environments for water management	Internet of Things (IoT) as a platform to monitor and assess water quality (SDG 6)	Ighalo et al. (2021)
	Federal University of Uberlândia (Brazil)	Topic Modeling	To identify how research in health postgraduate programs of an HEI contribute to the SDGs	Demonstrate how the University, through its research in the health area, has contributed to the SDGs	Queiroz et al. (2023)
	Federal University of Juiz de Fora (Brazil)	NLP	To analyse undergraduate research projects regarding SDGs	To build a database that helps to automatically identify SDGs in the goals of research projects	Capriles (2021)
	Wageningen University & Research (The Netherlands)	AI algorithms	To remotely control crop growth	To make breakthroughs in fresh food production with fewer resources (SDGs 2, 3, 12, 13 and 15)	Hemming et al. (2019)
Researching and experimenting	The Open University, University College London and Pipers Corner School (UK)	Virtual reality	Use and evaluation of technology-enabled virtual field trips to improve the effectiveness of real field trips	To inspire students to think of potential actions that they would take to protect the environment (SDGs 4, 11, 12, 13, 14 and 15)	Tudor et al. (2018)
	University of Oregon, University of Florida (USA)	Virtual reality (VR)	Design of VR simulation to create a learning experience on paleoclimatology	Overcoming limited access to hands-on learning and diverse scientists to identify with (SDG 4)	Pimentel and Kalyanaraman (2021)
	Universidad Nacional de Educación a Distancia (Spain)	Neural Networks	Predict creation of new significant MOOC platforms that will be about the SDGs	Forecasting and planning for teaching, learning and training needs and interventions for the SDGs (SDG 4)	Hueso Romero (2022)
	University of Kelaniya, University of Sri Lanka, University of Sri Jayewardenepura (Sri Lanka)	Machine learning	Evaluation of the sustainability of mobile learning frameworks for higher education	Evaluation algorithm to iteratively improve the sustainability of a mobile learning system (SDG 4)	Dolawattha et al. (2022)

(*Continued*)

Table 1. (Continued).

Themes (HEI and the SDGs)	Institution and Country	AI method used	Purpose	Expected outputs related to the SDGs	Source
University management	University of Zululand (South Africa)	Business intelligence and big data	Proposed business intelligence model based on data from a higher education institution	Overall improvement of the quality of the higher education experience (SDG 4)	Evans (2021)
	University of the South Pacific (Fiji)	Learner analytics	Using AI to inform decisions on the performance of students	Prediction of student performance early in courses, which allows early intervention (SDG 4)	Jokhan et al. (2022)
	Spanish universities	SEMrush platform	To analyse the visibility of the SDGs on the websites of universities	Create a platform to monitor the websites of the universities for the occurrence of the following keywords: 'sustainable development goals', '2030 Agenda' and 'SDGs'	Vallez et al. (2022)
	Arizona State University (USA)	Deep machine learning	Use cutting-edge computer science techniques to support terrain and environmental research	Use machine learning to develop richer geographic information sources. (SDGs 11 and 13)	Li (2020)
	Tlemcen University, Algeria	Artificial neuron networks	Using AI to predict droughts	Deployment of AI to reduce food losses (SDG 2)	Hadidi et al. (2021)

used in different databases, such as Scopus, Web of Science, and Google Scholar. An illustrative set of publications were then selected based on their relevance to the topic and the diversification of the AI Methods used, the university activity, and the study region.

3.3. Survey

To identify the challenges, the current and future trends related to the use of AI to foster the implementation of the UN SDGs in HEIs, a survey was designed by the authors with the Google Forms tool (survey questions are in a Supplementary file). The survey counted with 16 questions and was distributed by mailing lists to many HEIs around the world, using the snowball sampling technique.

According to Creswell (2014), there is a format for designing an overall plan, which was followed in this study. The survey was initially prepared by the authors seeking to align the survey questions with the study's central research question: 'What are the connections between artificial intelligence and the implementation of the UN SDGs at HEIs?' Once the first version of the survey was ready, it was reviewed by all authors, this being the second stage of survey preparation. After adjustments, the third and final stage of preparing the survey takes place: the pre-test for validation with experts. At this stage, the survey was sent by email to a panel of experts on the subject who evaluated both the content of the questions, the format in which they were presented, and the response options. The experts' feedback was taken into account, the survey was adjusted and finally, the final version of the survey was approved to send to the HEIs. The final instrument contained 16 questions in total: 6 background/and demographic questions, 4 single response questions, 3 multiple choice questions, and 2 open-ended questions focusing on techniques and tools used in the respondents' research, challenges in their research development, and the connection between AIs and SDGs for current and future research. The questionnaire was initially sent by email to the members of the Inter-University Sustainable Development Research Programme (IUSDRP), and after that it was sent to mailing lists focused on disseminating information to the research community on sustainability, Information and Communication Technology (ICT) and Artificial Intelligence in a snowball sampling technique. The population was compound by 4,356 members and the sample had 101 respondents. The survey collected responses during one month, from October 12 to 14 November 2022.

To ensure that survey responses come from experts within the topic of using AI to promote the SDGs in HEI, it was determined that to be able to answer the survey the participant must have carried out research on the topic of the SDGs in the last 4 years. The participants consented and were free to withdraw at any time during the process.

Considering the aim of presenting an overview of research trends, the data analysis technique used descriptive statistics, focusing on synthesising the information.

4. Results and discussion

4.1. Bibliometric analysis

Results of the term co-occurrence analysis are shown in Figure 2. It can be observed that issues related to different SDGs have been addressed in the literature. However, some SDGs have received relatively more attention. The red cluster in Figure 2 shows that machine learning techniques such as 'random forest' and 'support vector machine' have been widely used to study issues related to land use, land degradation, forest resources, and ecosystem services. These are directly linked to SDG 15 that aims to 'protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss' (United Nations 2024). Indeed, machine learning and deep learning techniques such as 'random forest' and 'artificial neural networks' have been widely used to accurately assess and predict land use and land cover changes by analysing the increasingly available remote sensing data (La Rosa and Wiesmann 2013; Shooshtari and Gholamalifard 2015; Paul et al. 2020). These methods have proven effective in informing land use planning and highlighting actions needed to preserve ecosystem services (Ladi et al. 2022). Urbanisation is a frequently-occurring term in the red cluster, indicating that techniques based on artificial intelligence have also been used to monitor urbanisation trends and patterns and guide efforts toward achieving SDG 11, which is focused on making cities resilient and sustainable (Mithun et al. 2021; Sharifi et al. 2024). Closely linked to the red cluster, terms in the yellow cluster are mainly focused on climate change adaptation and mitigation. These include terms such as GHGs, mitigation, adaptation, air pollution, and renewable energy and are directly linked to SDG 7 on 'affordable and clean energy' and SDG 13 on 'climate action'. Among other aspects, big data analytics and various techniques such as random forest and neural networks have been used to account for CO_2 and other emissions and predict emission patterns (Leerbeck et al. 2020; Magazzino et al. 2020).

Smart solutions based on big data analytics, IoT, and blockchain have also contributed to enhancing supply chain management, improving operational efficiency, and promoting circular economy. For instance, during the COVID-19 pandemic, smart solutions enabled by AI enabled the continuity of the supply chain (Sharifi et al. 2021). The utility of technologies like AI, machine learning, and big data analytics for implementing circular economy

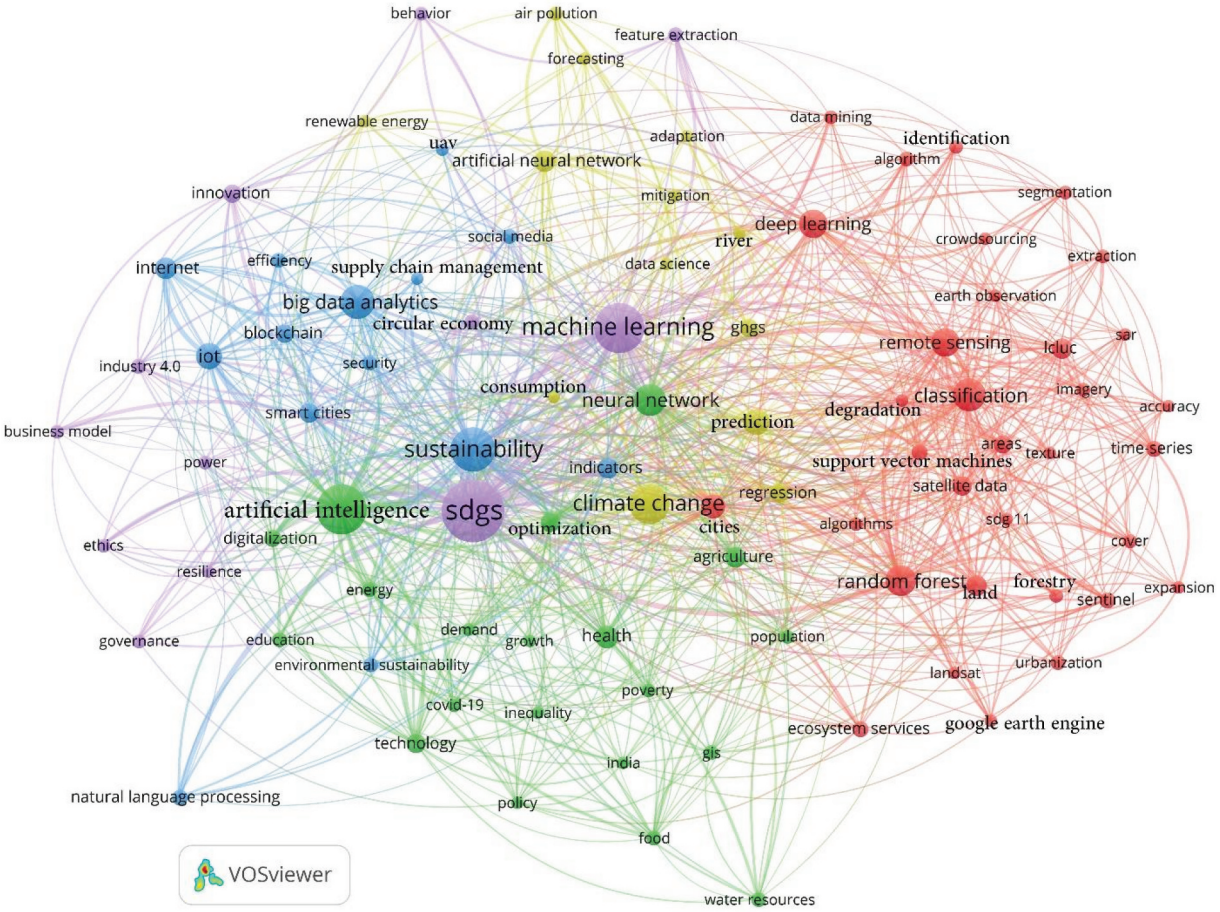

Figure 2. Main thematic areas at the interface of artificial intelligence and SDGs examined in the literature.

policies through the integration of different sectors is also well-recognised (Vinuesa et al. 2020; Agrawal et al. 2021). In fact, artificial intelligence can contribute to SDG 12 on 'responsible consumption and production' and SDG 8 on 'economic growth'. Related to this, innovations and advances in artificial intelligence also have implications for SDG 9 on industry, innovation, and infrastructure, as shown in the left side of the Figure 2. This can be achieved through, for instance, blockchain technology that facilitates the development of smart logistics models or new means of production, finance, and investment (Mora et al. 2021; Parmentola et al. 2022; Mazzi and Floridi 2023).

The green cluster is mainly focused on socio-economic issues such as poverty (SDG1), food (SDG 2), health (SDG 3), education (SDG4), and inequalities (SDG 10). Overall, the literature shows that, if designed and implemented properly, artificial intelligence can contribute to meeting these goals (Mora et al. 2021; Sharifi et al. 2024). However, it should be noted that the inappropriate application of artificial intelligence may exacerbate inequalities and result in the marginalisation of some social groups. In other words, it could have negative impacts on achieving these SDGs (Kourtit et al. 2020; Vinuesa et al. 2020; Sharifi et al. 2024).

Finally, Figure 2 includes terms such as ethics, power, and governance that are related to SDG 16 on 'peace, justice, and institutions' and SDG 17 on 'partnerships for the goals'. It is noted that artificial intelligence technologies can contribute to these goals by, among other things, improving transparency, reducing criminal activities, facilitating resource sharing, and enabling multi stakeholder engagement and collaboration (Ismagilova et al. 2019; Skill et al. 2020; Parmentola et al. 2022). However, in the absence of proper institutional and auditing procedures, artificial intelligence technologies may also result in trade-offs, as they could increase discriminatory practices and undermine user privacy (Mhlanga 2022; Sharifi et al. 2024).

As the following sections show, the utilities of AI technologies discussed in this section are also reflected in the practices of HEIs in different parts of the world. Indeed, as living labs, HEIs have played a leading role in promoting the adoption of AI solutions and technologies to assist the transition toward achieving SDGs in their respective contexts.

4.2. Case studies

Subsequent to the literature assessment, case studies regarding AI related to the implementation of the SDGs in HEIs were extracted from the literature and

examined using thematic analysis. In order to understand some practices carried out by universities towards sustainability through AI, Table 1 was developed, showing the institution and country, the AI method used, the purpose, and the connection with the SDGs. Table 1 is accompanied by a reflective discussion on the relationships between the selected case studies and key themes on the role of HEIs in SD and the SDGs, namely campus operations and greening, outreach and community engagement, teaching and learning, and university management, while research serves as cross-cutting theme.

The case studies on the application of AI in HEIs to support SD and the SDGs which have been included in this section, provide a view how integration of AI with various aspects of HEIs are initiating comprehensive changes in the way HEIs are conducting their business. This involves the full spectrum of thematic areas involved in the contribution of HEIs to SD and the SDGs. AI is also becoming an important factor in facilitation of teaching and learning, with a case from the Global South illustrating how machine learning (highlighted by the bibliometric analysis as important AI focus) is used to maintain the quality of mobile learning platforms. An additional application of AI in this context is automated assessment and grading, but with various concerns to be clarified before its validity will be generally accepted by the academic community. Similarly, but in a spectrum of ways, AI is also impacting on activities in HEIs in the thematic areas of campus operations and greening, outreach and community engagement, research, and university management. However, as the application of AI tools are becoming increasingly prevalent in HEIs, considerations regarding ethics, data privacy, resistance to change, and industry alignment, to mention a few, are coming to the forefront and will need to be dealt with going forward.

4.3. Survey

4.3.1. Characterisation of sample

The respondents (101) are from 38 states/countries, with a concentration (48%) in three countries: the United States (11), the United Kingdom (15), and Brazil (17), which represent 14%, 16%, and 18% of the sample, respectively. According to gender, 30% are female, 68% are male, and 2% answered 'Other/Prefer not to say'. The age group with the majority of respondents is 50–59 years (31%), followed by 40–49 years (29%), 30–39 years (22%), 60 years or over (15%), and 18–29 years (4%). The knowledge areas are concentrated in Education (23%), Engineering, manufacturing, and construction (17%), and Information and communication technologies (17%), which represent 57% of the sample.

Most respondents (80%) are in teaching and research, while 20% are working in a research position at the university. In this sample, 20% of respondents work at private higher education institutions (HEI), and 80% work at public HEI.

4.3.2. Descriptive statistics

In the last four years, 76% of the respondents carried out research on the SDGs, while 24% aren't developing research about this theme. Within the 76% of respondents with expertise in research focused on the SDGs, 50% currently use artificial intelligence (AI) as part of their research on the SDGs or related projects, and 50% do not. In the group using AI, most of them use it sometimes (37%), often (24%), and very frequently (29%). For this research, respondents provided information about what artificial intelligence techniques are applied (they could answer more than one option). Machine Learning (39%) was the most used, followed by Deep Learning (26%) and Neural Networks (21%). Figure 3 shows the AI applications in the respondents' research:

The areas of research where the respondents use artificial intelligence are theoretical foundation/literature review (26%), research formulation/project design (39%), data collection (29%), data analysis (42%), findings/outcomes presentation (21%), and manuscript writing (8%). The respondents answered questions about the challenges faced in relation to the use of artificial intelligence in their research on Sustainable Development Goals (SDGs) or related projects. Figure 4 shows the percentage of each one, using a psychometric response Likert scale (from 'strongly disagree' to 'strongly agree')

According to the sample, the challenges that had the highest number of citations are 'lack of access to software/materials' and 'lack of IT training for myself/my colleagues'. Other challenges are:

- the absence of textbooks related to the application of AI to SDGs
- the pace of innovation; obtaining unbiased data
- lack of Open Data to use as AI training/test data
- lack of maths skills taught in undergraduate degrees
- lack of baseline knowledge about what AI is or how it could be used
- lack of data availability and funding
- financial implications of using AI
- collaboration among all stakeholders like AI developers, end users, and regulators, etc
- collaborative groups
- mobile phone and internet connection service
- the correct use of AI

In comparing the answers from the questionnaire and the other challenges mentioned by the respondents, knowledge is lacking amongst professors and students

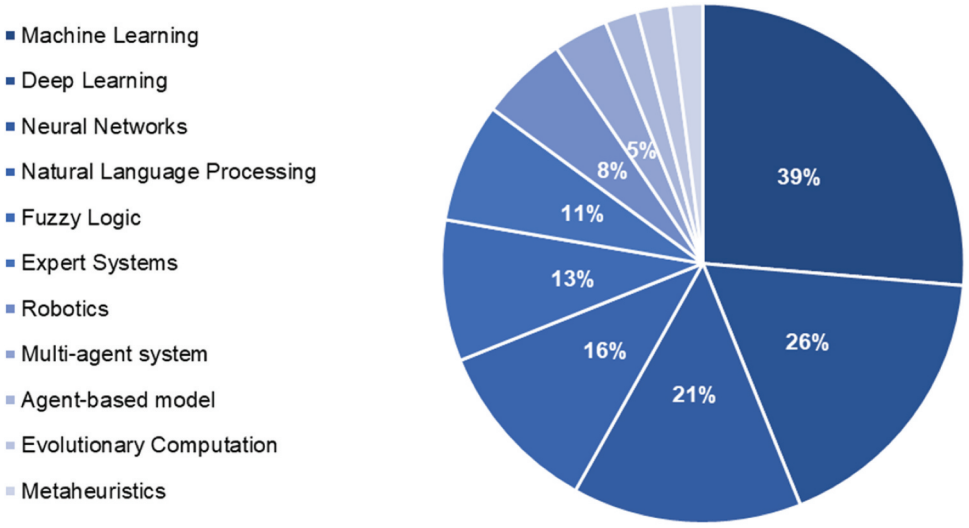

Figure 3. Artificial intelligence techniques used in SDGs research.

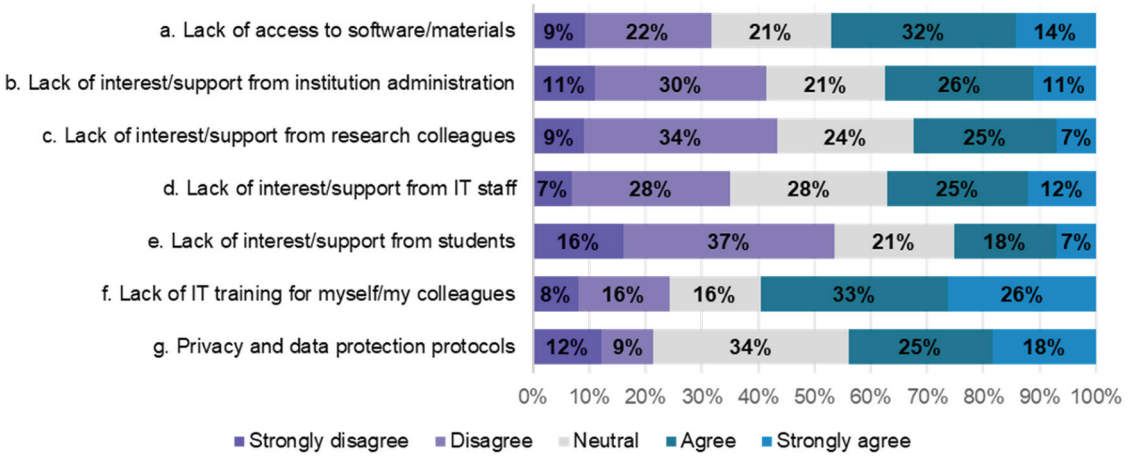

Figure 4. Challenges for the use of AI in SDG research and projects.

about IT and AI, and therefore investments and funds are necessary to provide the IT infrastructure for research activities in this stream of research.

When they were asked about in which SDGs the AI technologies are currently being deployed or could be of use in the future, the SDGs that received the highest number of responses are in Figure 5:

Respondents evaluated the future use of artificial intelligence in SDGs projects at the HEI (or department) where they work; the answers are in Figure 6:

There are other studies being developed, such as: AI for drug design; AI for reducing inequality; the use of Machine Learning for understanding interactions between SDGs; mapping accessibility/mobility through artificial intelligence; AI and detox and sound healing; real-data and sustainable transportation infrastructure; adult learning and online education; optimal plant fertilisation regimes for increasing food production and reducing fertilisers, pollution and waste; forestry, carbon stock estimation; and environmental education to combat plastic pollution and promote recycling.

After collecting the data – from developed and developing countries, from middle-age researchers, in majors directly related to the subject of this research (Information and Communication Technologies, Engineering and Education), from those in teaching and research, and those at public HEI – the results show specificities, mainly from public universities in developing countries.

In the last four years, a large number of teaching staff carried out research on the SDGs, and around 50% of them currently use AI as part of their research on SDGs or related projects. In this group, 37% use AI in their SDGs research, and Machine Learning is the artificial intelligence technique most applied.

These answers show that these techniques will provide more research analysis and demand more knowledge (training) and resources (IT and financial). Hence, there are gaps for future research on applying AI techniques in SDGs that are not so common in this stream of research, such as Metaheuristic, evolutionary computation, and agent-based models.

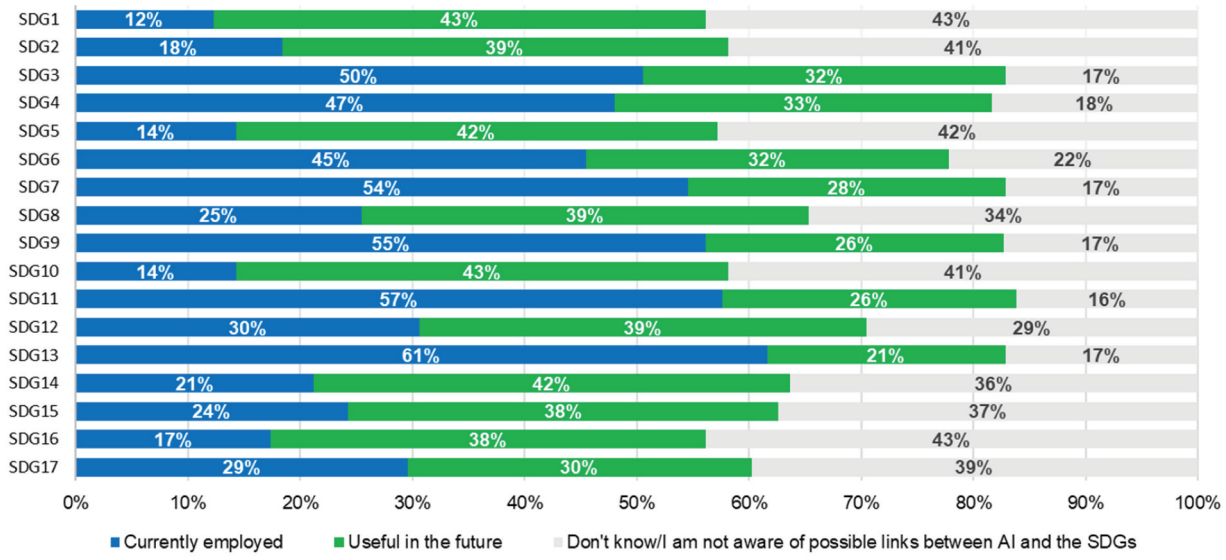

Figure 5. Trends for research in SDGs using AIs.

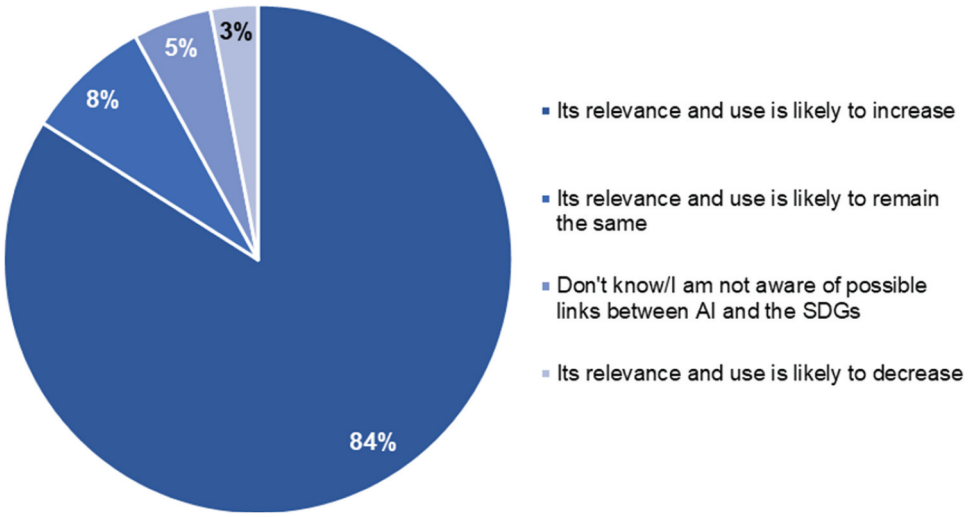

Figure 6. Future use of AI in SDGs research.

This study demonstrated the growing integration of AI also in research focused on SD and SDGs. Challenges can be identified especially in the form of the need for investment in IT infrastructure and training. On the other hand, promising areas for future investigation were also highlighted as potential for future use of AI in SDG-related projects in areas such as reducing inequality, health, education and the environment. Finally, the survey results suggest exploring less common AI techniques in this context, such as Metaheuristics, Evolutionary Computing and Agent-Based Models.

5. Conclusions

This paper explored the extent to which AI currently supports the worldwide implementation of the SDGs at HEIs, and offers a welcome addition to the literature pointing to opportunities for cross-cutting engagement for the use of AI in education and beyond. A remarkable depth and breadth in the scope of the application of AI in this context has been revealed, covering core performance areas of HEIs in terms of campus operations and greening, outreach and community engagement, research, teaching and learning, and university management.

The applications of AI at HEIs as highlighted in this paper are not occurring haphazardly, but, as shown by the bibliometric analysis, have a definite focus on certain thematic areas. Furthermore the term co-occurrence analysis showed that while various applications of AI in support of the SDGs are addressed in the literature, some of the SDGs are featuring more prominently then others. This includes machine learning in the context of land use and planning (SDGs 11 and 15), big data analytics

for climate change applications (SDG 13), blockchain technology, IoT, machine learning and big data analytics in terms of supply chain management, operational efficiency, and the circular economy (SDGs 8 and 12), various applications of AI in the context of the socio-economic dimension (SDGs, 1, 2, 3 and 4), and lastly the contribution by applications of AI to improve transparency, reduce criminality, facilitate resource sharing, etc. in the context of SDG 17. The usefulness of AI technologies for the SDG as highlighted by the bibliometric analysis, are reflected in the spectrum of case studies of HEIs which were herewith presented.

The case studies that have been analysed and discussed in this paper show that HEIs are implementing AI solutions in support of the SDGs in different areas. Some cases are connected with campus operations and greening and show how activities and research on campuses support the achievement of the SDGs. Other cases relate with the use of AI to measure the alignment of research and outreach/engagement at HEIs with the SDGs, for better understanding how the institutions are contributing to communities and society at large. Finally, some cases have been included that focus on the use of AI as an educational tool, and also for university management, all focussed on promoting the SDGs.

Whereas the case studies show that AI interventions at HEIs that are well planned, designed and implemented can contribute to meeting the SDGs, their inappropriate application may exacerbate inequalities and the associated marginalisation of some social groups. AI also poses several challenges and risks in educational contexts, especially concerning matters as authenticity and ethics in assessment. Issues such as these will need to be explored further to ensure the optimal application of AI in HEIs, so that it can be used in an informed and responsible way to improve educational quality and equity.

The survey among sustainability practitioners at HEIs delivered an overall higher than expected uptake of AI: of the 76% of respondents with expertise in research focused on the SDGs, 50% are currently using AI as part of their research on the SDGs or in related projects. The applications for which the respondents use AI include literature reviews, the formulation/design of research projects, the collection of data, the analysis of data, the presentation of findings/outcomes, and the writing/preparation of manuscripts. The survey furthermore confirms that AI has already significantly penetrated research practices in HEIs, to the extent that more than half of the researchers indicating they are using it, do so with considerable frequency, and with machine learning identified as the technique most often used. Challenges experienced by the respondents are multiple and diverse, but 'lack of access to software/materials' and 'lack of IT training for myself/my colleagues' are mentioned the most.

Similar to other studies, this paper has some limitations, mainly in terms of the bibliometric analysis (limited by selection of databases and search strings), selection of case studies (not fully representative), and sample of respondents to the survey (also not fully representative). For a fast developing field such as AI, the paper can also only present the situation at the time when the research was conducted – namely in the last quarter of 2022 and in the first quarter of 2023 – without being able to include new developments that may have occurred since then. Despite these limitations, the paper provides a valuable review and analysis of the use of AI in HEIs in support of the SDGs, the direction in which this innovation is developing, its focus areas, and the views of practitioners in this field.

Some pointers for future developments and research on the use of AI in support of the SDGs can be derived from the results of this paper. First and foremost is the requirement of universally available and reliable data, which is crucial for AI-based systems, since large volumes of data and necessary computational capacity, need to be available as well. Furthermore, the results of this paper indicate that several AI solutions exist, which have not yet been absorbed in initiatives to support the achievement of some targets of the SDG. This confirms the observations by Palomares et al. (2021) and indicates one of the future directions for research in this field. Since not all countries are equally capacitated in terms of their ability and infrastructure to use AI to implement the SDGs, care needs to be taken to ensure AI implementation proceeds according to such contextual realities. Last but not least, this implementation requires a high level of ethics and responsibility towards current and future generations.

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Acronym

UN	United Nation
SDGs	Sustainable Development Goals
AI	Artificial intelligence
SD	Sustainable Development
HEIs	High Education Institutions
HE	High Education
ANI	Artificial Narrow Intelligence
AGI	Artificial General Intelligence
IoT	Internet of Things
VR	Virtual Reality
UK	United Kingdom
USA	United States of America
MOOC	Massive Open Online Course
IT	Information Technology
CO_2	Carbon Dioxide
NLP	Natural Language Processing

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Appendix

Using Artificial Intelligence to Implement the UN Sustainable Development Goals in Higher Education

This study aims to investigate how artificial intelligence (AI) is being used in the implementation of the UN Sustainable Development Goals (SDGs) at higher education institutions (HEIs).

If you are a researcher at an HEI, we would like to invite you to participate in this survey. Please carefully read the following participant information. It will outline what is expected from you and what you can expect from the research team. It is up to you to decide whether to take part. To continue with the survey, please provide your consent below. You are free to withdraw at any time, without giving a reason.

– Only members of the research team will have access to the raw data files. All data will be used exclusively for the purposes of this study.

- We have identified no risks associated with participation in this study. All data collected within the survey will be anonymous, and no personally identifiable information will be collected.

- While there are no direct advantages to taking part in this study, this is your chance to contribute to the knowledge base regarding the use of Artificial Intelligence in the implementation of the UN Sustainable Development Goals at higher education institutions. In turn, this may influence future policy and action across the world.

- The data collected within the survey will be used to inform internal reports and academic publications as well as website/social media posts. In all cases, any information connected to the survey will be anonymised.

We thank you in advance for your responses to this short questionnaire, which will only take five minutes. Please also see our note at the end.

For general questions about this project, please contact the research team via email: FTZ-NKProjects@haw-hamburg.de

The Research Team

I have read the participant information and given my consent to participate in this study.

() Yes
() No

Participant Background Information

(A) Your country's institution:
(B) Your gender:

() Female
() Male
() Other/Prefer not to say

Your age group

() 18–29 years
() 30–39 years
() 40–49 years
() 50–59 years
() 60 years or over

In which knowledge area do you work? (Multiple choices)

() Agriculture, forestry, fisheries and veterinary
() Arts and humanities
() Business, administration and law
() Education
() Engineering, manufacturing and construction
() Health and welfare
() Information and communication technologies
() Natural sciences, mathematics and statistics
() Services
() Social sciences, journalism and information
() Other: _____

Your position at your university involves

() Research
() Teaching and Research

Which category better describes your institution?

() Public Higher Education Institution
() Private Higher Education Institution

G. In the last 4 years, have you carried out research on the topic of Sustainable Development Goals (SDGs)? (If the participant answered no is this question, the form ends here)
() No
() Yes

Questions

1. Do you currently use artificial intelligence as part of your research on Sustainable Development Goals (SDGs) or related projects? (If the answer is No, please go to question 5)
() No
() Yes

2. To what extent do you use artificial intelligence in your research on SDGs or related projects? (Only for participants who answered yes to question 1)
() Rarely
() Seldom
() Sometimes
() Often
() Very frequently

3. Which of the following artificial intelligence techniques do you use as part of your research on SDGs or related projects? (Multiple choices) (Only for participants who answered yes to question 1)
() Machine Learning
() Deep Learning
() Natural Language Processing
() Robotics
() Expert Systems
() Neural Networks
() Fuzzy Logic
() Others (please specify):

4. In which areas of your research on SDGs or related projects do you use artificial intelligence? (Multiple choices) (Only for participants who answered yes on question 1)
() Theoretical foundation/Literature review
() Research formulation/project design
() Data collection
() Data analysis
() Findings/outcomes presentation
() Manuscript writing

5. On a scale of 1 to 5, where **1 means strongly disagree and 5 means strongly agree**, please indicate your degree of agreement with the following sentence, being completed with the aspects listed below.

. . . may be a challenge for the use of artificial intelligence in my research on Sustainable Development Goals (SDGs) or related projects

	1	2	3	4	5
a. Lack of access to software/materials					
b. Lack of interest/support from institution administration					
c. Lack of interest/support from research colleagues					
d. Lack of interest/support from IT staff					
e. Lack of interest/support from students					
f. Lack of necessary IT skills or training among my research team					
g. Privacy and data protection protocols					
h. Others (please specify):					

6. Based on your experience, how do you perceive the use of artificial intelligence (AI) in projects related to the Sustainable Development Goals (SDGs) in your research area? Could you identify areas where AI is currently being deployed in your field as well as areas where it could be useful in the future? (Multiple choice)

SDGs connection	Currently employed	Useful in the future	Don't know/I am not aware of possible links between AI and the SDGs
SDG1 - No poverty			
SDG2 - Zero hunger			
SDG3 - Good health and well being			
SDG4 - Quality education			
SDG5 - Gender equality			
SDG6 - Clean water and sanitation			
SDG7 - Affordable and clean energy			
SDG8 - Decent work and economic growth			
SDG9 - Industry, innovation and infrastructure			
SDG10 - Reduced inequality			
SDG11 - Sustainable cities and communities			
SDG12 - Responsible consumption and production			
SDG13 - Climate action			
SDG14 - Life below water			
SDG15 - Life on land			
SDG16 - Peace, justice and strong institutions			
SDG17 - International Partnerships			
In connection with combined SDGs			

6. How do you evaluate the future use of artificial intelligence in SDGs projects at your higher education institution and/or department?

() Its relevance and use is likely to decrease
() Its relevance and use is likely to remain the same
() Its relevance and use is likely to increase
() Don't know

7. If you have specific examples of case studies or projects involving artificial intelligence in SDGs projects in your institution, please feel free to briefly describe your experiences as follows:

Title of the project:

Methods use

Results achieved

Thank you for taking part in this survey. If you wish to receive the paper with the results of this study, please let the research team know by sending an email to: SDG-Publications@haw-hamburg.de.

If you wish to be kept informed on projects, events, and publications on sustainable development, please feel free to subscribe to the mailing list of the Sustainable Development Research Programme (IUSDRP) at: https://www.jiscmail.ac.uk/cgi-bin/webadmin?A0=IUSDRP.