

Review Article

Enabling a Sustainable Digital Transformation

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Abstract: This paper explores the critical intersections between digital transformation and sustainable development, proposing an integrated framework for achieving sustainable digital transformation that combines technological advancement with environmental management. The study begins by defining sustainable digital transformation as an integrated approach that takes into account environmental, economic, and social perspectives. The environmental impacts of digital technologies, including the generation of e-waste, energy consumption, and resource depletion, are examined while identifying opportunities for digital solutions to address environmental challenges. Key strategies to drive sustainable digital transformation are discussed, such as developing energy-efficient technologies, implementing circular economy principles, and promoting green IT practices. The paper also discusses the role of policy frameworks, corporate social responsibility, and multi-stakeholder collaboration in promoting sustainable practices in digital industries. The paper illustrates successful examples of sustainable digital transformation through case studies from various industries, including the use of artificial intelligence to optimize energy consumption, blockchain to increase procurement chain transparency, and the use of the Internet of Things (IoT) to improve resource efficiency. Agriculture and manufacturing. The study concludes with a call to action for policymakers, business leaders, and researchers to prioritize sustainability in digital transformation initiatives, emphasizing the need for a holistic approach to ensure that the digital future is not only technologically advanced but also ecologically sustainable. This paper contributes to the current debate on sustainable development by providing practical insights and promoting collaborative efforts towards a sustainable digital era.

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1. Enabling Sustainable Digital Transformation

Sustainable digital transformation is the process of integrating digital technologies in ways that minimize environmental harm while promoting economic and social sustainability. This approach

emphasizes the intentional design, deployment, and use of digital tools and systems to reduce carbon footprints, increase resource efficiency, and support the Sustainable Development Goals (SDGs). As the world becomes increasingly connected through digital technologies, these advances must be integrated with broader environmental vision and long-term sustainability goals (Berkhout & Hertin, 2004). In doing so, sustainable digital transformation can contribute to a balanced and inclusive digital future that meets the needs of current and future generations.

The impact of digital on the environment is multifaceted, bringing both challenges and opportunities. On the one hand, digital solutions can significantly increase efficiency and reduce waste in everything from energy to transportation. For example, the use of smart grids, cloud computing, and digital platforms can significantly reduce resource consumption and greenhouse gas emissions (European Commission, 2020). However, on the other hand, the production, use, and disposal of digital devices lead to e-waste, energy consumption, and resource depletion. The rapid updating of electronic devices and the increasing demand for data storage and processing power have exacerbated these environmental problems, highlighting the need for a more sustainable approach to digital transformation (Berkhout & Hertin, 2004).

Achieving sustainable digital transformation requires a holistic approach that balances the benefits of digital innovation with its potential environmental costs. This includes designing digital products and systems with sustainability in mind, for example by using energy-saving technologies, promoting a circular economy, and encouraging responsible consumption of digital resources. The European Commission (2020) highlights the importance of adopting eco-design principles and promoting digital literacy to help consumers and businesses make more sustainable choices. In addition, governments and organizations need to implement policies and incentives that support the development and adoption of green digital technologies, ensuring that sustainability is at the heart of digital transformation strategies.

A key aspect of sustainable digital transformation is reducing the carbon footprint of digital industries. Data centers are an integral part of the functioning of the digital economy. They represent one of the largest consumers of electricity in the world and contribute significantly to carbon emissions (International Energy Agency, 2021). To address this issue, efforts are underway to switch to renewable energy sources, improve energy efficiency, and develop innovative cooling technologies to reduce the environmental impact of data centers. In addition, the concept of "green computing" is gaining ground, encouraging the design and use of computers and other digital devices in a way that minimizes their environmental footprint (Berkhout and Hertin, 2004).

Another important aspect of sustainable digital transformation is e-waste management. The disposal of electronic devices is a growing environmental problem, with millions of tonnes of e-waste generated

worldwide each year. Sustainable practices in the digital sphere involve not only reducing the amount of e-waste but also ensuring its proper recycling and disposal. This includes promoting the use of recycled materials in the production of new devices, extending the lifespan of digital products, and establishing efficient e-waste management systems (European Commission, 2020). By addressing the e-waste challenge, sustainable digital transformation can help mitigate the negative environmental impacts associated with the digital economy. Sustainable digital transformation is a complex and multifaceted process that requires a careful balance between technological innovation and environmental responsibility. It involves integrating digital technologies to minimize environmental damage while promoting sustainable economic and social development.

By adopting sustainable practices such as reducing energy consumption, managing e-waste, and designing green digital systems, we can ensure that digital transformation contributes to a more sustainable and equitable future. Successfully implementing a sustainable digital transformation will depend on the collective efforts of governments, businesses, and individuals to prioritize sustainable development in the digital age (Berkhout and Hertin, 2004; European Commission, 2020; International Energy Agency, 2021).

2. Environmental Impacts of Digital Technologies

The environmental footprint of digital technologies is a growing concern in the modern world, as these technologies continue to permeate all aspects of life. While digital innovations have undoubtedly brought numerous benefits, such as increased efficiency, improved communication, and enhanced access to information, they also have significant environmental impacts. These impacts are particularly evident in three key areas: e-waste generation, energy consumption, and resource depletion. Addressing these challenges is crucial to ensuring that the digital transformation is sustainable and does not exacerbate existing environmental issues.

E-waste generation is one of the most pressing environmental challenges associated with digital technologies. The rapid pace of technological advancement and the short lifecycle of digital devices resulted in the generation of massive amounts of electronic waste, or e-waste. According to Forti, Balde, Kuehr, and Bel (2020), global e-waste reached a staggering 53.6 million metric tons in 2019, and this number is expected to continue rising. E-waste contains hazardous materials, such as lead, mercury, and cadmium, which can leach into the environment if not properly managed. Improper disposal of e-waste can lead to soil and water contamination, posing serious risks to both the environment and human health.

The management of e-waste is further complicated by the fact that only a small fraction of it is properly recycled. Forti et al. (2020) estimate that less than 20% of global e-waste is formally recycled, with the remainder often ending up in landfills or being processed in

informal recycling facilities that lack the necessary safeguards to protect workers and the environment. The improper handling of e-waste not only leads to the release of toxic substances but also results in the loss of valuable materials, such as gold, silver, and copper, which could be recovered and reused. Addressing the e-waste problem requires concerted efforts to improve recycling rates, promote the design of longer-lasting products, and reduce the use of hazardous materials in electronic devices.

Energy consumption is another major environmental concern associated with digital technologies. The infrastructure that supports the digital economy, including data centers, servers, and cloud computing, consumes vast amounts of energy. Jones (2018) highlights that data centers alone account for approximately 1% of global electricity consumption, a figure that is expected to rise as the demand for digital services continues to grow. The energy required to power this infrastructure is often sourced from fossil fuels, contributing to higher greenhouse gas emissions and exacerbating climate change. As digital technologies become more pervasive, the need to reduce their energy consumption and transition to renewable energy sources becomes increasingly urgent.

In addition to energy consumption, the efficiency of digital infrastructure is a key factor in its environmental impact. While advances in technology have led to more energy-efficient data centers and devices, the overall increase in digital activity often offsets these gains. This phenomenon, known as the rebound effect, occurs when improvements in energy efficiency lead to increased usage, ultimately resulting in higher total energy consumption (Jones, 2018). To mitigate this effect, it is essential to adopt strategies that encourage responsible energy use, such as implementing energy-saving measures in data centers, optimizing software to reduce resource demand, and promoting digital literacy among consumers to reduce unnecessary usage.

Resource depletion is another significant environmental impact of digital technologies, particularly in the production of digital devices. The manufacture of smartphones, laptops, and other electronic devices requires substantial amounts of rare earth metals and other non-renewable resources. Graedel and Reck (2016) noted that the extraction and processing of these materials were associated with environmental degradation, including habitat destruction, soil and water pollution, and the generation of large amounts of waste. Furthermore, the increasing demand for digital devices is placing additional pressure on already limited natural resources, raising concerns about the long-term sustainability of current production practices.

The environmental costs of resource depletion extend beyond the immediate impacts of mining and material extraction. The reliance on non-renewable resources in digital device production also raises issues of resource scarcity and geopolitical tension. As the availability of certain rare earth metals decreases, competition for these resources is likely to intensify, potentially leading to conflicts and further

environmental degradation (Graedel & Reck, 2016). To address these challenges, it is crucial to explore alternative materials, improve the efficiency of resource use, and develop recycling technologies that can recover valuable materials from end-of-life devices.

The cumulative environmental impact of digital technologies highlights the need for a more sustainable approach to their development and use. While digital technologies offer numerous benefits, their environmental costs cannot be ignored. To achieve sustainable digital transformation, it is essential to address the environmental impacts of e-waste generation, energy consumption, and resource depletion. This requires a combination of technological innovation, policy intervention, and consumer awareness to ensure that the digital revolution contributes to a more sustainable and equitable future.

The environmental impacts of digital technologies are significant and multifaceted. Addressing these challenges is critical to ensuring that the benefits of digital transformation do not come at the expense of the environment. By promoting the responsible design, use, and disposal of digital technologies, we can minimize their environmental footprint and support the transition to a more sustainable digital economy. This will require the collective efforts of governments, businesses, and individuals to implement sustainable practices and prioritize environmental action in the digital age.

3. Strategies for Sustainable Digital Transformation

Achieving sustainable digital transformation requires a holistic approach that encompasses energy-efficient technologies, circular economy principles, and green IT practices. As digital technologies become increasingly integrated into all aspects of modern life, their impact on the environment is correspondingly increasing. To mitigate these impacts and ensure a sustainable future, strategies that minimize energy consumption, reduce waste, and improve resource efficiency must be implemented. These strategies are essential to balancing the benefits of digital innovation with the need to protect the environment.

Energy-efficient technologies are at the forefront of sustainable digital transformation. The development and implementation of energy-efficient hardware and software can significantly reduce the environmental footprint of digital technologies. For example, low-power processors are designed to perform complex calculations with minimal power consumption, which is critical for devices that operate continuously, such as servers and mobile devices (Kooimey, 2011). In addition, energy-efficient algorithms optimize the performance of software applications, reducing the required computing power and power consumption. These innovations play a vital role in mitigating the environmental impact of the growing demand for digital services.

Optimized data centers are another important component of energy-efficient technologies. Data centers, which house large amounts of data and form the backbone of digital services, are known for their

high energy consumption. However, the energy requirements of these facilities can be significantly reduced through the use of advanced cooling systems, energy-efficient server designs, and optimized data management practices. Koomey (2011) notes that improvements in data center energy efficiency have already led to significant reductions in energy consumption, suggesting that there is potential for further growth as technology continues to evolve. Implementing these energy-saving technologies is essential to minimizing the carbon footprint of digital infrastructure.

Circular economy principles offer another path to a sustainable digital transformation. The circular economy is a business model that focuses on designing products for their useful life, promoting repair and reuse, and facilitating recycling. In the context of the technology industry, this means creating digital devices that are durable, easily repairable, and recyclable at the end of their life cycle (Ellen MacArthur Foundation, 2013). By adopting circular economy principles, the tech industry can reduce the amount of electronic waste generated and save valuable resources, such as rare earth metals and other non-renewable materials. This approach not only benefits the environment but also creates economic opportunities by developing new business models focused on product life cycle management.

Product longevity is a key aspect of the circular economy in the tech industry. Designing products to last longer reduces how often consumers replace their devices, which reduces the overall demand for new products and associated resource mining. Additionally, by making products easier to repair, manufacturers can extend their useful life, reducing electronic waste and conserving resources. The Ellen MacArthur Foundation (2013) highlights that adopting such practices can yield significant environmental benefits while providing consumers with more cost-effective options for maintaining their digital devices. Encouraging repair and reuse is essential to ending the product lifecycle and achieving a truly circular economy.

Recycling is another important component of the circular economy in the tech industry. When digital devices reach the end of their useful life, recycling can recover valuable materials such as metals and plastics that can be used to manufacture new products. This reduces the need for raw material extraction, which is often associated with significant environmental degradation. Promoting recycling within the tech industry consumption and environmental impact (Murugesan, 2008).

Cloud computing further enhances energy efficiency by optimizing the use of shared resources across a network, allowing for more efficient use of computing power and storage. Sustainable data center management is another key aspect of green IT practices. As previously mentioned, data centers are major consumers of energy, and their environmental impact can be significant. However, by implementing sustainable management practices, such as using renewable energy sources, optimizing cooling systems, and employing energy-efficient hardware, data centers can reduce their environmental

footprint. Murugesan (2008) emphasizes that green IT practices not only benefit the environment but also provide economic advantages by reducing operational costs. Adopting these practices is essential for ensuring that the digital transformation contributes to sustainability goals rather than undermining them.

The strategies for sustainable digital transformation involve a combination of energy-efficient technologies, circular economy principles, and green IT practices. By implementing these strategies, the tech industry can minimize its environmental impact while continuing to drive innovation and economic growth. The transition to a sustainable digital economy requires the collective efforts of policymakers, businesses, and consumers to prioritize environmental sustainability in the design, deployment, and use of digital technologies. Through these efforts, it is possible to achieve a digital transformation that not only enhances our lives but also protects the planet for future generations.

4. The Role of Policy Frameworks and Corporate Responsibility

Policy frameworks play a critical role in fostering sustainable digital transformation. Governments can incentivize sustainable practices through regulations, standards, and financial support for green innovations. Corporate social responsibility (CSR) initiatives also drive sustainability, with companies adopting environmentally friendly practices to meet stakeholder expectations and regulatory requirements (Huber, Kirchler, & Sponhauer, 2017). Multi-Stakeholder Collaborations Policy frameworks are crucial in fostering sustainable digital transformation by setting the rules and incentives that guide both public and private sector actions. Governments play a pivotal role in this process by developing regulations, standards, and financial mechanisms that promote the adoption of environmentally friendly technologies and practices. For instance, governments can introduce policies that mandate the reduction of carbon emissions in the tech industry or provide tax incentives for companies that invest in green technologies (Huber, Kirchler, & Sponhauer, 2017). These policies help create a favorable environment for sustainable digital transformation by ensuring that sustainability considerations are embedded in the digital innovation process from the outset.

Regulatory frameworks are an essential component of these policy efforts. By establishing clear guidelines and standards for sustainable practices, governments can ensure that companies adhere to environmentally responsible behaviors. These frameworks might include regulations on energy efficiency, e-waste management, and the sustainable sourcing of materials used in digital devices. Such regulations not only protect the environment but also level the playing field, ensuring that all companies are held to the same standards, thereby preventing a “race to the bottom” where environmental concerns are sacrificed for competitive advantage (Huber, Kirchler, & Sponhauer, 2017). Effective regulatory frameworks are thus a cornerstone of sustainable digital transformation, guiding companies toward more sustainable practices. Financial support for green innovations is another

critical aspect of policy frameworks. Governments can provide grants, subsidies, or low-interest loans to companies that are developing or deploying sustainable technologies. This financial support can help overcome the initial cost barriers associated with green innovation, making it more accessible to a wider range of companies.

By incentivizing the adoption of sustainable technologies, governments can accelerate the transition to a more sustainable digital economy. For example, subsidies for renewable energy technologies can make them more competitive with fossil fuels, encouraging their adoption across the tech industry (Huber, Kirchler, & Sponhauer, 2017). Such financial incentives are vital for driving the widespread adoption of sustainable practices in the digital sector.

Corporate social responsibility (CSR) initiatives also play a significant role in driving sustainable digital transformation. Companies are increasingly recognizing that they have a responsibility not only to their shareholders but also to the broader society and the environment. As a result, many are adopting CSR strategies that focus on reducing their environmental footprint, improving resource efficiency, and supporting sustainable development goals. These initiatives are often driven by stakeholder expectations, as consumers, investors, and employees increasingly demand that companies act responsibly and sustainably (Huber, Kirchler, & Sponhauer, 2017).

By integrating sustainability into their business models, companies can enhance their reputation, meet regulatory requirements, and contribute to the global effort to combat climate change. Multi-stakeholder collaborations are essential for achieving sustainable digital transformation. No single entity—whether a government, company or civil society organization—can address the complex environmental challenges posed by digital technologies on its own. Collaboration between different stakeholders facilitates knowledge sharing, innovation, and the development of comprehensive solutions that take into account diverse perspectives and expertise (Schot & Steinmueller, 2018). For example, partnerships between tech companies and academic institutions can drive research into new sustainable technologies, while collaboration with civil society organizations can ensure that these technologies are deployed in a manner that benefits all members of society. Multi-stakeholder collaborations are thus a key enabler of sustainable digital transformation.

5. Examples of implementation for sustainable digital transformation

Several developing countries have made significant progress in implementing policy frameworks and corporate responsibility initiatives to drive sustainable digital transformation.

For instance, Kenya's adoption of mobile-based digital technologies for financial inclusion has been a game-changer. The government's policy support for mobile banking, particularly through

M-Pesa, has not only promoted financial inclusion but has also had positive environmental impacts by reducing the need for physical bank branches and paper-based transactions (Jack & Suri, 2011). This initiative highlights how policy frameworks can support the development of digital solutions that contribute to sustainability while addressing socio-economic challenges.

Another example is Brazil's National Solid Waste Policy (Política Nacional de Resíduos Sólidos - PNRS), which has played a crucial role in promoting sustainable waste management, including e-waste. This policy framework mandates extended producer responsibility, requiring manufacturers to take back and responsibly manage electronic waste. As a result, companies in Brazil are increasingly adopting CSR initiatives focused on e-waste recycling, which reduces environmental harm and recovers valuable materials for reuse (Brazilian Ministry of the Environment, 2010). This approach showcases the effectiveness of regulatory frameworks in driving corporate responsibility and sustainability in the digital age.

In India, the Digital India initiative has been a pivotal policy framework aimed at transforming the country into a digitally empowered society and knowledge economy. Under this initiative, the Indian government has promoted the use of renewable energy in data centers and incentivized energy-efficient technologies. Additionally, Indian corporations, as part of their CSR activities, have been involved in deploying solar-powered digital infrastructure in rural areas, thereby enhancing digital connectivity while reducing carbon emissions (Government of India, 2015). This example shows the importance of aligning policy frameworks with corporate responsibility to achieve sustainable digital transformation. Case studies provide concrete examples of how policy frameworks, CSR initiatives, and multi-stakeholder collaborations can drive sustainable digital transformation.

One such example is the use of artificial intelligence (AI) in smart grids to optimize energy use and reduce emissions. AI algorithms can predict energy demand and adjust supply in real time, minimizing waste and enhancing efficiency (McKinsey & Company, 2018). This not only reduces the environmental impact of energy consumption but also supports the broader goals of sustainable digital transformation by making energy systems more resilient and adaptable to changing conditions.

Another example is the use of blockchain technology to enhance supply chain transparency. Blockchain can provide a secure, transparent record of the movement of goods through the supply chain, enabling companies and consumers to verify that products have been sourced sustainably and ethically (Saber, Kouhizadeh, Sarkis, & Shen, 2019). This not only helps reduce the environmental impact of supply chains but also promotes ethical consumption by giving consumers the information they need to make informed choices. By leveraging blockchain technology, companies can enhance their CSR efforts and

contribute to a more sustainable digital economy.

In the agricultural sector, the Internet of Things (IoT) is being used to improve resource efficiency by providing real-time data on soil conditions, weather, and crop health. This information allows farmers to optimize their use of water, fertilizers, and pesticides, reducing environmental impacts while increasing crop yields (Wolfert, Ge, Verdouw, & Bogaardt, 2017). IoT applications in agriculture demonstrate how digital technologies can be harnessed to support sustainable development goals, contributing to food security while minimizing environmental harm.

These case studies illustrate the potential of policy frameworks, CSR initiatives, and multi-stakeholder collaborations to drive sustainable digital transformation across different sectors. The integration of robust policy frameworks, active corporate responsibility, and collaborative multi-stakeholder partnerships is essential for driving sustainable digital transformation. The examples from both non-developing and developing countries demonstrate that with the right strategies, digital technologies can be harnessed to promote environmental sustainability while addressing socio-economic challenges. As digital transformation continues to reshape economies and societies, sustainability must remain at the forefront of these efforts, ensuring that technological progress benefits both people and the planet.

6. Conclusion

In short, achieving sustainable digital transformation requires a multidimensional approach that combines energy-saving technologies, circular economy principles, green IT practices, and enabling policy frameworks. Thanks to advances in cooling systems, server design, and data management, optimized data centers offer solutions. Circular economy principles, focusing on product lifecycle, repair, reuse, and recycling, are key to addressing e-waste and protecting valuable resources, while green IT practices increase efficiency and recycling. Reducing environmental impact through strategies such as virtualization and cloud computing. Policy frameworks and corporate responsibility play a crucial role in facilitating this transformation. Effective regulations, financial incentives for green innovation, and corporate social responsibility initiatives guide the public and private sectors toward sustainable development actions. The multi-stakeholder collaboration further amplifies these efforts by bringing together diverse expertise and resources, promoting innovation, and ensuring global solutions. Examples from developed and developing countries illustrate the potential of these strategies to promote environmental sustainability and address socio-economic challenges. By continuing to prioritize sustainability in our digital transformation efforts, we can ensure that technological advancements not only drive economic growth but also protect and safeguard our planet for future generations. Adopting these integrated approaches will help build a resilient and sustainable digital economy that benefits all stakeholders while mitigating environmental impacts.

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