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Chapter 7: AI Development Probe into Decarbonization
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Chapter 7 - AI Development Probe into Decarbonization

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Chapter Information

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Abstract

The rise of artificial intelligence (AI) brings with it a broad range of challenges and opportunities for organizations. As we are aware that AI is a collection of tools, an intelligent toolbox. This article will explain why this toolbox is so valuable in helping humanity overcome key bottlenecks that currently hinder sustainability progress. Each passing year brings new record -high temperatures, larger catastrophic wildfires, and more frequent devasting floods. In response, international agreements have set ambitious global sustainability targets. the United Nations (UN) urges that net zero commitments require credible action for a living climate. Net zero refers to reducing carbon emissions to a chump change of residual emissions. Although there are numerous applications of AI, there is no leading-edge review of how AI applications can reduce net-zero carbon emissions (NZCEs) for sustainable building projects.
By mid-century (2050), carbon dioxide emissions must reach net zero and by 2030, the loss of biodiversity must be suspended and reversed. The encouraging news is that significant progress is being made toward these goals. More than 9,000 companies across more than 140 countries have joined the Race to Zero, a coalition that pledges to take immediate action to halve global emissions by 2030. But change is simply not happening fast enough. The scale and speed of changes that are needed to meet global sustainability goals is daunting. Consider a few examples, such as Global renewable power generation must triple in less than a decade – International Energy Agency (IEA) and methane emissions from fossil fuel operations must be reduced by 75%. Over the next couple of decades, food production must increase by 50%, and we will need to develop 1,000 times more durable carbon removal capacity than exists today.
A total of 124 published articles were retrieved and used to conduct science mapping analyses and qualitative discussions, including mainstream research topics, gaps, and future research directions. AI-powered learning platforms can help by providing:

- Provide personalized training
- Analyze existing skills
- Identifying gaps

• Recommend tailored learning paths

Keywords: *artificial intelligence; net-zero carbon emissions; science mapping approach; AI-powered learning platforms;*

7.1.Introduction

Humanity finds itself at a pivotal junction. It is imperative that we swiftly alter our course from the current trajectory of carbon-intensive and resource-depleting growth and transition towards a sustainable future in which both people and nature can flourish. The establishment of a sustainable future will necessitate transformative changes at an unprecedented pace and scale. Artificial Intelligence (AI) is a vital instrument for fostering the scale and pace that are essential. The era of AI is merely beginning to materialize. There exists considerable uncertainty on the horizon; however, one factor is unequivocal: AI will instigate significant transformations within the global economy, and this study will investigate the implications of these transformations for sustainability.

This research study aims to elucidate the opportunities and the challenges that exist at the intersection of AI and sustainability. In this study, we will gain an understanding of the following:

1. AI serves as a critical instrument for expediting advancements in sustainability. AI should not be regarded as a panacea nor as an assurance for resolving our climate and biodiversity crises.

2. It is essential to identify what must transpire to fully leverage AI's potential for sustainability.

3. An overview of the critical role of AI in transforming job performance, emphasizing key trends, challenges, and opportunities within the changing digital landscape.

AI is emerging as both an enabler and a force multiplier for the sustainability sector, by providing specialized assistance, optimizing workflows, and delivering individualized training. Traditional training modules frequently employ a one-size-fits-all approach, disregarding individual strengths and weaknesses. Artificial Intelligence (AI) enabled individualized training can be a powerful tool to bridge the sustainability gap. It can analyze an individual's existing skills, pinpointing deficiencies, and recommending customized learning pathways. This has the potential to significantly expedite the upskilling process, allowing a greater number of individuals to engage in sustainability initiatives. AI is empowering the workforce to tackle sustainability challenges more efficiently and effectively. As organizations strive to maintain competitiveness in an increasingly intricate and rapidly evolving environment, the adoption of AI technologies has become essential for enhancing productivity, efficiency, and innovation. Machine learning techniques enable AI systems to learn from data and enhance their performance over time, rendering them indispensable tools for improving decision-making processes across various professional sectors. One of the fundamental transformations facilitated by AI integration is the paradigm of human-AI collaboration. Rather than perceiving AI as a substitute for human employees, organizations are increasingly acknowledging its potential to augment human capabilities and elevate workforce productivity. Intelligent automation permits mundane and repetitive tasks to be assigned to AI systems, thus liberating human workers to concentrate on tasks that necessitate creativity, critical thinking, and emotional intelligence. This symbiotic relationship between humans and AI nurtures a more dynamic and adaptable workforce, where each side complements the strengths of the other.

It is clear that the integration of artificial intelligence is not simply a technological trend but a crucial catalyst for organizational success in the 21st century. Organizations that utilize the capabilities of AI to improve job performance are likely to achieve a substantial competitive edge, while those that do not keep pace may find themselves falling behind in a progressively dynamic and competitive market. This introduction establishes the foundation for a thorough examination of AI empowerment and its effects on job performance. Through a meticulous analysis of significant trends, case studies, and best practices, this paper seeks to offer insights into how organizations can utilize AI to unlock new dimensions of productivity, efficiency, and innovation. By comprehending the opportunities and challenges introduced by AI integration, organizations can devise a strategy for sustainable growth and success in the digital era. The swift advancements in AI algorithms, along with the exponential increase in data, have created unprecedented opportunities for organizations to optimize processes, automate tasks, and derive actionable insights.

As global focus on climate change keeps increasing, there is extensive acknowledgement within the international community regarding the need to lower greenhouse gas emissions and encourage a transition to a low-carbon economy (Wimbadi and Djalante, 2020). In this setup, AI, as a groundbreaking innovative technology, is significantly altering production methods, resource allocation techniques, and energy usage patterns across a range of industries (Waltersmann et al. , 2021), thus having a substantial effect on ECE. ECE denotes the cumulative carbon emissions linked to a product or service throughout its complete lifecycle, covering all phases including production, transportation, consumption, and disposal. This encompasses both direct and indirect emissions produced during the extraction of raw materials, manufacturing, transportation, usage, and final disposal or recycling (Meinrenken et al. , 2020).

Carbon emissions implications of AI necessitate consideration of both the direct and indirect effects of AI utilization on emissions. The direct effects pertain to the emissions produced from constructing and operating AI models. This is commonly termed the carbon footprint. The indirect effects of AI refer to the changes in emissions that may occur due to the manner in which AI tools are utilized. Most evaluations have concentrated on the direct effects, which are simpler to measure. The direct emissions resulting from developing and executing AI models are influenced by three factors:

1. The quantity of electricity required to train and operate models

2. The carbon intensity of the electricity consumed.

3. The greenhouse gas emissions linked to creating the infrastructure for running the AI models. These are referred to as embodied emissions.

A significant factor determining direct emissions from increasing AI operations will be the pace at which the global electricity grids transition to zero-carbon energy sources such as wind, solar, hydro, and geothermal. The speed of grid decarbonization will not only impact the level of emissions from the electricity used for operating AI models, but also the embodied emissions, which largely arise from energy utilized in assembling digital processors and constructing the facilities to accommodate them. At present, the carbon intensity of Australia's electricity grid is 17 times greater than that of Iceland's grid. Decarbonization rates also differ by region. For instance, in the past five years, the Netherlands decreased average grid carbon intensity by 31%, whereas India reduced average intensity by only 4%. To achieve the global sustainability goal of net zero emissions by 2050, AI tools and the infrastructure supporting them must be designed and operated to reduce their direct emissions. Major companies offering AI services are already making significant investments in renewable energy to meet or offset the energy demands of their data centres. Ongoing innovation will be essential to enhance efficiency, increase the availability of zero-carbon energy, and modernize electricity grids. The positive aspect is that AI can facilitate the acceleration of those innovations.

This section also will elaborate on how the development and operation of AI models require energy. The growth of AI is likely to have a relatively minor effect on energy consumption at a global level but can present local energy difficulties in certain areas. Let's examine the energy requirements of AI. At present, data centers and data transmission networks collectively account for approximately 2% of global electricity use. However, AI models themselves utilize only a small portion of this total. It is estimated that AI represents less than 1/10000 of global electricity consumption. Another approach to understand AI's electricity usage is by comparing it to other electricity consumption activities. For instance, the electricity utilized while watching television. Consider this: currently, ChatGPT processes around 200 million requests daily from users worldwide, consuming roughly 600 megawatt hours of electricity. While this may appear to be a substantial figure, it is equivalent to the electricity consumed in just one minute by individuals in the United States watching television at home. Now, naturally, as the use of AI grows, the energy required to run AI models will also rise. The International Energy Agency anticipates that the energy requirements of AI-specific data centres could rise by as much as tenfold by 2026. Between 2010 and 2020, despite a remarkable 900% increase in computing, electricity consumption increased by only 10% remaining fairly stable thanks to significant advancements in energy efficiency. Now, let's shift from the global viewpoint to the local outlook, where the energy situation can differ considerably. Locally, the electricity demand from data centers can be substantial in relation to supply, potentially imposing strain on local electrical grids. This situation arises because data centers have traditionally been situated in areas with advantageous economic and regulatory conditions. In these areas, data centers can utilize a considerable portion of the local grid's capacity.

7.2 Literature review

7.2.1 The Intersections of AI and Sustainability

The convergence of sustainability and artificial intelligence (AI) presents a transformative potential to tackle global environmental challenges, including climate change, resource depletion, and ecosystem degradation. This study examines the ways in which AI technologies, including machine learning and data analytics, are being employed across diverse sectors to bolster sustainability initiatives. Nevertheless, the incorporation of AI into sustainability practices also poses difficulties, such as the environmental repercussions of AI's energy use, the possibility of algorithmic biases, and the necessity for fair access to the advantages of AI. This section underscores the significance of creating transparent, accountable, and inclusive

AI systems and governance frameworks to ensure that AI positively contributes to sustainability objectives while alleviating potential risks and inequalities. The intersection of sustainability and artificial intelligence (AI) represents an intriguing frontier where technological innovations can substantially aid in addressing the urgent environmental issues we face today. As global apprehensions regarding climate change, resource depletion, and environmental degradation persistently rise, AI emerges as a transformative instrument with the ability to revolutionize sustainable practices across an array of sectors. AI technologies, encompassing machine learning, deep learning, and advanced data analytics, provide exceptional capabilities in processing extensive datasets, detecting complex patterns, and optimizing processes that are vital for sustainability. For example, AI-driven solutions have played a crucial role in enhancing energy consumption within smart grids, resulting in notable reductions in greenhouse gas emissions and improving energy efficiency.

AI constitutes a collection of powerful tools, created by humans. These tools can perform rigorous tasks that, in the past, only humans could execute. The intersection of sustainability and artificial intelligence (AI) represents an exciting frontier wherein technological advancements can make a significant contribution towards addressing the urgent environmental challenges of our era. As global concerns regarding climate change, resource depletion, and environmental degradation continue to rise, AI tools, when utilized efficiently, can serve as substantial accelerators for progress in sustainability. For example, AI-driven solutions have played a crucial role in optimizing energy consumption within smart grids, resulting in significant reductions in greenhouse gas emissions and improvements in energy efficiency. Furthermore, AI has the capability to optimize supply chains by analysing data related to material sources, manufacturing processes, and logistics, thereby identifying environmentally friendly and socially responsible methods that reduce carbon footprints and minimize waste. AI tools perform complex tasks by learning from data, often extensive amounts of data. The following three primary methods illustrate how machines can learn:

i) Supervised learning: Training AI with labelled data to identify patterns (e.g., categorizing images of forests).

ii) Unsupervised learning: Recognizing patterns in data without labels (e.g., enhancing weather forecasting).

iii) Reinforcement learning: Acquiring knowledge through trial and error with feedback (e.g., managing a building's energy system).

These methods empower AI to interpret data, make predictions, and continually enhance its capabilities, thereby adding organizations in the effective development and deployment of sustainability solutions.

The complete potential of AI in fostering sustainability can only be actualized through a comprehensive approach that equilibrates technological advancement with ethical considerations and sustainable practices. Nevertheless, the incorporation of AI into sustainability initiatives is not devoid of challenges. A notable concern is the environmental impact of AI itself, particularly the energy consumption linked to the training of extensive AI models. Shin and Rao address the paradox of utilizing energy-demanding AI technologies to tackle environmental issues, highlighting the necessity for more energy-efficient algorithms and hardware. The ethical ramifications of AI in sustainability also represent a vital area of concern. Khan and Patel investigate the dangers of algorithmic bias within AI systems, which can intensify pre-existing inequalities if not appropriately mitigated. Dubey and Singh further examine the obstacles associated with implementing AI-driven sustainability solutions in developing regions, where access to technology and data may be restricted, potentially exacerbating the digital divide. The significance of governance frameworks to ensure the responsible utilization of AI in sustainability is emphasized by Zhang et al. , who advocate for collaborative governance models that incorporate multiple stakeholders, including technologists, policymakers, and civil society. Johnson and Lee elaborate on this by discussing the necessity for transparency, accountability, and inclusivity within AI systems to guarantee their alignment with broader environmental and social governance (ESG) objectives.

Despite the progress made in AI-driven sustainability, the literature similarly advocates for a balanced perspective that addresses both the opportunities, and the risks associated with this convergence. The effectiveness of AI in advancing sustainability relies not solely on technological innovation but also on the creation of ethical, transparent, and inclusive frameworks that guarantee the equitable distribution of AI's benefits across society. The literature additionally investigates the convergence of artificial intelligence (AI) and sustainability and continues to underscore the potential of AI in transforming environmental management and policy. Recent research underscores the contribution of AI in improving the efficiency and effectiveness of renewable energy systems. For instance, AI has been implemented to optimize the functioning of wind farms through the prediction of energy production based on weather data, thus minimizing operational costs and enhancing reliability. The findings of this research will assist in the formulation of guidelines and best practices for the responsible implementation of AI in sustainability initiatives, ensuring that AI technologies are utilized effectively to attain long-term environmental and social benefits.

7.2.2 AI Can Help Empower the World's Sustainability Workforce

As we endeavor to fulfil global sustainability objectives, we encounter a significant challenge: an increasing gap in sustainability skills. The world requires a workforce capable of designing, implementing, and monitoring progress toward our sustainability objectives. However, at present, there are simply not enough individuals possessing the necessary skills and expertise to effect change at the pace the world demands. This is where AI can assume a transformative role. AI can function as a virtual assistant, offering specialized support that can enhance productivity. The sustainability workforce, which is already limited in size, is compelled to allocate a considerable portion of their time to repetitive, time-consuming manual tasks, such as data management and reporting. AI has the potential to automate a multitude of these tasks, significantly enhancing the efficiency of workflows. This matter extends beyond mere task efficiency; it also involves optimizing human potential within the sustainability sector. AI can assist companies in making more impactful decisions towards achieving net-zero objectives.

This study examines the transformative capacity of AI in improving productivity, efficiency, and effectiveness across various professional sectors. By utilizing advanced algorithms and machine learning methodologies, AI enables organizations to streamline processes, automate tasks, and derive valuable insights from extensive datasets. A significant element of AI empowerment is its capability to enhance human abilities instead of substituting them. Through intelligent automation, repetitive and monotonous tasks can be assigned to AI systems, permitting human workers to concentrate on higher-level decision-making and creative problem-solving. This cooperative interaction between humans and AI nurtures a more dynamic and adaptable workforce. AI improves decision-making processes universally. Tackling these challenges necessitates a collaborative initiative from policymakers, industry leaders, and educators to guarantee responsible AI implementation and alleviate potential risks. In summary, AI integration offers substantial promise for transforming job performance by optimizing processes, empowering workers, and fostering innovation. Embracing AI as a strategic partner rather than a threat is essential for unlocking its full potential and establishing a future where humans and machines collaborate seamlessly to achieve unparalleled levels of productivity and success.

Furthermore, AI-driven analytics enable organizations to execute data-driven decisions with accuracy and agility. By leveraging the capabilities of AI analytics, organizations can forecast market trends, enhance resource allocation, and provide tailored experiences to customers, thus securing a competitive advantage in today's data-driven economy. However, the widespread implementation of AI integration also introduces numerous challenges that must be confronted to achieve its full potential. Ethical considerations, including bias in algorithms and privacy concerns, pose significant questions regarding the responsible use of AI technologies. Furthermore, the accelerated pace of technological advancement demands ongoing upskilling and reskilling of the workforce to ensure that employees remain pertinent in an AI-driven economy [3]. By developing ethical guidelines, encouraging transparency, and investing in education and training programs, stakeholders can cultivate an environment favourable to responsible AI deployment and reduce potential risks. AI integration possesses tremendous potential for transforming job performance by streamlining processes, empowering employees, and fostering innovation. Adopting AI as a strategic partner rather than a threat is crucial for organizations aiming to excel in the digital era.

This research utilizes a mixed methods approach to explore the influence of AI integration on job performance across various industries. The methodology includes both quantitative analysis of empirical data and qualitative assessment of case studies and expert perspectives. By integrating these complementary research approaches, this research seeks to deliver a thorough understanding of the complex dynamics of AI empowerment in the workplace. The quantitative analysis entails the collection and examination of numerical data concerning AI adoption, job performance metrics, and organizational outcomes. Surveys and structured interviews are administered to a diverse sample of organizations across multiple sectors, which include manufacturing, healthcare, finance, and retail. These surveys are constructed to collect information on the degree of AI integration within organizations, the perceived effects of AI on job performance, and vital performance indicators (KPIs) such as productivity, efficiency, and revenue growth.

Expert interviews are carried out with industry professionals, academic researchers, and technology specialists in order to acquire varied perspectives on the influence of AI integration on job performance. These interviews investigate emerging trends, ethical considerations, and future ramifications of AI empowerment within the workplace. The insights acquired from these interviews yield valuable qualitative data that enhances the comprehension of AI's transformative capabilities. The results derived from both quantitative analysis and qualitative assessment are amalgamated to deliver a comprehensive and nuanced understanding of the effects of AI integration on job performance. By triangulating data obtained from multiple sources, this study endeavours to corroborate findings, discern patterns, and provide actionable insights for organizations aiming to utilize the potential of AI to enhance productivity, efficiency, and innovation in the workplace.

7.2.3 AI's Impact on the Global Race to Net Zero

As the largest carbon emitter in the world, China's initiatives to cut emissions are closely associated with the global path of climate change (Guo et al. , 2024). Simultaneously, China is among the rapidly advancing nations in the arena of

AI. The extensive use of AI across different sectors significantly influences energy consumption and carbon emissions. Consequently, a detailed comprehension of AI's effect on ECE, especially its unique mechanisms in both production and consumption, is crucial for formulating effective environmental policies and advancing sustainable development. ECE from the production side and ECE from the consumption side are two essential elements of total ECE, reflecting emissions from the viewpoints of production and consumption, respectively (Tian et al. , 2023). Production side ECE includes not just the direct emissions resulting from energy use within manufacturing facilities but also the indirect emissions stemming from activities like the transportation of raw materials and components, along with the energy needed throughout the production process (Ma et al. , 2024). On the other hand, consumption-side ECE emphasizes the emissions produced during the use of products by consumers, which encompasses energy use and other carbon emissions related to usage (Zhang et al. , 2023). In order to provide suitable policy suggestions, this chapter will empirically analyse how the growth of AI has influenced ECE from both the production and consumption perspectives.

In theory, the use of AI technologies can improve energy efficiency in production methods, diminish energy waste, and boost the use of clean energy (Rojek et al. , 2023). Nonetheless, AI technologies exert a complicated and multi-dimensional influence on ECE. Regarding production, AI technologies help decrease energy expenditure and carbon emissions for each product unit by refining automation, streamlining production methods, and enhancing resource allocation (Ahmad et al., 2022). Concerning consumption, the implementation of AI (e. g., intelligent recommendation systems, and smart home technologies) can modify consumer behaviour and consumption habits, thereby affecting ECE from the demand perspective (Puntoni et al. , 2021). Importantly, while advancements in AI improve the efficacy of products and services, they may simultaneously foster new consumer demand (André et al., 2018), which could result in an overall rise in carbon emissions.

Currently, the scholarly community has thoroughly explored the impacts of AI technologies on direct carbon emissions (Liu et al. , 2022; Xu and Song, 2023; Ding et al. , 2024). Most research indicates that AI technologies can assist in lowering direct carbon emissions and energy usage by enhancing energy efficiency (Zhao et al. , 2024), utilizing resources as effectively as possible (Lv et al. , 2022), and fostering technological innovation (Chen and Jin, 2023; Huang et al. , 2023). Specifically, Hsu et al. (2023) found that through automation and enhanced management, implementing AI technologies in manufacturing significantly reduces energy consumption and carbon emissions during the production process. In a similar vein, Liu et al. (2021) observed that the growing adoption of AI technologies would expedite the shift of traditional labour-intensive industries toward smart manufacturing, thereby further improving energy efficiency and diminishing energy consumption and carbon emissions.

The integration of the digital landscape within modern society presents a significant opportunity for advancing energy efficiency and monitoring carbon emissions, particularly in ML algorithms. The exponential growth and reliance on internet enabled devices, coupled with widespread internet accessibility, have revolutionized our understanding of online and offline realms. However, this digital revolution, despite its potential for smarter energy usage and management, has posed substantial challenges in terms of energy consumption [61]. In this context, Information Technology (IT) companies play a pivotal role in steering the transition toward a more sustainable, renewable energy-driven economy, crucial for reducing GHG emissions and mitigating climate change impacts. The IT sector, primarily based in energy-intensive manufacturing hubs like China and, generally, in Asia, currently consumes a considerable amount of global electricity, as depicted in Fig. 2.7. This highlights the pressing requirement for thorough monitoring and analysis to reduce carbon emissions in ML algorithms, which is essential in managing the environmental impact of this fast-growing technological field.

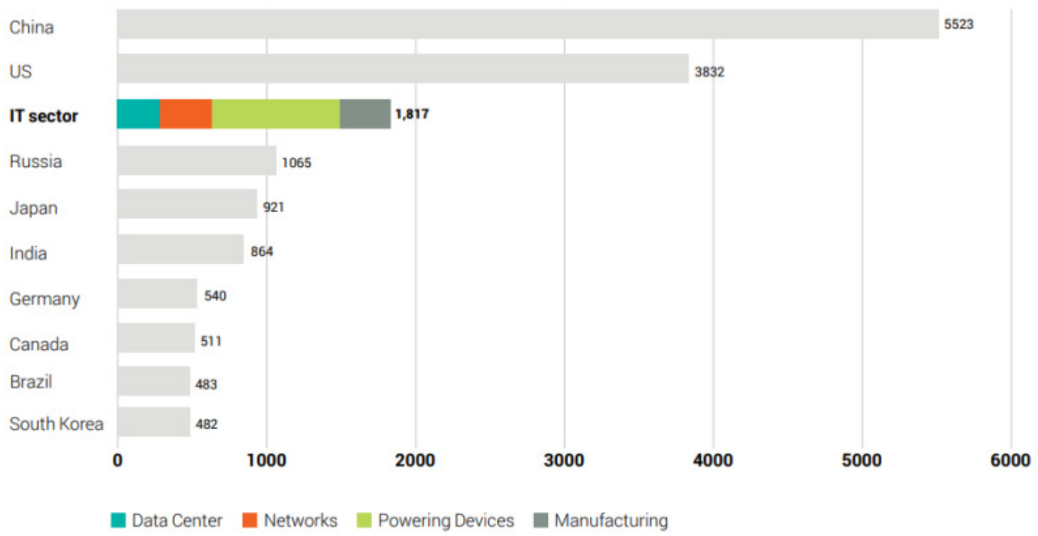

Figure 2.7: Comparison of Global Electricity Consumption in 2012 with the IT Sector's Energy Usage in billion kilowatt-hours (kWh)

In worldwide production networks, carbon emissions are frequently "embedded" in goods and services through cross-border trade and regional production activities (Jakob and Marschinski, 2013; Essandoh et al. , 2020). While the notion of ECE has been extensively utilized in domains like international trade and industrial structural modifications, studies examining the connection between AI development and ECE are still scarce. Yang et al. (2024) employ intricate network analysis techniques to investigate the global embodied carbon emission transfer network. They shed light on how nations engage in global value chains and propose a framework for understanding how stakeholders can take on emission reduction responsibilities to foster regional low-carbon economic development. Current research largely emphasizes spatial attributes of inter-regional carbon transfer, network features (Yang et al. , 2024), the carbon footprints associated with international trade, and the carbon emission efficiency within the manufacturing and service industries (Gao et al. , 2021; Wang et al. , 2024a).

The innovation of this study is reflected in four main aspects.

1. Current research frequently investigates the link between AI development and either production aspects or direct carbon emissions from a single standpoint. This study, in contrast, creatively takes a dual approach, addressing both production and consumption, to thoroughly examine the intricate effects of AI development on ECE and its foundational mechanisms. This dual-perspective analytical framework transcends the limitations of earlier studies and offers a fresh viewpoint for comprehending the intrinsic connection between AI and ECE. It provides significant insights for more precisely pinpointing emission reduction opportunities at various stages.

2. This study presents an innovative methodological contribution by merging the regional input-output model with a double fixed-effects model, thus creating a more extensive

analytical framework. By utilizing the regional input-output model, we initially estimate the carbon emissions on both the production and consumption sides for each province and city, furnishing essential data for the following empirical analysis. Building upon this, we subsequently use the double fixed-effects model to discern the net effects of AI development on ECE in both the production and consumption sectors. Furthermore, we perform a series of robustness checks and sensitivity analyses to confirm the dependability of our results. This methodological integration not only deepens the analysis but also guarantees the rigor of the investigation.

3. This research not only investigates the direct effects of AI advancement on both the production and consumption facets of ECE but also delves into the underlying mechanisms. In particular, it assesses whether AI impacts ECE via four essential channels: enhancements in energy efficiency, optimization of industrial structure, the uptake of low-carbon energy sources, and innovations in green products. This multidimensional analytical framework provides a more thorough grasp of the routes through which AI development influences ECE, offering a strong theoretical foundation for devising targeted strategies for emission reduction.

4. This research additionally expands the analytical scope by probing the moderating roles of both internal and external factors, such as the intensity of environmental regulations, the construction of ecological civilization, the capability for green innovation, and the consumption of renewable energy. From the viewpoints of government, market, and society, the analysis explores how these factors affect the carbon reduction effects of AI.

7.2.4 AI Energy Use – a Local Challenge

Rising energy usage and climate changes rank among the most urgent challenges confronting modern society. The swift increase in energy consumption, fueled by economic growth and technological progress, contributes to a rise in greenhouse gas emissions and accelerates global climate change. In this regard, the necessity of discovering innovative solutions to improve energy efficiency is becoming more pronounced. Artificial intelligence (AI) and machine learning (ML) have progressed quickly in recent years, demonstrating considerable promise in addressing intricate environmental issues, such as improving energy efficiency and lowering carbon emissions. Nevertheless, their influence on energy consumption and climate change is still unclear.

On one hand, AI possesses substantial potential to tackle global challenges identified by the UN, including climate change and various complex environmental and social problems, which encompass the following:

1. By forecasting energy consumption, optimizing energy systems, and incorporating renewable energy sources, AI has the capacity to emerge as a crucial asset in the battle against climate change.
2. Enhancing the energy efficiency of buildings and industrial frameworks and optimizing the functioning of energy systems in real time aids in decreasing total energy consumption and lessening environmental impact.
3. Machine learning (ML) is employed to forecast climate change and its effects on energy systems. Machine learning models enable us to develop scenarios for future

energy consumption and adjust infrastructure to new circumstances.

4. AI can improve the efficiency of renewable energy sources, including wind and solar power plants, which is especially vital in the decarbonization effort.
5. AI serves a vital function in observing, managing, and predicting energy demands, considering future climate change. This entails enhancing energy distribution, integrating renewable sources, and alleviating load on power systems during peak demand periods. These studies offer solutions to augment the sustainability of energy systems and lessen their carbon footprint.

The objective of this research is to compile and organize the available scientific literature, illustrating how artificial intelligence (AI) and machine learning (ML) methods can enhance energy efficiency across various industries and nations. The review additionally seeks to evaluate the role of AI in tracking contemporary climate issues, such as lowering carbon emissions and maximizing resource utilization. To achieve the established goal, the following tasks have been outlined:

- identify the primary trends and research areas where AI and ML are utilized to enhance energy efficiency and confront climate issues.

- evaluate the key technical obstacles that hinder the widespread implementation of AI and ML in practice and pinpoint strategies for overcoming them.

- investigate how AI and ML can aid in decreasing carbon footprints and optimizing resources for sustainable long-term development.

This review offers a thorough and detailed examination of the effects of AI and ML on energy efficiency, considering the interconnected energy and climate factors associated with these digital technologies. In contrast to earlier studies, this review centers on a detailed evaluation of technological obstacles and creative solutions, and it delineates pathways for future investigation. The results are intended to enhance the understanding of both the scientific community and practitioners engaged in the areas of sustainable development and energy management.

7.3 Methodology and Recommendation

AI techniques, particularly machine learning, have been utilized to examine satellite imagery and sensor data for the purposes of monitoring deforestation, land use changes, and biodiversity loss, thus facilitating more effective conservation efforts. Nonetheless, the implementation of AI in sustainability practices is accompanied by a number of challenges. A primary concern is the transparency and interpretability of AI models, which are frequently perceived as “black boxes. “ This lack of transparency may impede trust and the acceptance of AI solutions in crucial domains such as environmental policy and public decision-making. Furthermore, the substantial computational requirements of AI models, especially in deep learning, raise apprehensions regarding their energy consumption and carbon footprint, which could, paradoxically, lead to environmental degradation if not adequately managed. Finally, the ethical ramifications of sustainability are increasingly being addressed in the literature, with scholars highlighting the necessity for responsible AI development that emphasizes fairness, accountability, and inclusivity. As the domain continues to progress, it is vital to tackle these challenges through interdisciplinary research that merges technological innovation with ethical and sustainable practices.

The dynamic interaction between humans and machines has transformed the division of labor, with artificial intelligence (AI) playing a decisive role. It is important for AI implementation to allocate monotonous tasks to machines and technological systems, while reserving creative endeavors for human beings (Jarrahi, 2018). The implications of AI in organizational settings bring forth both advantages and disadvantages. To ensure responsible AI deployment, it is essential to address ethical concerns proactively. As a result, rules and legislation must be improved to protect organisations' and their employees' welfare from any potential repercussion associated with the deployment of AI (Brendel et al., 2021).

Statistical methods, including regression analysis and correlation analysis, are utilized to investigate the relationship between AI adoption and job performance metrics. By measuring the statistical significance of these relationships, this analysis seeks to uncover patterns and trends that clarify the impact of AI integration on organizational outcomes. In addition to quantitative analysis, this study undertakes a qualitative examination of case studies and expert interviews to offer nuanced insights into the mechanisms and implications of AI empowerment in the workplace. Case studies are chosen from prominent organizations recognized for their innovative application of AI technologies aimed at enhancing job performance. These cases are analysed thoroughly to identify best practices, challenges, and lessons learned in the implementation of AI solutions.

In the realm of carbon emissions calculation tools, a deep study reveals a diverse landscape that matches different preferences and study requirements. The first crucial distinction lies in the environment within which each tool operates: whether integrated into a Python script or accessible online. A meticulously organized Table 2.1 catalogs the surveyed tools, delineating them based on their respective environments. The primary divergence stems from whether the analysis is conducted in real-time, as is the case with Python libraries, or post-execution, characteristic of online tools. Regardless of the programming language being used, online tools may be utilized without changing the code. Python libraries provide measurements of the consumption of various parts of the script but clearly can only be used in

Python programming.

Python Libraries	Online Tools
Code Carbon	Green Algorithms
Carbon tracker	
Eco2AI	
Experiment impact tracker	ML Co2 Impact
Cumulator	
Energy usage	

Table 2.1: Commonly used carbon tracking tools available for online estimation afterward or at runtime in Python scripting.

The method used for this literature review was created to thoroughly examine existing studies on the use of artificial intelligence and machine learning techniques within the realm of energy efficiency and their effects on climate change. The main objective is to pinpoint trends and obstacles in the deployment of these technologies and predict their future influence on climate change.

A systematic methodology is applied to highlight the clarity and replicability of the findings. The literature search took place using the Scopus database, which includes a wide array of peer-reviewed scientific articles and patents. The purpose was to gather a diverse range of research across various fields and disciplines. Key phrases pertinent to the research inquiries were utilized to formulate the search approach. The logical search string was developed as follows: TITLE-ABS-KEY ((“artificial intelligence” OR “machine learning”) AND “energy efficiency” AND “climate change”) AND PUBYEAR AFT 2010 AND PUBYEAR BEF 2025. This search string was crafted to encompass both foundational and contemporary publications from 2010 to 2024, focusing on identifying overlaps between energy efficiency and climate solutions via AI and ML. The terms employed in this literature review were meticulously chosen to guarantee both the thoroughness and significance of the documents concerning the study’s aims and primary research questions. The search yielded 237 pertinent papers and 388 patents.

More than 60% of the documents were published in the previous two years (2023–2024), indicating an increasing interest in the subject. This upward trend is also observable in the industry, with 243 patents registered in the last three years (2022–2024), accounting for 63% of the total over the fourteen-year span. The growing number of patents is evident, with 59 filed in 2022, 85 in 2023, and 99 patents filed in 2024 (as of 16 October). The resulting review data were organized into significant categories, including industries, geographic distribution, and types of research documents.

Figure 1 displays the yearly distribution of published papers (as of 16 October 2024), showcasing trends and research activity over time. Source: Scopus Analytics.

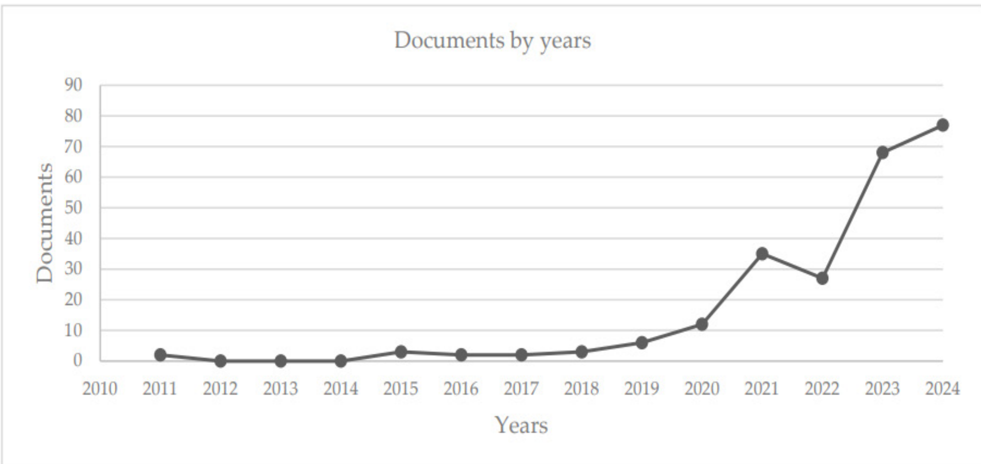

Figure 1. Distribution of documents by years. Source: compiled by authors.

Documents categorized by types, Article Conference Paper Review Book Chapter Conference Review, Book, Editorial Figure 3. Distribution of documents by countries. Source: compiled by authors. Figure 4 depicts the distribution of documents by types, showing that articles and conference publications make up more than 80% of the total, with articles taking the largestportion(Source:ScopusAnalytics).Energies2024,17,xFORPEERREVIEW5of38Figure 3 displays the number of articles released by researchers from different countries, emphasizing the geographic diversity and concentration of research activities, especially in China, India, the UK, and the US (Source: Scopus Analytics). Figure 3. Distribution of documents by countries. Source: compiled by authors. Figure 4 depicts the distribution of documents by types, showing that articles and conference publications make up more than 80% of the total, with articles taking the largest portion (Source: Scopus Analytics).

A methodical approach was utilized to guarantee thorough coverage of the area. The selection procedure adhered to the methodology described and complied with the guidelines established in ensuring clarity and precision. Publications were assessed utilizing a 3-point quality scoring system to evaluate relevance and validity (refer to Table 1). Each study was examined based on various criteria, including innovation, practical application 0 5 10 15 20 25 30 35 Documents 46% 35% 11% 6% 2% Documents by types Article Conference Paper Review Book Chapter Conference Review, Book, Editorial Figure 4. Distribution of documents by types. Source: compiled by authors. A methodical approach was utilized to guarantee thorough coverage of the area. The selection procedure adhered to the methodology described and complied with the guidelines established, ensuring clarity and precision. Publications were assessed utilizing a 3-point quality scoring system to evaluate relevance and validity (refer to Table 1). Each study was examined based on various criteria, including innovation, practical application and strength of evidence. The systematic review method advocated was implemented to guarantee the clarity and reproducibility of the findings.

Table 1. Evaluation of source quality.

Evaluation Question	Description	Evaluation Metric
1	Stage of implementation of the energy efficiency project using AI and ML	1: Experiments; 2: Economic impact; 3: Scalability.
2	The magnitude of the energy efficiency effect from AI and ML projects.	1: Negligible; 2: Enterprise level; 3: Country level.
3	Identification and discussion of challenges in implementing AI and ML for energy efficiency projects.	1: Minimal; 2: Key issues; 3: Detailed.
4	Proposing future research directions to improve ML models.	1: Some; 2: General; 3: Detailed and innovative.

Source: compiled by authors.

This research examined four essential questions concerning the use of AI and ML in energy efficiency. These evaluative inquiries (refer to Table 1) aided in an extensive evaluation of the research outcomes while maintaining the standards of relevance and impartiality. As a result, this methodology facilitated detailed analysis and the recognition of the most critical areas for additional investigation. One of the main obstacles in the ongoing energy transition is achieving decarbonization via the incorporation of renewable energy sources (RESs), including solar, wind, and geothermal energy. For example, the adoption of smart grids featuring AI can improve the reliability of energy systems and reduce energy losses by enabling more precise forecasting and resource management. Artificial intelligence (AI) is vital for overseeing energy usage, optimizing energy systems, and decreasing CO2 emissions. The application of machine learning and big data analytics allows for real-time forecasts of energy consumption, enhances the energy efficiency of industrial procedures, and lowers the overall carbon footprint. This is especially pertinent for the electronics industry, where refining energy management can lead to substantial emissions reductions.

7.4 Challenges and Considerations

The proposed position at the convergence of sustainability and artificial intelligence (AI) seeks to devise and execute innovative AI-driven solutions that substantially aid in addressing global environmental challenges. This chapter will emphasize the utilization of AI technologies, encompassing machine learning, deep learning, and advanced data analytics, to improve the efficiency and effectiveness of sustainability initiatives across diverse sectors. The primary aim is to construct AI models that optimize resource consumption, minimize environmental repercussions, and facilitate the transition to a low-carbon economy. Within the energy sector, the intended work will encompass the creation of AI algorithms for smart grid optimization allowing for more effective energy distribution and utilization while accommodating renewable energy sources such as solar and wind power. These AI-driven models will accurately forecast energy demand and production, enhancing the equilibrium of supply and demand and decreasing dependence on fossil fuels. Furthermore, the project will investigate the application of AI in augmenting the efficiency of energy storage systems, which are vital for stabilizing the grid as the portion of renewable energy rises.

The research will also explore the utilization of AI in waste management, where predictive models will be developed to anticipate waste generation patterns, enhance recycling processes, and facilitate the establishment of circular economies. By incorporating AI into waste management systems, the proposed work seeks to diminish waste, encourage resource recovery, and lessen landfill use. Another significant area of concentration is the application of AI in urban planning and smart cities. The proposed work will entail the creation of AI-driven tools for designing energy-efficient buildings, optimizing transportation networks, and managing urban resources in a more sustainable manner. These AI models will be employed to simulate various urban development scenarios, allowing city planners to make data-informed decisions that mitigate environmental impacts and improve the quality of life for urban inhabitants. The study will also integrate ethical considerations into the design and implementation of AI systems, emphasizing transparency, accountability, and inclusivity. This encompasses the development of frameworks for responsible AI utilization that avert algorithmic biases and guarantee equitable access to AI-driven sustainability solutions across diverse regions and communities.

The recommended endeavor will encompass interdisciplinary research that amalgamates insights from environmental science, artificial intelligence, ethics, and policy studies to formulate comprehensive solutions that address both the prospects and challenges at the convergence of AI and sustainability. Through the execution of case studies and pilot projects in varied environments, the initiative seeks to illustrate the practical applications of AI in promoting sustainability, while simultaneously identifying possible risks and strategies for mitigation. The results of this research will aid in the formulation of guidelines and best practices for the responsible implementation of AI in sustainability initiatives, ensuring that AI technologies are utilized effectively to attain enduring environmental and social advantages. Ultimately, the proposed undertaking aspires to position AI as a crucial instrument in the collective endeavour to combat climate change, safeguard natural resources, and cultivate a more sustainable and equitable future.

Embracing the integration of artificial intelligence in the workplace is not devoid of its challenges and considerations. One of the primary challenges is the ethical implications associated with AI-driven decision-making. Algorithmic bias, whether inadvertent or systemic, has the ability to sustain inequalities and intensify societal biases. Ensuring fairness, transparency, and accountability within AI systems is crucial in order to mitigate these risks and uphold ethical standards. Privacy concerns also significantly arise in the age of AI empowerment. The expansion of data collection and analysis prompts inquiries regarding the safeguarding of personal information and the potential for misuse or unauthorized access. Organizations must prioritize the implementation of data security and privacy measures to protect sensitive information and maintain trust with stakeholders. Furthermore, the rapid rate of technological advancement necessitates the continuous upskilling and reskilling of the workforce. As AI automates routine tasks, employees are required to develop new skills and competencies to remain relevant in the changing job market. Investing in training programs and lifelong learning initiatives is vital to empower workers and facilitate a seamless transition to an AI-enabled workforce. Interdisciplinary collaboration presents another key consideration in efforts towards AI integration. Effective deployment of AI necessitates cooperation among diverse stakeholders, including data scientists, domain experts, policymakers, and end-users. Promoting interdisciplinary dialogue and knowledge sharing is essential for harnessing the full potential of AI technologies and tackling complex challenges from various perspectives. Moreover, regulatory compliance presents a considerable challenge within the adoption of AI solutions. As governments globally contend with the ethical and legal ramifications of AI, organizations must navigate a complicated array of regulations and standards. Adhering to data protection laws, industry regulations, and ethical guidelines is imperative in order to circumvent legal liabilities and reputational risks. Beyond external challenges, the organizational culture and mindset are pivotal in the successful integration of AI. Resistance to change, anxiety regarding job displacement, and insufficient support from key stakeholders can obstruct the effective implementation of AI initiatives. Fostering a culture of innovation, openness, and collaboration is vital to surmount these obstacles and nurture an environment conducive to AI empowerment. Addressing these challenges and considerations mandates a comprehensive approach that incorporates technological, ethical, legal, and cultural dimensions. By proactively confronting these challenges, organizations can unlock the transformative potential of AI and create a future where humans and machines collaborate harmoniously to achieve mutual objectives.

According to the theory of production function in economics, advancements in technology like AI can boost productivity by enhancing the efficiency of labor and capital. AI applications during the upstream production process decrease resource requirements, improve energy efficiency, and reduce production side ECE. AI allows companies to utilize tools such as data analysis, predictive modelling, and automated controls to accurately manage energy usage throughout the entire production process (Ahmad et al. , 2021). Building upon the previous theoretical analysis, this study seeks to investigate the connection between the advancement of AI technology and concealed carbon emissions from both production and consumption perspectives. Regarding model specification, the Hausman test is used to evaluate the suitability of applying a fixed effects model compared to a random effects model. The findings of the test reject the null hypothesis at the 1% significance level, suggesting that the fixed effects model is more appropriate. Utilizing the theoretical analysis and model (1), we apply a fixed effects model to analyse the effect of AI development levels on ECE in both production and consumption aspects.

Despite advancements in AI applications, the prediction of energy efficiency at the city level remains insufficiently explored, particularly regarding the interactions among various spatial functions and climate scenarios. Modern research indicates that machine learning (ML) and artificial intelligence (AI) can significantly enhance energy consumption management and reduce the carbon footprint of buildings. For instance, in smart and energy-efficient buildings

(SEEs), ML-based control systems allow thermal comfort and energy consumption to be effectively balanced. Prediction models utilizing ML and genetic algorithms can improve the energy efficiency of existing buildings by analyzing historical data, including considering climate change forecasting. Additionally, the application of multi-criteria optimization techniques for assessing the thermal performance of buildings further underscores the critical role of AI in adapting structures to shifting climatic conditions.

7.5.Findings and Outcomes

The proposed position at the convergence of sustainability and artificial intelligence (AI) seeks to devise and execute innovative AI-driven solutions that substantially aid in addressing global environmental challenges. This research study will emphasize the utilization of AI technologies, encompassing machine learning, deep learning, and advanced data analytics, to improve the efficiency and effectiveness of sustainability initiatives across diverse sectors. The primary aim is to construct AI models that optimize resource consumption, minimize environmental repercussions, and facilitate the transition to a low-carbon economy. Within the energy sector, the intended work will encompass the creation of AI algorithms for smart grid optimization allowing for more effective energy distribution and utilization while accommodating renewable energy sources such as solar and wind power. These AI-driven models will accurately forecast energy demand and production, enhancing the equilibrium of supply and demand and decreasing dependence on fossil fuels. Furthermore, the project will investigate the application of AI in augmenting the efficiency of energy storage systems, which are vital for stabilizing the grid as the portion of renewable energy rises.

The research will also explore the utilization of AI in waste management, where predictive models will be developed to anticipate waste generation patterns, enhance recycling processes, and facilitate the establishment of circular economies. By incorporating AI into waste management systems, the proposed work seeks to diminish waste, encourage resource recovery, and lessen landfill use. Another significant area of concentration is the application of AI in urban planning and smart cities. The proposed work will entail the creation of AI-driven tools for designing energy-efficient buildings, optimizing transportation networks, and managing urban resources in a more sustainable manner. These AI models will be employed to simulate various urban development scenarios, allowing city planners to make data-informed decisions that mitigate environmental impacts and improve the quality of life for urban inhabitants. The study will also integrate ethical considerations into the design and implementation of AI systems, emphasizing transparency, accountability, and inclusivity. This encompasses the development of frameworks for responsible AI utilization that avert algorithmic biases and guarantee equitable access to AI-driven sustainability solutions across diverse regions and communities.

The integration of carbon emissions as a metric in machine learning is a relatively new concept. Nowadays, a predominant focus in research lies in achieving high-performance levels without taking computational efficiency into account. This neglect could be attributed to the lack of familiarity with existing approaches to evaluate energy consumption in this domain.

7.6.Conclusions and Looking Forward

The incorporation of artificial intelligence (AI) into job performance signifies a fundamental shift with extensive implications for organizations, industries, and society at large. Through an in-depth investigation of AI empowerment, this research has revealed the transformative capabilities, obstacles, and future possibilities of AI incorporation in the workplace. AI empowerment presents significant opportunities for transforming job performance across various sectors.

By utilizing sophisticated algorithms, machine learning methodologies, and big data analytics, organizations are able to optimize operations, automate duties, and uncover valuable insights to enhance productivity, efficiency, and innovation. The collaborative relationship between humans and AI promotes a more dynamic and flexible workforce, wherein each party enhances the other's strengths to achieve remarkable levels of performance and success.

Nonetheless, AI integration also introduces challenges and considerations that must be addressed proactively to fully leverage its potential. Ethical issues related to bias, transparency, and accountability in AI-driven decision-making prompt crucial inquiries regarding the responsible use of AI technologies. Concerns regarding privacy, adherence to regulations, and the necessity for workforce upskilling further highlight the intricacies of AI integration initiatives. Tackling these challenges necessitates a comprehensive approach that includes technological, ethical, legal, and cultural aspects.

AI has the potential to both help and harm the environment, and it is crucial to focus on sustainable AI practices throughout the lifecycle of AI. While deep learning may be necessary for some specific tasks, simpler machine learning algorithms can often achieve similar results with less computational power and energy, making them more environmentally responsible.

The research concentrated on organizing the current scientific literature to pinpoint significant shared themes and patterns in the utilization of AI and ML tools to enhance energy efficiency across various sectors and nations, specifically targeting climate issues, such as minimizing carbon emissions and optimizing resource utilization. This literature survey emphasizes notable advancements in the use of artificial intelligence (AI) and machine learning (ML) methods designed to improve energy efficiency and tackle climate change challenges. The literature review conducted enables us to draw multiple conclusions regarding the function and potential of AI and ML in boosting energy efficiency and confronting climate challenges. Future investigations into the usage of artificial intelligence and machine learning for improving energy efficiency require a comprehensive strategy focused on creating technological solutions, enhancing the sustainability of energy systems, and taking socio-economic factors into account. Essential priorities for the research community in the upcoming years should involve integrating renewable energy sources, enhancing system reliability and cybersecurity, and decreasing the carbon footprint of AI technologies.

7.6.1 The Benefits of AI for Sustainability are not guaranteed

International researchers investigate how AI and broader digitalization might affect the future of greenhouse gas emissions. Together, we outlined three potential scenarios. In the initial scenario that we envisioned, AI and other digital technologies would boost economic productivity but also raise energy demand and resource usage, resulting in an increase in greenhouse gas emissions. This is clearly not a sustainable or preferable course. In the second scenario, AI and other digital technologies hasten the implementation of renewable energy and enhance efficiency while preventing overconsumption, but with limited human agency. This results in a reduction of greenhouse gas emissions but leads to unsustainable social outcomes. In the third scenario, AI technologies are utilized efficiently and effectively under trusted governance, empowering individuals and speeding up decarbonization. This represents a sustainable path that AI can assist the world in achieving. To leverage AI's potential for guiding the world toward a genuinely sustainable path, intentional efforts are necessary to establish the conditions required for success. So, let's conclude by detailing the enabling conditions necessary for achievement.

7.6.2 What's Needed to Unlock AI's Potential for Sustainability

Let me conclude this research study by guiding you through the five essential enabling conditions that are necessary to unleash AI's full capability for sustainability. These were pinpointed in partnership with sustainability researchers and practitioners with extensive experience in the domain

We require increased investment in AI for sustainability, which entails offering financial incentives, generating opportunities for AI research cantered on sustainability, and establishing collaborations between AI and sustainability specialists

1. We need to increased investment in AI for sustainability, which includes providing financial incentives, creating opportunities for AI research-focused on sustainability and fostering partnerships between AI and sustainability experts.

2. We require further development of inclusive digital and data infrastructure. This necessitates investing in bridging crucial data gaps, especially in underrepresented areas of the globe.

3. We must minimize resource utilization and emphasize renewable resources. As demand for AI escalates, reducing the resource footprint of AI activities becomes vital. Prioritizing zero-carbon energy sources in AI infrastructure and operations is crucial for mitigating the environmental footprint associated with developing and operating AI models.

4. We must advance AI policy principles and governance. Establishing solid policy principles and governance frameworks for AI in sustainability is critical. Policies are necessary to facilitate the transition to carbon-free electricity grids, and the assimilation of AI into current sustainability structures.

5. We need to strengthen workplace capacity to utilize AI for sustainability. Unlocking AI's potential for sustainability will depend on a workforce capable of utilizing AI tools. This involves creating educational and training pathways that empower the sustainability workforce with the skills and knowledge to employ AI proficiently.

With these five essential conditions established, AI has the potential to be the transformative force we require to implement sustainability solutions more swiftly, cost-effectively, and efficiently. Consider how you might develop AI capabilities for sustainability and reflect on what actions you or your organization can take to foster the broader enabling conditions necessary for AI to assist the world in advancing towards sustainability.

The timeframe for transitioning to global sustainability is diminishing. Thankfully, the expanding AI toolkit offers a remarkable chance to instigate change at the speed necessary to meet our international sustainability objectives. In summary, as an advancing technology, AI is still in its inception. However, there are several use cases that demonstrate its effectiveness in helping companies decarbonize to achieve their Net Zero goals. However, this can only be achieved if we, as a collective society, concentrate on creating the enabling conditions for success. Together, we can accomplish this.

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