Digital Leadership and Technology Innovation for Sustainable Corporate Practices: A Survey

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Abstract

This survey paper examines the strategic integration of digital leadership and technology innovation in enhancing corporate sustainability, focusing on reducing carbon emissions and promoting eco-friendly practices. The paper highlights the pivotal role of digital transformational leadership and organizational agility in navigating digital advancements, particularly within the Environmental, Social, and Governance (ESG) framework. It underscores the significance of digital tools, such as the Digital Procurement Workspace and AI-driven innovations, in optimizing resource use and minimizing environmental impacts. The survey explores challenges in measuring carbon emissions and integrating green technologies, addressing cost, infrastructure, and cultural barriers. It also identifies opportunities for innovation and collaboration, emphasizing the need for energy-efficient AI models and sustainable manufacturing practices. The paper concludes with future research directions, advocating for the development of hybrid energy solutions, refined emissions calculators, and standardized metrics for sustainability in AI. By synthesizing existing knowledge, this survey provides a comprehensive overview of how digital and green technologies can drive corporate sustainability, offering insights for practitioners and policymakers to support a sustainable future.

1 Introduction

1.1 Relevance of Digital Leadership and Technology Innovation

The integration of digital leadership and technology innovation is crucial for addressing sustainability challenges within corporate environments, particularly under the Environmental, Social, and Governance (ESG) framework [1]. These components are essential for transforming traditional business models into sustainable ones, as demonstrated by the strategic emphasis on digital transformation in sectors such as renewable energy [2]. The digital economy significantly fosters green technology innovation, which is vital for sustainable development [3].

Digital transformational leadership (DTL) and organizational agility (OA) play pivotal roles in navigating the complexities of digital advancements and institutional changes, especially for public organizations undergoing digital transformation [4]. In the context of Industry 4.0, developing organizational capabilities is critical for aligning with technological advancements [5]. The Information Systems (IS) research community further highlights the importance of digital leadership in enhancing corporate sustainability [6].

The proposed Digital Procurement Workspace (DPW) illustrates how the integration of information, automation, and analytics can streamline procurement processes while emphasizing sustainability [7]. Additionally, optimizing inventory management within reverse logistics is essential due to the rising demand for repaired products and the environmental costs associated with waste disposal [8].

The transportation sector contributes approximately 23% of global greenhouse gas emissions (GHGs), underscoring the need for innovative technologies to mitigate environmental impacts [9]. Moreover,

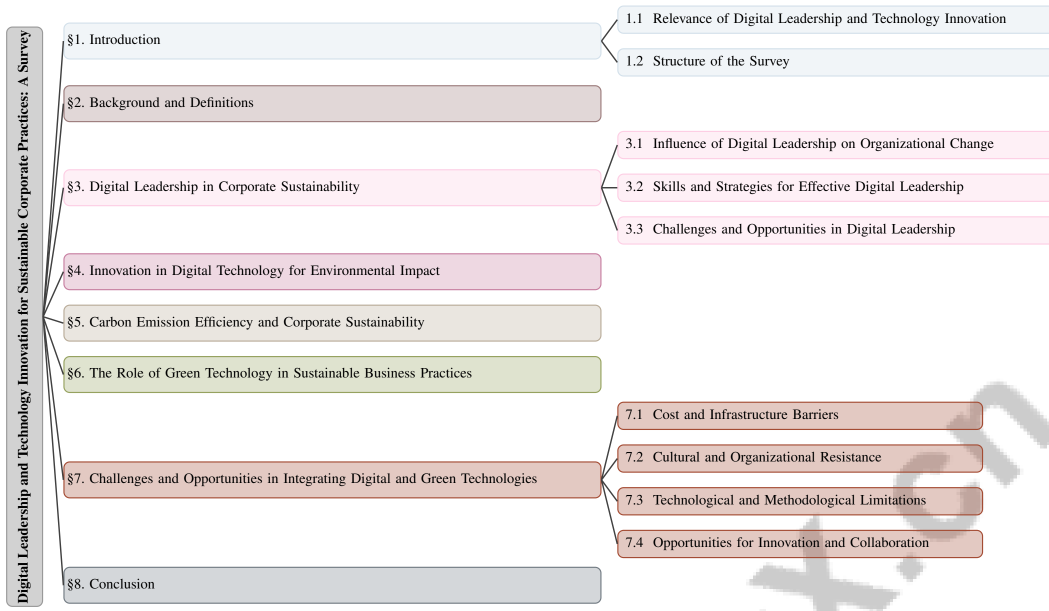

Figure 1: chapter structure

the largest international corporations account for nearly 30% of global CO2e emissions, necessitating efficient methods to assess corporate environmental performance amid increasing sustainability objectives [10]. Evaluating corporate sustainability performance is vital for transitioning to a greener economy [11].

Corporate sustainability (CS) and corporate social responsibility (CSR) are increasingly critical in response to a crisis of confidence in business, with human resource management (HRM) playing a vital role in these efforts [12]. The intersection of responsible and sustainable finance emphasizes the role of local communities as stakeholders in corporate decisions [13].

Digital leadership must also address the environmental impacts of AI technologies, particularly the significant carbon emissions and water consumption associated with training large language models. The sustainability of code generated by AI models further highlights the necessity of incorporating sustainability into software development [14].

In e-commerce, the 'attitude-behavior gap' in sustainable consumption presents challenges for consumers making eco-friendly choices, necessitating digital leadership to bridge this gap [15]. This survey aims to provide an updated overview of the changes in work design and leadership resulting from digital transformation, addressing gaps in existing literature and structuring knowledge in this domain [16]. Consequently, digital leadership and technology innovation are essential for navigating the complexities of modern corporate sustainability practices, enabling organizations to meet current and future environmental challenges.

The environmental impact of concrete production underscores the need for sustainable concrete formulas that minimize energy consumption and greenhouse gas emissions [17]. Additionally, user behavior in video streaming significantly affects greenhouse gas emissions, emphasizing the importance of consumer decisions [18]. The energy consumption and carbon footprint associated with advancing AI technology also raise concerns [19].

This survey synthesizes existing knowledge on digital innovation, highlighting its significance in contemporary corporate practices [20]. The growing carbon footprint of modern data centers and the lack of support for environmental sustainability further underscore the need for innovation in this area [21]. The integration of artificial intelligence (AI) in the production and cybersecurity of electric and hybrid vehicles (EHVs) aims to enhance efficiency, sustainability, and safety in response to environmental challenges [22].

The necessity of developing agile manufacturing techniques utilizing recycled and reclaimed metals to promote environmental sustainability is also addressed [23]. The current state of digital entrepreneurship and digital innovation research emphasizes their intersection with digital technologies,

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further highlighting their significance in modern corporate practices [24]. Additionally, integrating water consumption awareness within information retrieval models is crucial in the context of energy consumption and CO2 emissions [25].

1.2 Structure of the Survey

This survey is structured to comprehensively examine the intersection of digital leadership, technology innovation, and corporate sustainability. It begins with an introduction that emphasizes the relevance of these elements in contemporary corporate practices, particularly within the ESG framework [26]. The initial sections define core concepts such as digital leadership, digital technology innovation, carbon emission efficiency, corporate sustainability, environmental impact, and green technology, elucidating their interconnections and collective impact on sustainable business practices.

Subsequent sections explore the role of digital leadership in fostering organizational change towards sustainability, highlighting the necessary skills and strategies for effective leadership in this domain. The survey also addresses the challenges and opportunities associated with digital leadership, drawing insights from the digital transformation journeys of large, established companies employing SMACIT technologies [27].

The focus then shifts to technological innovations that reduce environmental impact, emphasizing advancements in AI and machine learning for sustainability [21]. It also covers digital tools for environmental monitoring and assessment, providing a detailed analysis of their applications in improving carbon emission efficiency.

In analyzing corporate sustainability, the survey discusses strategies for enhancing carbon emission efficiency and the challenges in measuring and verifying carbon emissions. The role of green technology in sustainable business practices is examined, focusing on its development, implementation, and environmental impact assessment [28]. The integration of green technology with AI and machine learning is also considered, reflecting on the environmental footprint of generative AI, including carbon emissions and water usage [26].

The survey further identifies challenges and opportunities in integrating digital and green technologies, addressing cost and infrastructure barriers, cultural and organizational resistance, and technological and methodological limitations. Opportunities for innovation and collaboration in overcoming these challenges are explored, particularly in the context of digital entrepreneurship and innovation [24].

Lastly, the conclusion synthesizes key findings, reflecting on the importance of digital leadership and technology innovation in achieving corporate sustainability. It suggests future research directions and practical implications for businesses, supported by benchmarks that facilitate better understanding and decision-making for practitioners and policymakers [11]. The survey also considers the effects of digital transformation on work design and leadership, including themes such as work-life balance and organizational hierarchies [16].The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Definitions and Interconnections

Digital leadership strategically manages organizational digital transformations, focusing on adopting advanced technologies to boost operational efficiency and sustainability. It is crucial for embedding sustainability within AI governance and aligning operational practices with sustainability objectives [29]. This leadership is particularly significant in manufacturing and cybersecurity, where AI and predictive analytics are applied to enhance energy efficiency and reduce emissions, notably in electric and hybrid vehicles (EHVs) [22].

Digital technology innovation entails the development and application of new digital solutions that enhance efficiency and sustainability. Machine learning plays a vital role in addressing carbon emissions, necessitating tools for their assessment and mitigation [30]. In agile manufacturing, the integration of recycled metals and machine learning is essential for achieving environmental sustainability [23]. Moreover, innovations in scheduling methods aim to minimize energy consumption in manufacturing while maintaining productivity [31].

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Carbon emission efficiency (CEE) is a key metric evaluating the reduction of carbon emissions relative to industrial output, informing corporate sustainability strategies. It is pivotal for understanding the environmental implications of digital transformations and the role of green innovation in linking ESG activities with corporate sustainability [1]. The environmental impact of digital technologies, especially convolutional neural networks (CNNs), highlights the need to address energy consumption and carbon emissions [32].

Corporate sustainability involves balancing financial performance with social and environmental responsibilities, a challenge amplified by digital technology-driven transformations in entrepreneurship and innovation [24]. This balance is particularly crucial in sectors where water consumption, alongside energy use and CO2 emissions, significantly impacts environmental sustainability [25].

Environmental impact refers to the effects of organizational activities on the natural environment, including resource consumption, waste generation, and emissions. Digital leadership and technological innovation are vital in mitigating these impacts, particularly in areas like information retrieval models, where energy and water consumption are considerable [25].

Green technology, or eco-friendly technology, involves developing sustainable solutions that reduce environmental harm. Transitioning from brown to green technologies is crucial for corporate sustainability, with digital leadership playing a key role in advancing renewable energy and decarbonization initiatives [22].

The intricate interconnections among digital leadership, technology innovation, and corporate sustainability underscore their collective impact on enhancing carbon emission efficiency. Digital leadership facilitates the adoption of advanced technologies, driving innovative practices that improve sustainability outcomes. This synergy enables organizations to navigate digital transformation complexities while meeting environmental, social, and governance (ESG) standards, fostering a sustainable corporate framework [6, 2, 1, 5, 4]. By integrating digital and green technologies, organizations can mitigate environmental impacts while enhancing resilience and competitiveness in a rapidly evolving market. This integrated approach fosters a culture of innovation and sustainability, empowering organizations to effectively address environmental challenges and contribute to a sustainable future.

In examining the multifaceted role of digital leadership in corporate sustainability, it is crucial to understand the underlying structures that facilitate effective organizational change. As illustrated in Figure 2, the hierarchical structure of digital leadership encompasses various elements that influence this transition. This figure details not only the necessary skills and strategies required for successful implementation but also the challenges and opportunities that organizations may encounter. Furthermore, it highlights the technological advancements and industry applications that are essential for embedding sustainability into core business strategies, thereby providing a comprehensive framework for understanding the dynamics at play in contemporary corporate environments.

3 Digital Leadership in Corporate Sustainability

3.1 Influence of Digital Leadership on Organizational Change

Digital leadership is essential for guiding organizations towards sustainable practices by strategically employing advanced technologies and fostering an environmentally conscious culture. For instance, Conditional Variational Autoencoders (CVAEs) have been pivotal in developing eco-friendly concrete, aligning construction with sustainability goals [17]. In human resource management, Green HRM practices enhance organizational citizenship behavior towards the environment (OCBE), boosting environmental performance in academic settings [33].

The adoption of energy-efficient technologies like 5G drives organizational change towards sustainability, particularly in communication systems [34]. The environmental impact of user behavior in video streaming highlights the need for digital leaders to promote sustainable media consumption [18]. Additionally, transfer learning models in waste management improve waste classification, advancing organizational sustainability [35].

Digital leaders are instrumental in integrating eco-innovation with service innovation capabilities, crucial for sustainable business outcomes [36]. Overcoming challenges in leveraging digital technologies is vital for fostering sustainable practices [20]. For example, reconfigurable hardware accelerators that

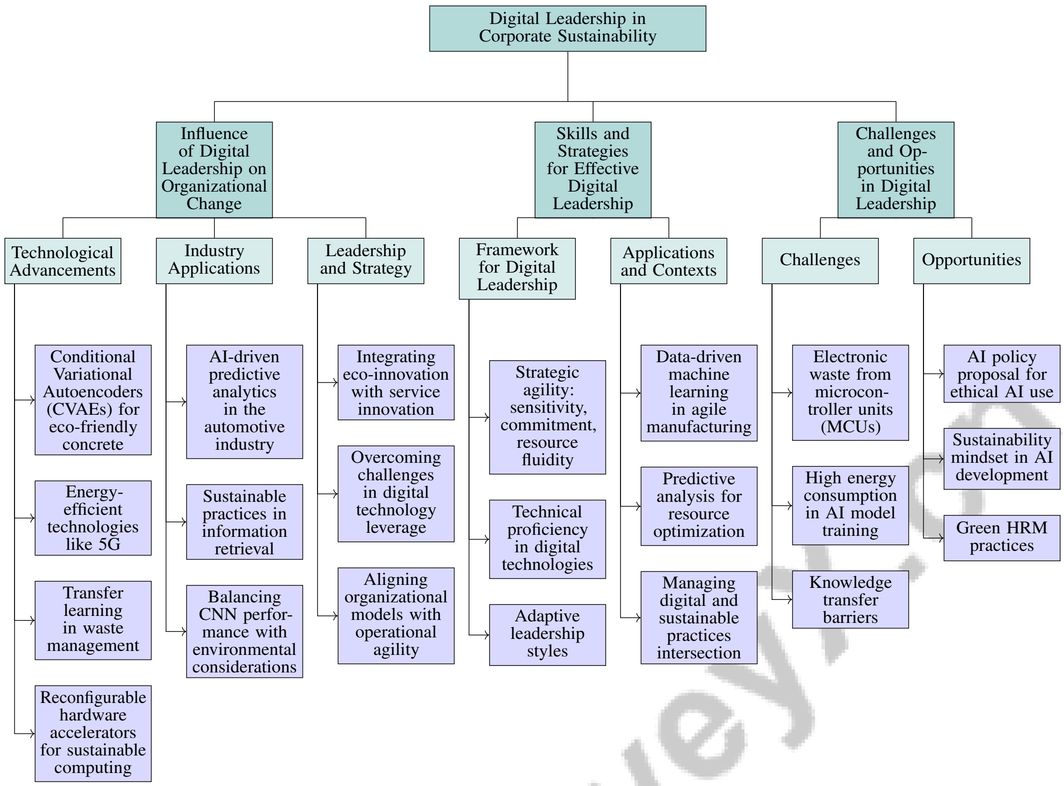

Figure 2: This figure illustrates the hierarchical structure of digital leadership in corporate sustainability, detailing the influence on organizational change, necessary skills and strategies, and the challenges and opportunities faced. It highlights the technological advancements, industry applications, and strategic frameworks essential for embedding sustainability into core business strategies.

adapt to renewable energy fluctuations enhance data center Quality of Service, promoting sustainable computing [21].

In the automotive industry, AI-driven predictive analytics optimize electric vehicle (EV) manufacturing and improve cybersecurity, reducing energy consumption and carbon footprints [22]. However, a gap between digital entrepreneurship and innovation research limits understanding of digital technologies' impact on traditional processes [24].

Moreover, sustainable practices in information retrieval significantly affect water consumption, underscoring the need for sustainable AI approaches [25]. Promoting sustainability in deep learning, particularly in balancing CNN performance with environmental considerations, further exemplifies digital leadership's impact on organizational change [32].

These initiatives underscore digital leadership's role in embedding sustainability into core business strategies and facilitating organizational transformation to address environmental challenges and achieve long-term sustainability goals. This transformation involves aligning organizational models with operational agility and leveraging digital technologies like AI to enhance corporate sustainability practices. Effective digital leadership navigates digital transformation complexities, securing top management's commitment to integrating sustainability into strategic vision, enabling organizations to adapt and thrive in rapidly changing environments [6, 1, 5, 37, 4].

3.2 Skills and Strategies for Effective Digital Leadership

Promoting sustainable practices through effective digital leadership requires a framework encompassing strategic agility, technical proficiency, and adaptive leadership styles. As illustrated in Figure 3, these core components of effective digital leadership are supported by insights from key literature. Strategic agility, as outlined by [38], involves strategic sensitivity, collective commitment, and resource fluidity. These meta-capabilities enable leaders to navigate digital transformation complexities and promote sustainability. Strategic sensitivity allows leaders to anticipate and respond to external changes, while collective commitment ensures organizational alignment and engagement. Resource fluidity supports dynamic resource allocation for sustainability initiatives.

Technical proficiency in digital technologies is crucial for digital leaders. A robust understanding of data-driven machine learning methods is essential for informed decision-making, particularly in agile manufacturing contexts [23]. This includes using predictive analysis to optimize resource use and minimize environmental impact, aligning manufacturing processes with sustainability objectives.

Adaptive leadership styles are vital for fostering innovation and sustainability within organizations. The framework proposed by [24] categorizes research into digital entrepreneurship and innovation, highlighting digital technologies' unique characteristics. This framework equips leaders to tailor approaches to specific sustainability goals, effectively managing the intersection of digital and sustainable practices.

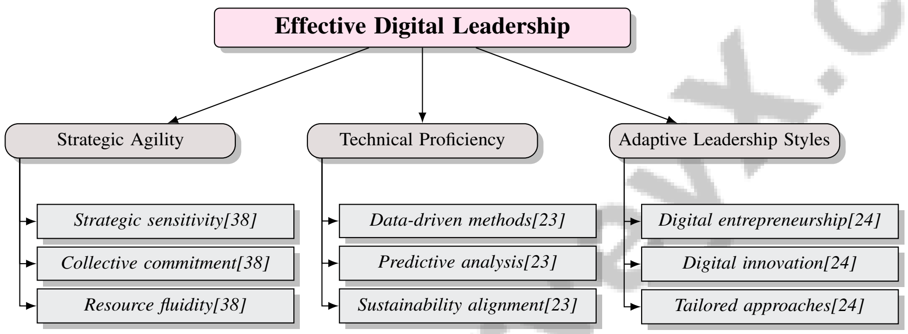

Figure 3: This figure illustrates the core components of effective digital leadership, highlighting strategic agility, technical proficiency, and adaptive leadership styles, supported by insights from key literature.

3.3 Challenges and Opportunities in Digital Leadership

Digital leadership in sustainability presents numerous challenges and opportunities, requiring a nuanced understanding of technological advancements and organizational dynamics. A significant challenge is the growing electronic waste from microcontroller units (MCUs), necessitating comprehensive data on their environmental impact [39]. High energy consumption associated with AI model training and deployment complicates regulatory compliance, highlighting the need for sustainable AI practices [29].

Research emphasizes flexibility, technology adoption, and evolving leadership roles in the digital era as crucial for navigating digital transformation complexities [16]. However, digital leaders face uneven research coverage and knowledge transfer barriers, posing significant obstacles to sustainability [20]. Additionally, digitization's adverse effects, such as role conflict and stress among entrepreneurs, are often overlooked, presenting further challenges for digital leadership [24].

Opportunities for digital leadership arise from structured frameworks like the AI policy proposal, advocating ethical and responsible AI technology use [40]. A sustainability mindset in AI development is crucial, emphasizing operational and embodied carbon footprint optimization [41].

Green HRM practices offer another opportunity, positively influencing organizational citizenship behavior towards the environment (OCBE) and enhancing environmental performance in academic institutions [33]. Improving computational efficiency in AI models for intrusion detection, focusing on programming languages and feature selection methods, presents a significant opportunity for advancing sustainability in digital practices [19].

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4 Innovation in Digital Technology for Environmental Impact

4.1 Technological Innovations and Their Impact

Technological innovations play a pivotal role in enhancing carbon emission efficiency and fostering sustainable practices across diverse sectors. Transfer learning models, assessed through computational carbon emission metrics, exemplify their efficacy in boosting carbon efficiency [35]. A comprehensive framework categorizes digital innovation into seven dimensions, illustrating how these advancements significantly enhance carbon emission efficiency [20].

In 3D printing, innovations such as Active Rheology Control (ARC) and Active Stiffening Control (AsC) facilitate real-time adjustments that optimize material usage and minimize emissions [42]. The Amoeba method, a reconfigurable hardware accelerator, reduces carbon emissions while improving computing tasks in data centers, thereby supporting sustainable computing [21].

Green 5G technologies expand spectrum availability and improve spatial degrees of freedom, contributing to enhanced carbon emission efficiency [34]. The Machine Learning Emissions Calculator estimates carbon emissions from ML model training, promoting best practices to mitigate environmental impacts [30].

In the automotive sector, research on Electric and Hybrid Vehicles (EHVs) focuses on manufacturing optimization, cybersecurity, and AI applications, including quantum AI, to enhance performance and sustainability [22]. A survey comparing ML models' carbon footprints reveals significant variability based on architecture and training methods, highlighting the need for sustainable AI practices [41].

Advancements in cooling technologies are essential to address data centers' environmental impact, reducing water consumption and improving outcomes [25]. A standardized evaluation framework integrating energy consumption metrics with traditional performance indicators underscores the environmental consequences of technological innovations, advocating for balanced development [32].

These innovations collectively demonstrate the transformative potential of advanced methodologies in achieving carbon emission efficiency and promoting sustainable development. By adopting green innovations, such as eco-friendly technologies and sustainable supply chain practices, organizations can significantly reduce energy consumption and pollution while enhancing competitive advantage and economic performance. Integrating corporate environmental ethics and leveraging large-scale data further propels these initiatives, establishing green innovation as a vital element of long-term sustainable growth [1, 43, 44].

4.2 AI and Machine Learning for Environmental Impact

AI and machine learning are critical in mitigating environmental impacts and advancing sustainability across sectors. Super-linear growth trends in AI computing reveal a significant carbon footprint throughout the AI lifecycle, emphasizing the need for sustainable practices addressing environmental and regulatory challenges [41, 29].

As illustrated in Figure 4, which depicts the hierarchical structure of AI and machine learning's role in environmental impact, these technologies encompass various dimensions, including AI lifecycle sustainability, machine learning applications, and corporate sustainability efforts. Machine learning enhances resource efficiency and reduces greenhouse gas emissions, vital for achieving sustainable development goals. By employing advanced algorithms and data analysis, it optimizes operations across sectors, enabling businesses to minimize environmental footprints while maintaining economic viability. This advancement aids compliance with sustainability regulations and helps companies adapt to climate change challenges [45, 43, 46, 47]. ML-driven power dispatch models focus on reducing energy consumption and carbon footprints, significantly impacting environmental sustainability. AI enhances decision-making in sustainable manufacturing, promoting eco-friendly practices and resource efficiency.

The environmental implications of AI systems, particularly their substantial energy consumption and associated carbon and water footprints, necessitate thorough assessments of both dynamic and static energy usage throughout their lifecycle. Monitoring AI technologies' environmental impact is essential for informing policymakers and stakeholders about sustainable practices aimed at mitigating ecological effects [26, 25, 48, 41, 47]. Current tools often neglect static emissions during deployment, limiting environmental evaluations. Innovations in AI, such as incorporating energy awareness into the training loop, facilitate real-time adjustments based on energy metrics, promoting sustainable AI practices.

AI's application in enhancing wind forecasts illustrates its potential to optimize operational efficiency and reduce environmental impacts in sectors like aviation. Future research should explore innovative strategies, such as eco-friendly conferencing, to leverage AI's capabilities in achieving sustainability goals. These advancements highlight AI and machine learning's significant role in enhancing sustainability efforts by minimizing environmental impacts—through optimizing hardware-software design to reduce AI computing's carbon footprint—and enabling innovative approaches to assess corporate sustainability practices, exemplified by using Natural Language Processing to analyze extensive datasets of news articles for insights on companies' eco-friendly initiatives [41, 43].

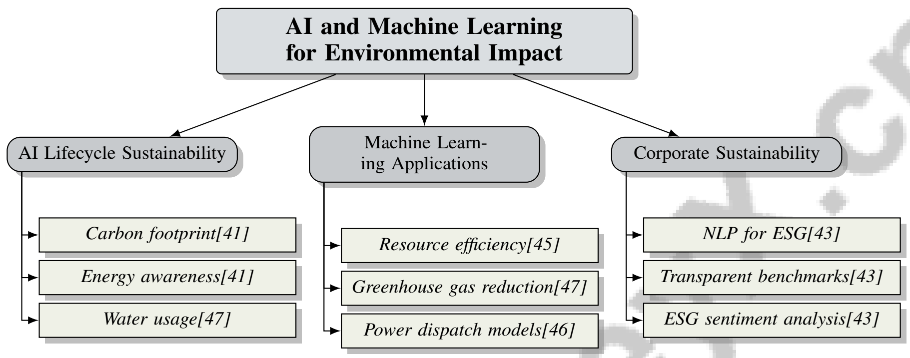

Figure 4: This figure illustrates the hierarchical structure of AI and Machine Learning's role in environmental impact, highlighting AI lifecycle sustainability, machine learning applications, and corporate sustainability efforts.

4.3 Digital Tools for Environmental Monitoring and Assessment

Digital tools are essential for monitoring and assessing environmental impacts, providing organizations with data necessary to drive sustainable practices. Advanced computing facilities and software solutions enable comprehensive environmental assessments, optimizing energy consumption and reducing carbon footprints across sectors. A benchmarking dataset, incorporating energy consumption data from diverse computing facilities, highlights variations in power usage across hardware components, serving as a foundation for identifying improvement areas [49].

The EnergiBridge project exemplifies the use of digital tools in promoting software sustainability by collecting detailed measurements of CPU and system power consumption [50]. These insights into software operations' environmental impact support developing sustainable computing practices, empowering organizations to make informed decisions about hardware and software configurations, ultimately reducing their environmental footprints.

Moreover, digital tools are critical for organizations aiming to capitalize on digital opportunities while addressing environmental concerns. Semi-structured interviews with executives from 25 companies reveal that strategic organizational changes are often driven by the need to adapt to digital advancements [27]. These changes include adopting digital tools for environmental monitoring, aligning operations with sustainability goals, and enhancing overall environmental performance.

Collectively, these digital tools provide a robust framework for environmental monitoring and assessment, enabling organizations to implement effective sustainability strategies. By leveraging advanced data-driven insights, including Natural Language Processing (NLP) and Large Language Models (LLMs), companies can improve resource efficiency, reduce environmental footprints, and play a significant role in fostering a sustainable future. This approach allows organizations to analyze extensive sustainability reports and news articles, identifying key climate-related information and sentiments that inform decision-making processes and strategies for mitigating climate risks and adapting to changing environmental conditions [45, 43].

5 Carbon Emission Efficiency and Corporate Sustainability

5.1 Strategies for Enhancing Carbon Emission Efficiency

Improving carbon emission efficiency is pivotal for aligning corporate sustainability with environmental goals. A comprehensive approach integrates energy-efficient models and carbon footprint considerations into risk management, optimizing resource use and reducing environmental impact [29]. Benchmarks for deep learning, particularly convolutional neural networks (CNNs), are crucial for developing models that balance computational needs with sustainability [32]. In information retrieval, addressing both water consumption and carbon emission efficiency ensures a holistic sustainability strategy, reflecting a commitment to minimizing environmental footprints while maintaining operational effectiveness [25].

Sustainable AI practices, such as energy-efficient architectures, are vital for reducing emissions and advancing corporate sustainability in line with the United Nations' Sustainable Development Goals. These practices foster innovation in AI technologies, including Explainable Natural Language Processing, enhancing accuracy and transparency in sustainability assessments and supporting informed decision-making [45, 1, 43, 46]. By adopting these strategies, organizations can significantly enhance carbon emission efficiency, ensuring technological progress contributes to a sustainable future.

5.2 Challenges in Measuring and Verifying Carbon Emissions

Benchmark	Size	Domain	Task Format	Metric
EcoVerse[51]	3,023	Ecology	Stance Detection	Accuracy, F1-score
Nano-ESG[43]	51,087	Corporate Sustainability	Sentiment Analysis	Accuracy, F1-score
MLCarbon[52]	1,287	Natural Language Processing	Model Training	CO2 emissions, Energy consumption
FL-Carbon[53]	70,000	Image Classification	Image Classification	CO2 emissions, Accuracy
IRISCAST[49]	19,000	Environmental Impact Assessment	Carbon Emission Quantification	Active Carbon, Embodied Carbon
CEEIE[54]	30	Industrial Energy Consumption	Efficiency Measurement	Gini Coefficient, CEEIE
GAD-ML[55]	308,772	Anomaly Detection	Classification	F1 Macro, CO2 equivalent
SCI[56]	1,000,000	Environmental Impact Assessment	Carbon Intensity Measurement	SCI, gCO2eq/kWh

Table 1: This table presents a comprehensive overview of various benchmarks used in the assessment of carbon emissions and related environmental impacts across different domains. Each benchmark is characterized by its size, domain, task format, and the specific metrics utilized for evaluation, highlighting the diversity in methodologies and focus areas within this field of study.

Accurately measuring and verifying carbon emissions is challenging due to methodological limitations and data availability issues. Variability in power consumption and greenhouse gas emissions across different computing architectures and locations complicates assessments [57]. This complexity is furthered by the spatial distribution of natural resources, which may not be fully captured at local levels, leading to discrepancies in emission assessments [58].

Table 1 provides a detailed overview of representative benchmarks that address the challenges in measuring and verifying carbon emissions, illustrating the diversity of approaches and metrics employed across different domains. A significant challenge is the lack of data transparency from service providers, which hinders accurate assessments of server-side emissions and data processing impacts [59]. Existing methods often prioritize accuracy over energy efficiency, resulting in a scarcity of tools designed to evaluate the energy efficiency of machine learning models [60]. These methods typically rely on static features and overlook dynamic changes in workload and hardware configurations during model training, limiting their scope and accuracy [61].

Moreover, existing benchmarks inadequately consider geographical and energy source variability in carbon emissions, resulting in insufficient insights for emission reduction efforts [30]. Addressing these challenges is crucial for advancing carbon emission measurement and verification, thereby supporting more effective corporate sustainability initiatives.

6 The Role of Green Technology in Sustainable Business Practices

6.1 Development and Implementation of Green Technology

The advancement and integration of green technology are crucial for sustainable business practices, addressing environmental challenges while optimizing resource use. A cultural shift in AI emphasizes energy efficiency, as seen in the development of energy-efficient CNN architectures supporting sustainable AI practices [32]. In manufacturing, adopting low-emission technologies and alternative materials mitigates the environmental impact of solar photovoltaics, with machine learning facilitating sustainable manufacturing by optimizing material choices and processes [62, 23, 1, 63, 9].

Digital transformation, particularly through AI, enhances corporate sustainability by streamlining eco-friendly operations and fostering innovation in the renewable energy sector [44, 2, 64, 1, 43]. Tools like web-based calculators for monitoring water and CO2 emissions exemplify digital integration in sustainability efforts. In data centers, employing reconfigurable hardware and fractional NAND flash technology reduces carbon footprints by extending server lifecycles and incorporating renewable energy sources [65, 66, 67].

Energy harvesting technologies in sustainable 5G networks and advanced NLP techniques in corporate sustainability analysis further highlight the role of green technology in communication systems [45, 43, 46]. Benchmarks for sustainable practices in recommender systems research, and frameworks for assessing the ecological impact of machine learning models, underscore the importance of comprehensive monitoring of AI's environmental effects [35, 47]. These initiatives demonstrate how green technology reshapes sustainable business practices, enhancing competitive advantage and fostering environmental responsibility [1, 44, 2, 36].

6.2 Environmental Impact Assessment of Green Technologies

Environmental impact assessments (EIAs) are essential for evaluating green technologies' effectiveness in promoting sustainability. Blockchain technology, despite its transparency and security benefits, presents environmental challenges due to its energy demands, necessitating efforts to optimize energy consumption [68]. EIAs, integrated with digital tools and data analytics, enable comprehensive evaluation of ecological risks associated with technology deployment, aligning with ESG criteria and supporting sustainable corporate growth [44, 1].

AI-driven digital transformation enhances EIAs' accuracy, informing decisions on green technology implementation and fostering eco-friendly operational processes [1, 2]. These assessments enable monitoring of environmental indicators, providing insights into corporate sustainability performance. As organizations face pressure to adopt eco-friendly practices, EIAs help align operations with sustainability objectives, enhancing efficiency and competitiveness [46, 44, 1, 45, 47].

6.3 Green Technology in AI and Machine Learning

Integrating green technology with AI and machine learning is transformative for enhancing environmental sustainability. The GAISSALabel tool provides a framework for assessing energy efficiency in AI models, allowing customization of metrics according to sustainability goals [60]. Optimizing algorithms and computational architectures is crucial for minimizing AI's environmental impact, especially given the energy demands of large-scale model training [1, 41, 26, 47].

Machine learning supports sustainable solutions across sectors, enhancing renewable energy systems' efficiency and aligning corporate practices with sustainability goals [28, 46, 69, 45, 43]. By prioritizing energy-efficient practices and innovative tools like GAISSALabel, organizations can enhance technological capabilities while minimizing environmental footprints, contributing to a responsible and sustainable future [44, 1, 45, 60, 43].

7 Challenges and Opportunities in Integrating Digital and Green Technologies

Integrating digital and green technologies presents complex challenges and opportunities that organizations must navigate to adopt sustainable practices. Key obstacles include cost and infrastructure barriers that hinder the effective deployment of innovative solutions. This section examines these challenges, particularly concerning digital operations, communication systems, and the automotive industry, while exploring the complexities of integrating these technologies.

7.1 Cost and Infrastructure Barriers

Cost and infrastructure barriers significantly hinder the widespread adoption of digital and green technologies. A major concern is the high energy consumption of digital operations, especially in data centers. Integrating technologies like the Amoeba method into existing infrastructures is complicated by the need for reconfigurable hardware accelerators that can adapt to fluctuating energy demands while minimizing carbon emissions [21]. Additionally, the often-overlooked water consumption in data centers necessitates comprehensive assessments and infrastructure adjustments to mitigate environmental impacts [25].

In communication systems, integrating energy harvesting technologies into 5G networks involves substantial cost and infrastructure challenges, requiring significant modifications to accommodate the expanded spectrum and enhanced spatial capabilities of green technologies [34]. These modifications entail considerable investments and policy interventions to transition to sustainable communication infrastructures.

The automotive sector faces similar hurdles in adopting green technologies, particularly in electric vehicle (EV) manufacturing. High energy consumption and material use, coupled with data privacy concerns and cybersecurity threats, complicate efforts toward sustainability [22]. These challenges highlight the need for robust cybersecurity measures and innovative manufacturing techniques that reduce energy and material consumption.

Moreover, existing benchmarks often inadequately address energy consumption and carbon emissions, creating additional barriers to integrating sustainable practices, particularly in recommender systems research [70]. This underscores the necessity for comprehensive benchmarking frameworks that incorporate environmental considerations, facilitating the adoption of sustainable digital technologies.

Overcoming these cost and infrastructure barriers is crucial for successfully integrating digital and green technologies, as they enhance operational efficiency and environmental sustainability while contributing to financial performance and corporate competitiveness in a digital economy. Addressing these challenges enables organizations to leverage innovative solutions, such as smart grids and green technology innovations, essential for adapting to market demands and achieving long-term growth [71, 44, 2, 1, 27]. By addressing these challenges, organizations can utilize technological advancements to enhance sustainability and foster a more environmentally responsible future.

7.2 Cultural and Organizational Resistance

Cultural and organizational resistance significantly challenges the adoption of new technologies, particularly in environmental sustainability initiatives. Such resistance often stems from entrenched practices that prioritize traditional methods over innovative solutions. For example, the adoption of simplified methods like EcoDiag for assessing environmental impacts can be obstructed by organizational reluctance to abandon established protocols [72], thereby limiting the effectiveness of environmental assessments and slowing the transition to sustainable practices.

In the aviation sector, cultural resistance to advanced technologies, such as machine learning for flight optimization, exemplifies barriers to reducing environmental impact. Despite their potential to enhance fuel efficiency and lower carbon emissions, organizational inertia and skepticism about new methodologies can hinder implementation [73]. This reluctance often arises from a preference for familiar processes and a lack of awareness regarding the benefits of innovative technologies.

To address cultural and organizational resistance, a strategic approach is necessary, encompassing change management initiatives, education, and stakeholder engagement. Cultivating an organizational culture that prioritizes innovation and sustainability can effectively reduce resistance to change and enhance the adoption of technologies aligned with environmental objectives. This approach not only fosters green innovation—through eco-friendly products and processes—but also leverages management commitment and human resource practices to tackle technological challenges. Furthermore, integrating service innovation capability can mediate the relationship between sustainable performance and environmental innovation, ultimately leading to improved competitive advantage and long-term business sustainability. Companies that embrace these practices are better positioned to navigate environmental stewardship pressures while achieving economic and competitive gains [1, 44, 36]. Encouraging open dialogue and providing training on the benefits and applications of new technologies can further ease the transition towards a sustainable future.

7.3 Technological and Methodological Limitations

The integration of digital and green technologies is hindered by technological and methodological limitations that challenge sustainability goals. A critical technological challenge is the reliance on accurate carbon intensity predictions, as demonstrated by the CarbonClipper approach, which reveals difficulties in effectively integrating these technologies due to potential inaccuracies in carbon data [74]. Additionally, the complexity of model construction, highlighted by the use of colored Petri nets in green supply chains, underscores the need for precise data and robust modeling techniques for successful integration [75].

Methodological limitations also arise from the current state of research in digital technologies. The absence of a clear framework for measuring energy consumption during machine learning training leads to an inadequate understanding of the overall energy footprint, resulting in inefficient resource utilization [76]. Furthermore, variability in tool accuracy for estimating the carbon footprint of AI models complicates researchers' ability to assess environmental impacts accurately [77].

In natural language processing (NLP), technological limitations include biases in AI models and the necessity for comprehensive peer review, which are critical for ensuring the reliability of sustainability analyses [46]. The potential for a failed green transition, despite the profitability of green technologies, is exacerbated by adjustment costs and transition risks, emphasizing the need for strategic planning and risk management [78].

The scalability of multi-objective optimization frameworks, such as MOSAIC, poses another challenge. As workloads and data centers increase in complexity, integrating sustainable practices becomes increasingly difficult [79]. Moreover, adapting machine learning models to various industrial contexts while ensuring robustness across applications remains a significant hurdle [23].

The technological and methodological limitations highlighted in current research underscore the urgent need for ongoing research and development efforts to effectively tackle the challenges of integrating digital and green technologies. This integration is vital for organizations aiming to adapt their business models to the digital age while contributing to sustainable development through eco-innovation in areas such as renewable energy and decarbonization. Furthermore, the uneven coverage of research streams and the need for a cohesive understanding of digital leadership and organizational change emphasize the importance of a strategic approach to overcoming these barriers [27, 80, 20, 6]. By addressing these challenges, organizations can better leverage technological advancements to achieve sustainability objectives and foster a more environmentally responsible future.

7.4 Opportunities for Innovation and Collaboration

The integration of digital and green technologies presents abundant opportunities for innovation and collaboration, offering pathways to address existing challenges and enhance sustainability efforts. A promising area is the development of energy-efficient machine learning models, crucial for minimizing the carbon footprint of AI technologies [52].

Sustainable assortment planning also provides opportunities for collaboration between retailers and sustainability advocates. By incorporating sustainability metrics, retailers can align their product offerings with environmental objectives, fostering partnerships that promote eco-friendly practices [81]. This approach not only enhances sustainability but also strengthens relationships with stakeholders committed to environmental stewardship.

Future research should explore AI strategy documents, conduct context analyses, and broaden studies to encompass a wider range of countries. Such efforts can yield a comprehensive understanding of how AI aligns with Sustainable Development Goals (SDGs) and inform strategies for international collaboration [82]. Additionally, investigating end-of-life frameworks in physicalization can reveal emerging trends and foster collaboration among practitioners, further advancing sustainability initiatives [83].

AI-generated, for reference only.

Establishing standard methodologies for measuring energy consumption and clearer reporting obligations is essential for operationalizing AI climate transparency. Developing these standards can facilitate broader policy changes and encourage collaborative efforts to mitigate AI's environmental impact [84]. Moreover, representative studies on user behavior in video streaming can enhance understanding of sustainable streaming practices and inform strategies to promote eco-friendly user choices [18].

By leveraging these opportunities for innovation and collaboration, stakeholders can effectively address integration challenges and drive progress towards a more sustainable future. These initiatives not only advance technological innovation but also reinforce a shared commitment to environmental stewardship and sustainable development, highlighting the critical role of ESG (Environmental, Social, and Governance) principles and AI-driven digital transformation in fostering corporate sustainability. Utilizing extensive datasets and advanced analytical techniques, these efforts aim to enhance transparency in corporate sustainability practices, tackle societal challenges, and prepare future software engineering professionals to integrate sustainability into their work, ultimately contributing to a more resilient and eco-friendly economy [1, 43, 64].

8 Conclusion

8.1 Future Directions and Implications for Business Practices

Research in the coming years should prioritize the creation of hybrid energy solutions and the efficient allocation of resources in energy harvesting systems to bolster the sustainability of 5G networks. It is crucial to refine emissions calculators and assess the environmental impact of deploying machine learning models to promote sustainable AI practices. Establishing comprehensive guidelines for sustainable machine learning will help mitigate the environmental impact of AI technologies.

In the realm of electric vehicles, the focus should be on developing robust AI models capable of managing diverse datasets and exploring the potential of quantum AI applications. Addressing existing methodological gaps will enhance the sustainability and efficiency of electric vehicle production and operation. Furthermore, advancements in computer vision models can improve accuracy and efficiency in sustainable practices, especially within agile manufacturing contexts.

Understanding the negative implications of digital technologies is essential for addressing potential inequalities. Future studies should aim to inform policies that mitigate adverse effects while fostering equitable digital transformation. Developing efficient algorithms and architectures to reduce both operational and embodied carbon costs, along with establishing standardized sustainability metrics for AI, are critical areas of focus.

Improving water consumption estimates and developing real-time monitoring tools for environmental impact assessments are vital for advancing sustainability metrics in digital practices. Additionally, refining carbon accounting tools and methodologies in AI will help reduce its environmental impact, supporting more sustainable business practices.

Expanding benchmarks to include diverse datasets and tasks will provide valuable insights for businesses seeking to adopt sustainable AI development practices. Investigating alternative moderating variables and developing methodologies to better understand the interplay between ESG, digital transformation, and corporate sustainability will offer new perspectives for integrating sustainability into corporate strategies. By concentrating on these areas, future research can significantly advance sustainable business practices, driving progress toward an environmentally responsible digital era.

References

[1] Chenglin Qing and Shanyue Jin. Does esg and digital transformation affects corporate sustainability? the moderating role of green innovation, 2023.

[2] Yangjun Ren and Botang Li. Digital transformation, green technology innovation and enterprise financial performance: Empirical evidence from the textual analysis of the annual reports of listed renewable energy enterprises in china. *Sustainability*, 15(1):712, 2022.

[3] Xin Huang, Shuiping Zhang, Jin Zhang, and Kun Yang. Research on the impact of digital economy on regional green technology innovation: Moderating effect of digital talent aggregation. *Environmental Science and Pollution Research*, 30(29):74409–74425, 2023.

[4] Bora Ly. The interplay of digital transformational leadership, organizational agility, and digital transformation. *Journal of the Knowledge Economy*, 15(1):4408–4427, 2024.

[5] Birgit Oberer and Alptekin Erkollar. Leadership 4.0: Digital leaders in the age of industry 4.0. *International journal of organizational leadership*, 7(4):404–412, 2018.

[6] Raluca A. Stana, Louise Harder Fischer, and Hanne Westh Nicolajsen. Review for future research in digital leadership, 2024.

[7] Jan-David Stütz, Oliver Karras, Allard Oelen, and Sören Auer. A next-generation digital procurement workspace focusing on information integration, automation, analytics, and sustainability, 2023.

[8] I. B. Wadhawan and M. M. Rizvi. Optimizing inventory management through multiobjective reverse logistics with environmental impact, 2024.

[9] Maurizio Clemente, Luuk van Sundert, Mauro Salazar, and Theo Hofman. A framework to estimate life cycle emissions for vehicle-integrated photovoltaic systems, 2024.

[10] Rossana Mastrandrea, Rob ter Burg, Yuli Shan, Klaus Hubacek, and Franco Ruzzenenti. Scaling laws in global corporations as a benchmarking approach to assess environmental performance, 2023.

[11] Caterina Morelli, Simone Boccaletti, Paolo Maranzano, and Philipp Otto. Multidimensional spatiotemporal clustering – an application to environmental sustainability scores in europe, 2024.

[12] Günter K Stahl, Chris J Brewster, David G Collings, and Aida Hajro. Enhancing the role of human resource management in corporate sustainability and social responsibility: A multi-stakeholder, multidimensional approach to hrm. *Human resource management review*, 30(3):100708, 2020.

[13] Baridhi Malakar. Essays on responsible and sustainable finance, 2024.

[14] Tina Vartziotis, Ippolyti Dellatolas, George Dasoulas, Maximilian Schmidt, Florian Schneider, Tim Hoffmann, Sotirios Kotsopoulos, and Michael Keckeisen. Learn to code sustainably: An empirical study on llm-based green code generation, 2024.

[15] Md Saiful Islam, Adiba Mahbub, Caleb Wohn, Karen Berger, Serena Uong, Varun Kumar, Katrina Smith Korfmacher, and Ehsan Hoque. Seer: Sustainable e-commerce with environmental-impact rating, 2022.

[16] Tanja Schwarzmüller, Prisca Brosi, Denis Duman, and Isabell M Welpe. How does the digital transformation affect organizations? key themes of change in work design and leadership. *Management Revue*, 29(2):114–138, 2018.

[17] Xiou Ge, Richard T. Goodwin, Jeremy R. Gregory, Randolph E. Kirchain, Joana Maria, and Lav R. Varshney. Accelerated discovery of sustainable building materials, 2019.

[18] Paul Suski, Johanna Pohl, and Vivian Frick. All you can stream: Investigating the role of user behavior for greenhouse gas intensity of video streaming, 2020.

[19] Pedro Pereira, Paulo Mendes, João Vitorino, Eva Maia, and Isabel Praça. Intelligent green efficiency for intrusion detection, 2024.

[20] Rajiv Kohli and Nigel P Melville. Digital innovation: A review and synthesis. *Information Systems Journal*, 29(1):200–223, 2019.

[21] Fan Chen. System support for environmentally sustainable computing in data centers, 2024.

[22] Ishan Shivansh Bangroo. Ai-based predictive analytic approaches for safeguarding the future of electric/hybrid vehicles, 2023.

[23] Aparna S. Varde and Jianyu Liang. Machine learning approaches in agile manufacturing with recycled materials for sustainability, 2023.

[24] Elisabeth SC Berger, Frederik Von Briel, Per Davidsson, and Andreas Kuckertz. Digital or not–the future of entrepreneurship and innovation: Introduction to the special issue, 2021.

[25] Guido Zuccon, Harrisen Scells, and Shengyao Zhuang. Beyond co2 emissions: The overlooked impact of water consumption of information retrieval models, 2023.

[26] Thomas Le Goff. Recommendations for public action towards sustainable generative ai systems, 2024.

[27] Ina M Sebastian, Jeanne W Ross, Cynthia Beath, Martin Mocker, Kate G Moloney, and Nils O Fonstad. How big old companies navigate digital transformation. In *Strategic information management*, pages 133–150. Routledge, 2020.

[28] Marc J Epstein. *Making sustainability work: Best practices in managing and measuring corporate social, environmental and economic impacts*. Routledge, 2018.

[29] Nataliya Tkachenko. Integrating ai's carbon footprint into risk management frameworks: Strategies and tools for sustainable compliance in banking sector, 2024.

[30] Alexandre Lacoste, Alexandra Luccioni, Victor Schmidt, and Thomas Dandres. Quantifying the carbon emissions of machine learning, 2019.

[31] Ahmed Missaoui, Cemalettin Ozturk, Barry O'Sullivan, and Michele Garraffa. Energy efficient manufacturing scheduling: A systematic literature review, 2023.

[32] Ahmed Badar, Arnav Varma, Adrian Staniec, Mahmoud Gamal, Omar Magdy, Haris Iqbal, Elahe Arani, and Bahram Zonooz. Highlighting the importance of reducing research bias and carbon emissions in cnns, 2021.

[33] Nosheen Anwar, Nik Hasnaa Nik Mahmood, Mohd Yusoff Yusliza, T Ramayah, Juhari Noor Faezah, and Waqas Khalid. Green human resource management for organisational citizenship behaviour towards the environment and environmental performance on a university campus. *Journal of cleaner production*, 256:120401, 2020.

[34] Qingqing Wu, Geoffrey Ye Li, Wen Chen, Derrick Wing Kwan Ng, and Robert Schober. An overview of sustainable green 5g networks. *IEEE wireless communications*, 24(4):72–80, 2017.

[35] Suman Kunwar. Managing household waste through transfer learning, 2024.

[36] Yudi Fernando, Charbel Jose Chiappetta Jabbour, and Wen-Xin Wah. Pursuing green growth in technology firms through the connections between environmental innovation and sustainable business performance: does service capability matter? *Resources, conservation and recycling*, 141:8–20, 2019.

[37] Hera Antonopoulou, Constantinos Halkiopoulos, Olympia Barlou, and Grigorios N Beligiannis. Leadership types and digital leadership in higher education: Behavioural data analysis from university of patras in greece. *International Journal of Learning, Teaching and Educational Research*, 19(4):110–129, 2020.

[38] Sarah Birrell Ivory and Simon Bentley Brooks. Managing corporate sustainability with a paradoxical lens: Lessons from strategic agility. *Journal of business ethics*, 148:347–361, 2018.

[39] Shvetank Prakash, Matthew Stewart, Colby Banbury, Mark Mazumder, Pete Warden, Brian Plancher, and Vijay Janapa Reddi. Is tinyml sustainable? assessing the environmental impacts of machine learning on microcontrollers, 2023.

[40] William Franz Lamberti. Artificial intelligence policy framework for institutions, 2024.

[41] Carole-Jean Wu, Ramya Raghavendra, Udit Gupta, Bilge Acun, Newsha Ardalani, Kiwan Maeng, Gloria Chang, Fiona Aga Behram, James Huang, Charles Bai, Michael Gschwind, Anurag Gupta, Myle Ott, Anastasia Melnikov, Salvatore Candido, David Brooks, Geeta Chauhan, Benjamin Lee, Hsien-Hsin S. Lee, Bugra Akyildiz, Maximilian Balandat, Joe Spisak, Ravi Jain, Mike Rabbat, and Kim Hazelwood. Sustainable ai: Environmental implications, challenges and opportunities, 2022.

[42] Geert De Schutter, Karel Lesage, Viktor Mechtcherine, Venkatesh Naidu Nerella, Guillaume Habert, and Isolda Agusti-Juan. Vision of 3d printing with concrete—technical, economic and environmental potentials. *Cement and Concrete Research*, 112:25–36, 2018.

[43] Fabian Billert and Stefan Conrad. Nano-esg: Extracting corporate sustainability information from news articles, 2024.

[44] Contents lists available at scie.

[45] Alexandra Luccioni, Emily Baylor, and Nicolas Duchene. Analyzing sustainability reports using natural language processing, 2020.

[46] Keane Ong, Rui Mao, Ranjan Satapathy, Ricardo Shirota Filho, Erik Cambria, Johan Sulaeman, and Gianmarco Mengaldo. Explainable natural language processing for corporate sustainability analysis, 2024.

[47] Srija Chakraborty. Towards a comprehensive assessment of ai's environmental impact, 2024.

[48] Pengfei Li, Jianyi Yang, Adam Wierman, and Shaolei Ren. Towards environmentally equitable ai via geographical load balancing, 2024.

[49] Adrian Jackson, Jon Hays, Alex Owen, Nicholas Walton, Alison Packer, and Anish Mudaraddi. Evaluating total environmental impact for a computing infrastructure, 2023.

[50] June Sallou, Luís Cruz, and Thomas Durieux. Energibridge: Empowering software sustainability through cross-platform energy measurement, 2023.

[51] Francesca Grasso, Stefano Locci, Giovanni Siragusa, and Luigi Di Caro. Ecoverse: An annotated twitter dataset for eco-relevance classification, environmental impact analysis, and stance detection, 2024.

[52] David Patterson, Joseph Gonzalez, Quoc Le, Chen Liang, Lluis-Miquel Munguia, Daniel Rothchild, David So, Maud Texier, and Jeff Dean. Carbon emissions and large neural network training, 2021.

[53] Xinchi Qiu, Titouan Parcollet, Daniel J. Beutel, Taner Topal, Akhil Mathur, and Nicholas D. Lane. Can federated learning save the planet?, 2021.

[54] scientific reports.

[55] Álvaro Huertas-García, Carlos Martí-González, Rubén García Maezo, and Alejandro Echeverría Rey. A comparative study of machine learning algorithms for anomaly detection in industrial environments: Performance and environmental impact, 2023.

[56] Jesse Dodge, Taylor Prewitt, Remi Tachet Des Combes, Erika Odmark, Roy Schwartz, Emma Strubell, Alexandra Sasha Luccioni, Noah A. Smith, Nicole DeCario, and Will Buchanan. Measuring the carbon intensity of ai in cloud instances, 2022.

[57] Loïc Lannelongue, Jason Grealey, and Michael Inouye. Green algorithms: Quantifying the carbon footprint of computation, 2020.

[58] Keying Wang, Meng Wu, Yongping Sun, Xunpeng Shi, Ao Sun, and Ping Zhang. Resource abundance, industrial structure, and regional carbon emissions efficiency in china. *Resources Policy*, 60:203–214, 2019.

[59] Jason Kayembe, Iness Ben Guirat, and Jan Tobias Muehlberg. Exploring privacy and security as drivers for environmental sustainability in cloud-based office solutions (extended abstract), 2024.

[60] Pau Duran, Joel Castaño, Cristina Gómez, and Silverio Martínez-Fernández. Gaissalabel: A tool for energy labeling of ml models, 2024.

[61] Zhaojian Yu, Yinghao Wu, Zhuotao Deng, Yansong Tang, and Xiao-Ping Zhang. Opencarboneval: A unified carbon emission estimation framework in large-scale ai models, 2024.

[62] Satish Vitta. Environmental impact of terwatt scale si-photovoltaics, 2021.

[63] Ajay Chatterjee and Srikanth Ranganathan. Representation learning of complex assemblies, an effort to improve corporate scope 3 emissions calculation, 2024.

[64] Damiano Torre, Giuseppe Procaccianti, Davide Fucci, Sonja Lutovac, and Giuseppe Scanniello. On the presence of green and sustainable software engineering in higher education curricula, 2017.

[65] Justin Gould. A framework for auditing data center energy usage and mitigating environmental footprint, 2021.

[66] Udit Gupta, Young Geun Kim, Sylvia Lee, Jordan Tse, Hsien-Hsin S. Lee, Gu-Yeon Wei, David Brooks, and Carole-Jean Wu. Chasing carbon: The elusive environmental footprint of computing, 2020.

[67] Shixin Ji, Zhuoping Yang, Alex K. Jones, and Peipei Zhou. Advancing environmental sustainability in data centers by proposing carbon depreciation models, 2024.

[68] Sadiq Jaffer, Michael Dales, Patrick Ferris, Thomas Swinfield, Derek Sorensen, Robin Message, Srinivasan Keshav, and Anil Madhavapeddy. Global, robust and comparable digital carbon assets, 2024.

[69] Review article.

[70] Tobias Vente, Lukas Wegmeth, Alan Said, and Joeran Beel. From clicks to carbon: The environmental toll of recommender systems, 2024.

[71] Randal E. Bryant, Randy H. Katz, Chase Hensel, and Erwin P. Gianchandani. From data to knowledge to action: Enabling the smart grid, 2020.

[72] Béatrice Montbroussous, Jonathan Schaeffer, Gabriel Moreau, Francoise Berthoud, and Gabrielle Feltin. Calculate the carbon footprint of your it assets with ecodiag, an ecoinfo service, 2019.

[73] Ashish Kapoor. Helping reduce environmental impact of aviation with machine learning, 2020.

[74] Adam Lechowicz, Nicolas Christianson, Bo Sun, Noman Bashir, Mohammad Hajiesmaili, Adam Wierman, and Prashant Shenoy. Carbonclipper: Optimal algorithms for carbon-aware spatiotemporal workload management, 2024.

[75] Daffa R. Kaiyandra, Farizal F, and Naly Rakoto. Colored petri nets for modeling and simulation of a green supply chain system, 2024.

[76] Daniel Geissler and Paul Lukowicz. Leveraging hybrid intelligence towards sustainable and energy-efficient machine learning, 2024.

[77] Lucia Bouza Heguerte, Aurélie Bugeau, and Loïc Lannelongue. How to estimate carbon footprint when training deep learning models? a guide and review, 2023.

[78] Davide Radi and Frank Westerhoff. The green transition of firms: The role of evolutionary competition, adjustment costs, transition risk, and green technology progress, 2024.

[79] Sirui Qi, Dejan Milojicic, Cullen Bash, and Sudeep Pasricha. Mosaic: A multi-objective optimization framework for sustainable datacenter management, 2023.

[80] Regina Tuganova, Anna Permyakova, Anna Kuznetsova, Karina Rakhmanova, Natalia Monzul, Roman Uvarov, Elizaveta Kovtun, and Semen Budennyy. Relationships between patenting trends and research activity for green energy technologies, 2022.

[81] Nupur Aggarwal, Abhishek Bansal, Kushagra Manglik, Kedar Kulkarni, and Vikas Raykar. Hyper-local sustainable assortment planning, 2020.

[82] Andreas Theodorou, Juan Carlos Nieves, and Virginia Dignum. Good ai for good: How ai strategies of the nordic countries address the sustainable development goals, 2022.

[83] Luiz Morais, Georgia Panagiotidou, Sarah Hayes, Tatiana Losev, Rebecca Noonan, and Uta Hinrichs. From exploration to end of life: Unpacking sustainability in physicalization practices, 2024.

[84] Nicolas Alder, Kai Ebert, Ralf Herbrich, and Philipp Hacker. Ai, climate, and transparency: Operationalizing and improving the ai act, 2024.

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