# The Environmental Impact of Digital Technology: How can we Reconcile Progress and Ecology?

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**Abstract: The rapid expansion of the digital sector, a major driver of innovation, raises pressing environmental concerns. While information and communication technologies (ICT) provide numerous opportunities, their development entails high-energy consumption and increasing generation of electronic waste. This ecological footprint, far from negligible, represents a significant challenge to the health of our planet. Addressing it requires adopting more sustainable practices to mitigate the environmental impact of digital technologies. In this context, the concept of Green IT, sometimes also referred to as sustainable IT, has emerged as a promising approach. It aims to minimize the environmental impact of ICT throughout their entire life cycle, from design to disposal. Key practices include eco-design, energy efficiency improvements, and responsible management of electronic waste. Adopting such strategies, helps reduce the environmental damage associated with the digital industry. Our research examines the environmental challenges arising from the widespread use of digital technologies and explores initiatives promoting sustainability. By focusing on energy efficiency and the integration of renewable energy sources, we investigate how companies can decrease their ecological footprint while still benefiting from digital innovation. We also explore how technological progress can be aligned with environmental responsibility. To achieve this, we combine a comprehensive literature review with a field survey of companies that have implemented Green IT practices. The study identifies best practices, the obstacles encountered, and the levers that can accelerate the transition to sustainable digitalization. Our analysis addresses several dimensions: assessing the environmental footprint of ICT (notably carbon emissions and electronic waste), reviewing initiatives such as eco-design and energy optimization, examining factors that facilitate or hinder adoption, and evaluating the environmental, economic, and social benefits of these practices. The findings of this study provide concrete recommendations for businesses, policymakers, and civil society actors, aiming to foster a digital economy where innovation and environmental stewardship are pursued together rather than as competing priorities.**

***Keywords:*** *Sustainable IT, Green IT, Eco-Design, Energy Efficiency, Ecological Transition, Sustainable Development.*

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## I. INTRODUCTION

The advent of digital technology has profoundly reshaped the foundations of contemporary economies, establishing itself as a central pillar that is radically transforming production methods, exchange mechanisms, and communication channels (Castells, 2000). As a key driver of economic growth, digital technology has led to significant improvements in efficiency and productivity across various sectors, such as the rise of e-commerce, the sophistication of digital financial services, and the dynamic development of software (Brynjolfsson & McAfee, 2014; Van Ark et al., 2016). Beyond its direct economic impact, digital technology is also regarded as a potential catalyst for sustainability, contributing to reduced energy consumption and lower greenhouse gas emissions through diverse applications and optimizations (Hilty, 2015; Berkhout & Hertin, 2004). Furthermore, it facilitates the modernization of traditional industries by integrating advanced technologies and supports the emergence and growth of innovative economic sectors,

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thereby opening up new development opportunities (Schumpeter, 1942; Perez, 2002).

Nevertheless, this profound technological transformation conceals a fundamental paradox: while it fosters economic growth and stimulates innovation at multiple levels, it simultaneously generates considerable environmental and social challenges (Bourg & Whiteside, 2010). In response to this duality, the concept of Green IT has emerged as a strategic approach aimed at mitigating the ecological footprint inherent in Information and Communication Technologies (ICT), while optimizing their performance not only in economic terms, but also in social and societal dimensions (Watson et al., 2010; Melville, 2010).

Within this evolving context, the notion of environmental sustainability is emerging as an imperative. It is defined as the intrinsic ability to reconcile advanced technological efficiency with rigorous environmental responsibility and long-term economic viability (Dyllick & Hockerts, 2002). This concept extends beyond the mere adoption of eco-responsible practices, such as reducing the energy consumption of digital infrastructures and recycling obsolete equipment. It requires the deeper integration of sustainability concerns into the digital strategies of private companies and public institutions, influencing the design of digital products and services, operational processes, and business models (Porter & Kramer, 2011; Hart, 1995).

The Souss-Massa region, recognized as a strategic economic and agricultural hub within the Kingdom of Morocco, faces a dual imperative: to accelerate its transition toward a digitally competitive economy at both national and international levels, while minimizing the potentially negative environmental impacts of this structural transformation (OECD, 2019). It is within this specific context that our empirical study takes on its full meaning, aiming to provide concrete insights into the following question: how can an ambitious digital transition be reconciled with the growing demands of environmental sustainability, without slowing down the economic development momentum of the Souss-Massa region?

To provide a rigorous, evidence-based answer to this complex question, we adopted a hypothetico-deductive methodological approach. This involved formulating specific hypotheses concerning the relationships between the variables studied and validating them empirically through the analysis of data collected from a sample of 160 local companies operating in various sectors of activity within the Souss-Massa region (Babbie, 2010). The results of our empirical investigation highlight a set of effective organizational and technological practices that align the imperative of technological innovation with the requirements of environmental preservation. Moreover, our analysis identifies the political and economic levers that appear essential to support and amplify this transition toward sustainable digitalization within the specific regional context of Souss-Massa (North, 1990; Williamson, 2000).

## II. GREEN IT AND ENVIRONMENTAL SUSTAINABILITY

Faced with growing awareness of contemporary environmental challenges, organizations are increasingly encouraged to integrate ecological considerations into their core strategic orientations (Elkington, 1997). Central to this organizational transformation is the concept of Green IT. This systemic approach encompasses a structured set of practices, policies, and technologies specifically designed to minimize the overall environmental footprint associated with all Information and Communication Technologies (ICT) (San-Jose et al., 2019). The essence of Green IT lies in promoting more sustainable and responsible management of IT assets throughout their entire life cycle, from initial design and manufacturing to operational use, maintenance, and finally disposal or recycling (Schmidt et al., 2009).

Integrating Green IT principles into a company's operations is increasingly recognized as a critical lever for enhancing environmental sustainability (Dyllick & Muff, 2016). From a triple bottom line perspective, environmental sustainability goes beyond financial profitability to encompass the environmental and social dimensions of an organization's activities (Savitz, 2013). By adopting Green IT practices, companies can significantly reduce energy consumption, optimize the use of natural resources, decrease electronic waste generation, and potentially strengthen their brand image among stakeholders (Porter & Kramer, 2011). These actions not only support environmental preservation but can also yield long-term economic benefits, such as reduced operating costs and improved efficiency (Hart, 1995). Consequently, Green IT is no longer merely an ecological initiative; it is increasingly recognized as an integral component of a company's overall environmental sustainability strategy.

### *A. The Impact of Digital Technology on Environment*

Despite its dematerialized appearance, the digital world has a substantial and often overlooked environmental footprint. Every online interaction, whether a simple click, sending an email, or streaming a video, relies on a complex, resource-intensive infrastructure (Salleh et al., 2020). The foundations of this digital ecosystem consist of tangible physical components: servers, computers, smartphones, and communication networks, whose production, operation, and eventual decommissioning entail significant environmental consequences (Hilty et al., 2011). These impacts are observable at every stage of a digital device's life cycle, from the extraction of raw materials for manufacturing to end-of-life disposal, including production processes, transportation, and periods of active use (George et al., 2016).

The environmental sustainability of the digital sector is therefore an increasingly critical concern. It involves minimizing the negative effects of ICT-related activities on the natural environment (Coroama et al., 2019). This requires careful attention to the high energy consumption of data centers and networks, the depletion of natural resources used in equipment manufacturing, the growing generation of electronic waste, and the greenhouse gas emissions associated

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with these processes (Murugesan, 2008). Achieving environmental sustainability in the digital sector thus demands a holistic approach, integrating responsible practices throughout the value chain, from eco-design of devices to promoting a circular economy for end-of-life equipment (Bocken et al., 2014).

- *Depletion of Non-Renewable Resources*

The exploitation of non-renewable natural resources exerts major pressure on the global environment. Among these resources, precious metals such as gold and silver, as well as rare earth elements like terbium, play a crucial role in the manufacture of digital devices (Ali et al., 2017). The extraction of these raw materials has significant environmental impacts, including ecosystem degradation, soil and water pollution, and substantial energy consumption (Norgate & Jahanshahi, 2010).

A major challenge lies in the non-renewable nature of these resources. They are formed over geological timescales, making their replenishment impossible within a human timeframe. The current rate of extraction, driven by growing demand from the digital industry, is leading to the gradual and potentially rapid depletion of these deposits (Bardi, 2011). Prospective studies suggest that some reserves of critical metals could be significantly depleted, or even disappear, within the next three decades if current consumption trends continue (Elshkaki et al., 2018).

This prospect raises serious concerns about the sustainability of the digital industry and the urgent need to adopt circular economic models and more sustainable production and consumption practices. The search for substitute materials, improved recycling rates, and the design of more durable and repairable products appear to be essential avenues for alleviating pressure on non-renewable resources.

- *Pollution from Toxic Substances*

The production of electronic components is both an energy-intensive process and a significant source of pollution. For instance, manufacturing a single microprocessor weighing only two grams requires approximately two kilograms of raw materials and around 30 kilograms of water (Williams et al., 2002). This industrial stage is also responsible for the emission of various toxic substances, including mercury, lead, and cadmium (Grant et al., 2013). These elements pose serious threats to both the environment and human health, particularly when electronic waste is illegally exported to developing countries, where it is often processed under unsafe and unsanitary conditions (Balde et al., 2015).

Similarly, the end-of-life phase of electronic equipment raises significant challenges. Waste electrical and electronic equipment (WEEE), or e-waste, contains a variety of toxic substances that can contaminate soil and water resources if not properly recycled (Robinson, 2009). Unfortunately, a substantial proportion of this waste ends up in uncontrolled landfills, often in developing countries, where its treatment exposes local workers to serious health risks due to inadequate protective equipment and unsafe handling practices (Sepúlveda et al., 2010). This situation underscores the ethical and environmental issues inherent in the global management of electronic waste.

- *Electricity Consumption and Greenhouse Gas Emissions*

The environmental footprint of the Information and Communication Technologies (ICT) sector is significantly influenced by its high demand for electrical energy. The continuous operation of computers, energy-intensive data centers hosting vast amounts of information, the constant flow of billions of emails through networks, and the latent energy consumption of devices in standby mode all place substantial strain on energy resources (Salahuddin & Alam, 2016). Much of this consumption is powered by fossil fuels, contributing significantly to greenhouse gas (GHG) emissions, which are major drivers of climate change (IPCC, 2014). Globally, ICTs account for approximately 2% of total GHG emissions (Andrae & Edler, 2015), a proportion comparable to that of the aviation sector, underscoring the magnitude of their impact.

Moreover, this digital carbon footprint continues to grow, reflecting the accelerating digitalization of societies and the integration of digital technologies into an ever-expanding range of human activities (Shu et al., 2021). The widespread adoption of connected devices, the rise of artificial intelligence and big data, and the continuous expansion of online services demand increasingly powerful and energy-intensive digital infrastructures, further intensifying the challenges associated with electricity consumption and GHG emissions in the ICT sector (Hintemann & Böhm, 2019). Consequently, it is imperative to understand and manage these dynamics to guide digital development toward a more sustainable and environmentally responsible trajectory.

*B. Green IT: Conceptual Framework*

Beyond its contributions to efficiency and connectivity, the contemporary digital environment raises critical issues regarding environmental sustainability. A key framework for addressing these issues is the concept of Green IT. As originally defined by Murugesan (2008), Green IT refers to computing practices that are inherently environmentally friendly. This approach encompasses the entire life cycle of IT equipment, from design and manufacturing to use and final disposal, with the goal of minimizing or even eliminating its negative impact on ecosystems.

However, the scope of Green IT extends beyond purely ecological concerns. It also incorporates significant economic dimensions, such as improving energy efficiency and reducing the overall costs associated with technology ownership. These costs include not only acquisition and operational expenses, but also those related to recycling and the responsible disposal of electronic waste. Furthermore, Green IT emphasizes social and ethical responsibilities, positioning itself as a holistic strategy that seeks to harmonize technological advancement with environmental stewardship and social equity.

From a complementary perspective, Herzog, Lefevre, and Pierson (2012) offer a broader understanding of Green IT that goes beyond environmental impact alone. Through a critical analysis of existing definitions, they advocate for an approach that fully integrates economic and social dimensions. According to their analysis, Green IT represents a concerted, multidimensional effort to optimize resource use and mitigate the environmental footprint inherent in information technology. This commitment may be motivated by ecological awareness as well as economic logic, generating efficiency gains and cost reductions.

Green IT practices apply across the entire life cycle of information technology, from inception to obsolescence, including daily use. This comprehensive perspective underscores that Green IT is not merely a technological concern, but a responsibility-driven imperative and a source of innovation supporting truly sustainable development.

Broadening this perspective further, the concept of sustainable IT provides an even more comprehensive framework based on three fundamental principles. First, IT for Green highlights the potential of digital technologies to reduce the ecological footprint of other human activities, thereby actively contributing to sustainable development goals, for example, by optimizing energy management, supporting sustainable agriculture, or improving urban mobility. Second, Human for IT focuses on mitigating the social impact of the digital sector itself, particularly by promoting equitable access to technology and addressing various forms of the digital divide. Finally, IT for Human emphasizes the use of digital tools to reduce the negative social consequences generated by other sectors, for instance by facilitating access to education and healthcare services.

Thus, the environmental sustainability of the digital sector, while rooted in Green IT principles, forms part of a broader vision of sustainable IT that integrates interconnected environmental, economic, and social considerations.

### *C. Definition of Corporate Environmental Sustainability*

Corporate environmental sustainability refers to the integration of sustainable development objectives into operational practices, seeking to balance economic, social and environmental dimensions in the interests of present and future generations. In concrete terms, it involves adopting practices that reduce environmental impact while ensuring profitability, notably through greater resource efficiency, the use of renewable energies, waste reduction and ethical supply chain management (De Lange et al., 2012; Ms., 2020; , 2023).

To this end, a number of practices are being implemented to put this approach into practice. On the one hand, companies are using sustainable manufacturing techniques to limit waste and pollution, while conserving energy and natural resources (Ms., 2020; Abdulhafedh, 2021). On the other hand, the increasing use of renewable energies is a key lever for reducing their carbon footprint (Abdulhafedh, 2021). At the same time, the development of eco-responsible products contributes not only to improving the company's brand image, but also to strengthening its financial performance (Ms., 2020).

However, these initiatives are only effective if they are supported by coherent strategic integration. Indeed, more and more companies are integrating sustainability into their business strategies, adopting responsible and sustainable policies in order to create long-term value (Singh, 2024; Lloret, 2016). Nevertheless, this transition also brings challenges, particularly for small and medium-sized enterprises (SMEs), which must adapt to economic and social changes while efficiently managing their resources (Jayasundara et al., 2019). Despite this, these efforts can turn into opportunities, offering sustainable competitive advantages and better long-term performance (Lloret, 2016).

Ultimately, environmental sustainability is not just about regulatory compliance: it is a strategic approach that aims to balance economic, social and environmental imperatives, thus contributing to business sustainability while actively participating in building a more sustainable future.

## III. RESARCH ISSUES AND HYPOTHESES

The urgent need to reduce the ecological footprint of digital products and services is a fundamental issue in today's world, and is intrinsically aligned with the growing commitment of companies to social responsibility (Elkington, 1997).

In this context, the Souss-Massa region, characterized by significant economic dynamism and a capacity to adapt skills to the transformations brought about by the digital transition, offers a particularly relevant field of study for examining the challenges and opportunities linked to the development of responsible digital business (Porter & Kramer, 2011).

The present investigation revolves around a central and complex question: *"How is it possible to combine the imperatives of digital transition and the demands of environmental sustainability without hindering the economic development trajectory of the Souss-Massa region?"* This question highlights the potential tension between the rapid adoption of digital technologies and the need to minimize their ecological impact, while preserving local economic growth and business competitiveness (Hawken et al., 1999).

In order to provide rigorous, substantiated answers to this problem, a quantitative methodological approach will be favored. This approach will be based on the collection and analysis of empirical data gathered directly from a representative sample of companies operating in the Souss-Massa region. The aim of this quantitative approach is to enable objective measurement of the variables under study and to identify possible correlations and significant relationships between digital practices, sustainability initiatives and the economic performance of local businesses (Creswell & Creswell, 2018).

Data collection instruments, such as standardized questionnaires, will be designed to obtain accurate and comparable information, enabling robust statistical analysis and the formulation of conclusions that can be generalized to the specific context of the region studied (Bryman, 2016).

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*A. Research Hypotheses*

The relationship between responsible digital practices and environmental sustainability is an emerging field of study in managerial and environmental literature. This research follows on from work that seeks to understand how to maximize the positive contributions of digital while mitigating potential negative effects on sustainable development (Covucci et al., 2024). Based on the theoretical concepts of Green IT and Environmental Sustainability, we formulate the following hypotheses to guide our study.

- *Hypothesis 1: Adoption of "Green IT" Practices has a Positive Impact on the Environmental Sustainability of the Digital Sector*

The digital sector, often wrongly perceived as an immaterial industry, reveals an alarming ecological footprint. The exponential growth in energy consumption and emissions associated with digital technology makes it imperative to adopt Green IT practices as a solution for reconciling digital transformation and environmental sustainability. This hypothesis is based on the idea that the integration of these practices in digital companies has a significant positive effect on environmental sustainability.

The adoption of Green IT has been shown to have a positive effect on the perceived environmental performance of organizations. This adoption is reinforced by the strategic alignment between IT and business, as well as by companies' environmental motivation (Lei et al., 2023). In addition, the adoption of Green IT contributes to the reduction of energy consumption and carbon emissions, which is crucial to minimizing the negative environmental impacts of IT-related activities (Gupta, 2024).

Green IT practices include the use of paperless digital archiving systems, resource-efficient IT equipment, and responsible management of electronic waste. These practices, while still at an early stage in some sectors such as education, show practical and research implications for encouraging the adoption of Green IT (Hernandez, 2020). In addition, Green IT adoption is associated with improved organizational performance, partly due to institutional pressure and increased openness to future consequences (Ainin et al., 2015).

The adoption of digital technologies plays a crucial role in improving green innovation and environmental sustainability. For example, the integration of digital transformation strengthens the relationship between green technology adoption and environmental sustainability, facilitating innovation and natural resource management (Riaz et al., 2024). Moreover, digitalization contributes to environmental sustainability by reducing $CO_2$ emissions, particularly in the transport sector (Kwiliński et al., 2023).

- *Hypothesis 2: Policies and Regulations Significantly Influence the Environmental Sustainability of the Digital Sector*

The environmental impact of digital technologies is both complex and ambiguous. While they can optimize resource use and reduce carbon footprints in some sectors, their own production and consumption generate considerable challenges. Managing these direct and indirect effects depends crucially on the synergy between digital and environmental policies. In other words, effective regulation is crucial to the environmental sustainability of the digital sector.

Digital policies, such as those observed in sub-Saharan Africa and East Asia, show a growing awareness of the opportunities and risks associated with information and communication technologies (ICT) for environmental sustainability. However, these policies often focus more on positive indirect impacts, such as improving energy efficiency, rather than negative direct impacts, such as ICT electricity consumption (Kunkel & Matthess, 2020).

At the same time, the call for a "Digital Green Deal" highlights the lack of global regulations that address the opportunities and risks of digital technologies for sustainability. Such a deal should aim for greater policy coherence, integrating digital measures that serve environmental goals (Santarius et al., 2023). Furthermore, the study on China's digital economy reveals that environmental regulations positively moderate the link between the digital economy and regional green growth, underlining the importance of environmental policies in this context (Li et al., 2025).

In the European Union, the integration of digital technologies in the transport sector, as part of the Green Deal, shows how digitalization can contribute to environmental sustainability by reducing $CO_2$ emissions (Kwiliński et al., 2023). Similarly, innovation and environmental policies in the EU have a positive impact on sustainable production, although the negative link between GDP and sustainability persists (Martínez et al., 2022).

- *Hypothesis 3: Awareness and Commitment have a Positive Effect on the Environmental Sustainability of the Digital Sector*

The growth of the digital sector, while synonymous with innovation and progress, is accompanied by a growing environmental impact. The hypothesis that greater awareness of ecological issues and an active commitment to sustainable practices can mitigate this impact is increasingly being explored. This perspective is based on several fundamental arguments from the academic literature.

Digital marketing strategies play a crucial role in raising environmental awareness. Well-designed digital marketing techniques can significantly influence people's awareness of and attitudes towards environmental concerns. For example, one study showed that engagement with environmental content via digital marketing approaches can increase sustainability awareness (Daoud et al., 2024).

Digitization, particularly in the information and communication technology (ICT) sector, has been identified as a key tool for improving energy efficiency and reducing greenhouse gas emissions. A systematic review has revealed that digitization generally contributes to environmental sustainability, although negative effects have been observed in some contexts (Charfeddine & Umlai, 2023). In addition, the

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integration of digital technologies in the transport sector has shown positive effects on the reduction of $CO_2$ emissions (Kwiliński et al., 2023).

Environmental education using digital tools is also an important vector for promoting sustainability awareness. The use of digital tools in education has demonstrated a positive impact on students' awareness of the planet's sustainability (Hajj-Hassan et al., 2024).

Process innovation, particularly in technology companies, is strongly linked to commitment to environmental sustainability. Companies that innovate in their processes show a stronger commitment to sustainability, highlighting the importance of innovation in achieving environmental goals (Moyano-Fuentes et al., 2018).

➢ *Hypothesis 4: Sustainable Technological Innovation has a Positive Effect on the Environmental Sustainability of the Digital Sector*

The digital sector, paradoxically often perceived as a major contributor to energy consumption and waste production, also has the potential to become a driver of environmental sustainability. Technological innovation, when geared towards sustainable solutions, is thus proving to be an essential lever for radically transforming the sector.

The hypothesis that sustainable technological innovation significantly improves the environmental sustainability of digital technology is based on solid foundations. Indeed, new technologies can optimize the energy consumption of infrastructures, reduce the production of electronic waste through the design of more durable and recyclable products, and encourage the emergence of more efficient monitoring and environmental management solutions. In short, sustainable technological innovation is much more than just a corrective measure; it represents a sine qua non for a truly environmentally-friendly digital future.

Digitization is a key driver in achieving environmental sustainability. It reduces carbon dioxide emissions through the integration of digital technologies in various sectors, including transport and industry (Kwiliński et al., 2023). For example, the European Union has implemented ambitious policies to reduce $CO_2$ emissions, in part thanks to the adoption of digital technologies in the transport sector (Kwiliński et al., 2023). In addition, digitalization improves the efficiency of supply chains, leading to more sustainable environmental practices (Liu et al., 2024).

Technological innovation is a catalyst for sustainable development. It fosters green innovation and corporate social practices, transforming the economic landscape and facilitating sustainable business development (Javeed et al., 2025). In China, for example, technological innovation has been identified as a key factor in reducing $CO_2$ emissions and promoting sustainable development (Ahma et al., 2022). Companies that adopt technological innovations often see an improvement in their environmental and economic performance (Saqib & Qin, 2024).

Integrating digital technologies into logistics and industrial operations is crucial to improving sustainability. Digital innovations enable better resource management, waste reduction and improved energy efficiency (Cricelli & Strazzullo, 2021; De La Calle et al., 2021). Companies that integrate these technologies into their production and distribution processes can reduce their environmental impact while increasing their competitiveness in the marketplace (Xiao & Su, 2022; Salamzadeh et al., 2022).

*B. Conceptual Model*

These hypotheses are linked the independent variables (Adaptation of Green IT practices, Policies & regulations, Awareness and commitment, and Sustainable technological innovation) and the dependent variable (Environmental sustainability of the digital sector) by the conceptual model can be presented in the following diagram:

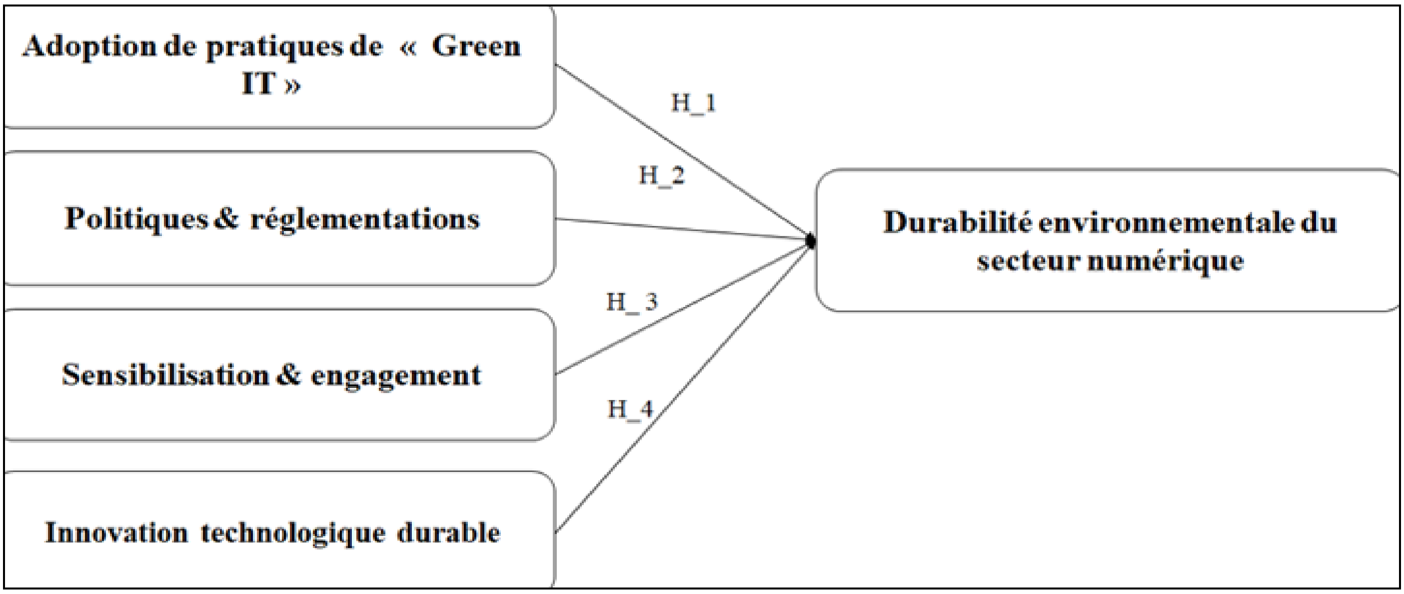


Fig 1 Conceptual Model (Our Own Figure Based on Collected Data.)

## IV. RESEARCH METHODOLOGY

This work is based on a hypothetico-deductive approach, drawing on the theoretical foundations of management. Our aim is to explore the relationship between responsible digital practices and corporate environmental sustainability.

### *A. Data Collection Method*

A survey was conducted among 160 participants in the Souss-Massa region between February 1 and March 15, 2025. The questionnaire was structured in two sections. The first section asked respondents to indicate their level of agreement with statements relating to the five variables examined: environmental sustainability of the digital sector, integration of "Green IT" practices, sustainable technological innovation, policies and regulations, and awareness and commitment. The second section gathered socio-demographic information on the service managers of the companies surveyed, as well as data on the specific characteristics of these companies. The companies' digital practices and level of environmental sustainability were assessed using five-point Likert scales. Each practice was measured by 5 indicators, totalling around 30 questions. Five statements on a five-point Likert scale ranging from «strongly disagree «to» strongly agree measured the dependent variable, «environmental sustainability of the digital sector".

### *B. Data Analysis*

Using Smart-PLS 4 software, we were able to implement a PLS structural equation analysis to test theoretical relationships between digital environmental variables and the environmental sustainability of the digital sector, based on data collected from interviewees.

### *C. Model Validation using Structural Equation Modeling*

The measurement model, also known as the external model, represents the assumed linear relationships between latent variables and their indicators. To assess the quality of the measurement model, we used three key criteria: reliability of measurement scales, convergent validity and discriminant validity.

- *Examination of the Psychometric Properties of the Measurement Model*

The psychometric properties of the measurement model, namely reliability, convergent validity and discriminant validity, were examined to ensure the quality of the measures used.

- *Scale Reliability*

Scale reliability was assessed using factor loadings and Cronbach's alpha. Factor loadings, generally above 0.70, indicate good convergence between the items and the latent construct. Cronbach's alpha, although commonly used, was complemented by loadings analysis for a more refined assessment. Indicators with loadings below 0.40 were eliminated (Hair, Ringle and Sarstedt, 2011). As shown in the table below, the majority of items display adequate factor loadings, ranging from 0.50 to 0.92, indicating good convergence between items and latent constructs. In line with methodological recommendations (Evrard et al., 2003), only items with loadings below 0.40 were excluded from further analysis.

Table 1 Loadings with Smart-PLS.4 software. (Smart-PLS.4 output)

| Variables | Items | Loading | Alpha Crombach |
|---|---|---|---|
| **Environmental sustainability in the digital sector** | Env.sustain_1 ← Enviro. Sustainability of the Digital. sect | 0,856 | |
| | Env.sustain_2 ← Enviro. Sustainability of the Digital. sect | 0,911 | |
| | Env.sustain_3 ← Enviro. Sustainability of the Digital. sect | 0,856 | 0,916 |
| | Env.sustain_4 ← Enviro. Sustainability of the Digital. sect | 0,901 | |
| | Env.sustain_5 ← Enviro. Sustainability of the Digital. sect | 0,801 | |
| **Adoption of "Green IT" practices** | Green.IT_1 ← Green IT | 0,785 | |
| | Green.IT_2 ← Green IT | 0,892 | |
| | Green.IT_3 ← Green IT | 0,891 | |
| | Green.IT_4 ← Green IT | 0,917 | 0,923 |
| | Green.IT_5 ← Green IT | 0,886 | |
| **Sustainable technological innovation** | S.Tec.Inno_1 ← Sustainable technological innovation | 0,822 | |
| | S.Tec.Inno_2 ← Sustainable technological innovation | 0,849 | |
| | S.Tec.Inno_3 ← Sustainable technological innovation | 0,838 | |
| | S.Tec.Inno_4 ← Sustainable technological innovation | 0,894 | 0,91 |
| | S.Tec.Inno_5 ← Sustainable technological innovation | 0,883 | |
| **Policies & regulations** | Pol.Reg_1 ← Policies & regulations | 0,831 | |
| | Pol.Reg_2 ← Policies & regulations | 0,926 | |
| | Pol.Reg_3 ← Policies & regulations | 0,867 | 0,939 |
| | Pol.Reg_4 ← Policies & regulations | 0,925 | |
| | Pol.Reg_5 ← Policies & regulations | 0,934 | |
| **Awareness & commitment** | Awar.Commit_1 ← Awareness & commitment | 0,930 | |
| | Awar.Commit_2 ← Awareness & commitment | 0,938 | |
| | Awar.Commit_3 ← Awareness & commitment | 0,914 | 0,956 |
| | Awar.Commit_4 ← Awareness & commitment | 0,923 | |
| | Awar.Commit_5 ← Awareness & commitment | 0,903 | |

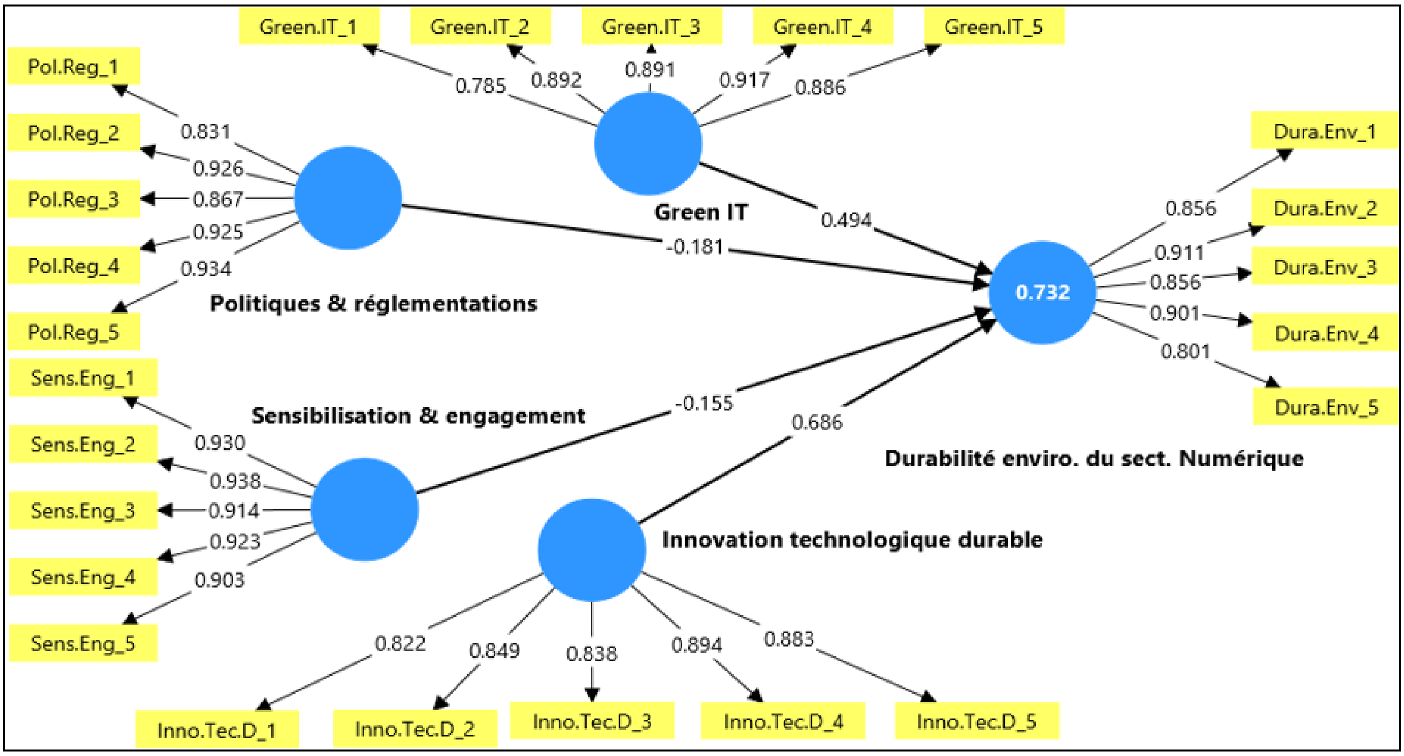

Fig 2 Measurement Model after Adjustment (Smart-PLS.4 output)

- *Assessment of Convergent Validity*

To check whether the items actually measure the concept they are supposed to represent, we assessed the convergent validity of the scales. This assessment is based on the calculation of Cronbach's alpha and internal consistency. These indices measure the internal consistency of the scales, i.e. the extent to which items on the same scale measure the same concept. According to Nunnally (1978), an alpha coefficient greater than 0.7 indicates satisfactory composite reliability. The results obtained for our scales far exceed this threshold, attesting to their convergent validity.

Table 2 Significance and Composite Reliability (ρ) (Smart-PLS.4 output)

| Built | Composite Reliability |
|---|---|
| Environmental sustainability in the Digital sector | 0,937 |
| Green IT | 0,942 |
| Sustainable technological innovation | 0,933 |
| Policies & regulations | 0,954 |
| Awareness & commitment | 0,966 |

- *Assessing Discriminant Validity*

Discriminant validity guarantees that each construct measures a unique and distinct concept. It is assessed by comparing the average variance extracted (AVE) of a construct, which represents the proportion of the construct's variance explained by its indicators, with the squares of the correlations between this construct and the other constructs. To ensure discriminant validity, the AVE of a construct must be greater than the square of its correlation with any other construct. In other words, a construct must share more variance with its own indicators than with the indicators of other constructs.

Table 3 Discriminant Validity (Smart-PLS.4 output)

| Built | AVE | E.Sust. | Gr.IT | S.T.I. | P&R | A.&C |
|---|---|---|---|---|---|---|
| **Environ.sustainability in the Digital sector** | 0,749 | 0,866 | | | | |
| **Green IT** | 0,766 | 0,820 | 0,875 | | | |
| **Sustainable technological innovation** | 0,735 | 0,835 | 0,813 | 0,858 | | |
| **Policies & regulations** | 0,806 | 0,732 | 0,803 | 0,813 | 0,898 | |
| **Awareness & commitment** | 0,850 | 0,735 | 0,817 | 0,806 | 0,839 | 0,922 |

*D. Evaluating the Structural Model*

To explore the causal links between our concepts, we developed a structural model and evaluated it using Lohmöller's structural diagram, a recognized method for analyzing this type of model.

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➢ *Analysis of Hypothesis-Testing Results*

To validate our hypotheses, we tested the significance of the path coefficients (β) linking the latent variables. To do this, we used a bootstrap resampling method with 5000 iterations, in accordance with the recommendations of Chin (1998). The results of this test are shown in the table below.

Table 4 Using the Bootstrap to Estimate Causal Model Parameters

| Hypotheses | β (Correlation coef.) | T-Student (>1,96) | P values | Signification |
|---|---|---|---|---|
| Green IT → Enviro. sustainability of Digital sect. | **0,494** | **4,064** | **0,000** | **Validated** |
| Sustainable technological innovation → Enviro. sustainability of Digital sect. | **0,686** | **5,917** | **0,000** | **Validated** |
| Policies & regulations → Enviro. sustainability of Digital sect. | **-0,181** | **1,511** | **0,131** | **Not validated** |
| Awareness & commitment → Enviro. sustainability of Digital sect. | **-0,155** | **1,314** | **0,189** | **Not validated** |

Source: Designed by us Based on the output of Smart PLS.4 Software.

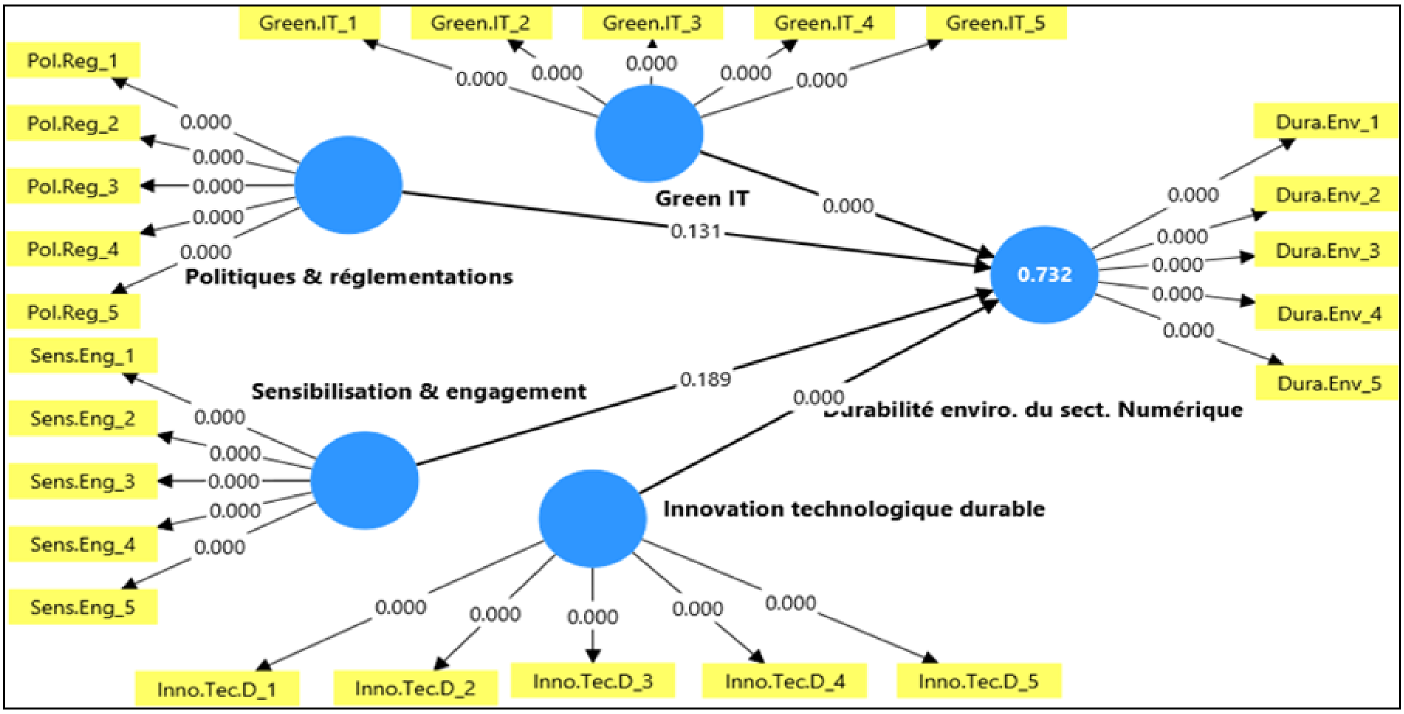

Fig 3 Structural Model (Smart PLS.4 Software outputs)

➢ *In-Depth Discussion and Empirical Validation of Hypotheses*

The aim of this section is to examine in detail the results of our data analysis. We will proceed to an in-depth discussion of these findings and assess the empirical validity of the hypotheses formulated beforehand, thus shedding light on the relationship between digital environment tools and the environmental sustainability of the digital sector in the context studied.

- *Assessment of H_1: Adoption of Green IT Practices has a Positive Impact on the Environmental Sustainability of the Digital Sector*

The hypothesis examined concerns the link between the adoption of Green IT practices and the environmental sustainability of the digital sector. The results reveal a positive and moderate correlation (β = 0.494) between the intensity of Green IT strategies and improved environmental performance. This association is statistically significant, as evidenced by the Student's t-value (T = 4.064), which is well above the critical threshold of 1.96, and the P-value (P = 0.000), which is effectively zero, confirming that the observed effect is highly unlikely to be due to chance. These results therefore corroborate the initial hypothesis, demonstrating the positive and significant influence of Green IT practices on environmental sustainability.

The overall interpretation of these data suggests that the adoption of Green IT strategies, through the implementation of measures such as eco-design, energy optimization, and responsible electronic waste management, plays a central role in improving the environmental impact of the digital sector. Companies that integrate these practices are thus able to reduce their ecological footprint while meeting growing expectations regarding environmental responsibility and the transition to a more sustainable digital sector.

In conclusion, these results show that Green IT practices are not limited to one-off or symbolic actions, but constitute genuine levers for enhancing the environmental sustainability of the digital sector. Their adoption can lead to long-term benefits, including reduced energy consumption,

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less electronic waste, and support for a transition toward a more environmentally responsible digital economy.

- *Assessment of H_2: Policies and Regulations Significantly Influence the Environmental Sustainability of the Digital Sector*

The hypothesis examined concerns the link between public policy instruments and the environmental sustainability of the digital sector. The results reveal a substantial positive correlation (β = 0.686) between a stronger regulatory framework and improved environmental performance. This association is statistically significant, as evidenced by a Student's t-value (T = 5.917) well above the critical threshold and a p-value (P = 0.000) below the conventional significance level. These results corroborate the initial hypothesis, demonstrating the positive and significant influence of policies and regulations on the environmental sustainability of the digital domain.

The overall interpretation of these data suggests that regulatory frameworks, by defining precise environmental standards and promoting sustainable practices, exert a primary influence on the ecological orientation of the digital sector. The imposition of requirements regarding eco-design, e-waste management, and energy efficiency enables public authorities to encourage more responsible behavior within the industry. A structured regulatory context also motivates companies to innovate in green technologies while meeting growing societal expectations for environmental responsibility.

In conclusion, the results confirm that policies and regulations are not merely instruments of control, but powerful levers for the sustainable transformation of the digital sector. Their positive impact on environmental sustainability is likely to bring long-term benefits, including a reduction in the carbon footprint of digital activities, an extension of the lifespan of technological equipment, and support for a transition toward a more circular and environmentally friendly economy.

- *Assessment of H_3: Awareness and Commitment have a Positive Effect on the Environmental Sustainability of the Digital Sector*

Numerous initiatives aim to make the digital sector more environmentally friendly by raising awareness and fostering engagement. It is commonly believed that training stakeholders, promoting social responsibility, and involving citizens are key to encouraging greener behaviors.

However, our study reveals a surprising result: the link between awareness and engagement and environmental sustainability in the digital sector is weak and uncertain (β = -0.181). The figures (T = 1.511; P = 0.131) indicate that this relationship is not strong enough to be considered statistically significant. In other words, the assumption that raising awareness and engaging stakeholders automatically improves the digital environment is not supported by our data.

This suggests that, while awareness and engagement are theoretically beneficial, their actual impact is more complex. Possible explanations include overly general awareness campaigns, poor integration into corporate environmental strategies, or a lack of consistency between intentions and actions, which may slow the effect of engagement.

In conclusion, the role of awareness-raising and engagement in promoting a greener digital sector must be considered with caution. To achieve meaningful change, these efforts need to be complemented by concrete measures, clear incentives, and rigorous monitoring. Strengthening the connection between individual commitment and corporate action may be a critical factor in advancing true digital sustainability.

- *Assessment of H_4: Sustainable Technological Innovation has a Positive Effect on the Environmental Sustainability of the Digital Sector*

The relationship between sustainable technological innovation and environmental sustainability represents a key area of research in the ecological transition of the digital sector. Sustainable technological innovation is defined as the integration of technologies aimed at minimizing environmental impact, optimizing energy efficiency, and promoting a circular economy within digital systems.

However, our empirical analysis reveals a weak and insignificant correlation between these two variables (β = -0.155). With the t-value (1.314) below the significance threshold (1.96) and the p-value (0.189) exceeding 0.05, we cannot confirm the hypothesis of a positive impact of sustainable technological innovation on the environmental sustainability of the digital sector based on our data. Several factors may explain this lack of a significant relationship, including insufficient large-scale deployment of innovations, the presence of rebound effects that offset environmental benefits, and a lack of synergy with organizations' overall sustainability strategies.

In conclusion, although sustainable technological innovation represents a potentially important tool for enhancing the environmental sustainability of the digital sector, our results suggest that its effectiveness depends on broader structural and organizational factors. Supporting technological innovation with integration policies, appropriate regulatory frameworks, and coherent environmental governance appears essential to optimize its ecological impact.

## V. CONCLUSION

Green IT and digital responsibility represent an indispensable approach to reconciling technological development and environmental preservation. The practices identified in specialized literature outline a comprehensive roadmap for reducing the ecological impact of information technologies while optimizing their operational efficiency.

Energy efficiency is the fundamental pillar of this transformation. As pointed out by Oduor and Franklin (2024)

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and Rahman (2024), the choice of energy-efficient hardware combined with software optimization enables substantial reductions in power consumption. Virtualization and cloud computing solutions are emerging as particularly effective, with savings of up to 50%. At the same time, rigorous management of the lifecycle of electronic equipment is essential. Rahman's work (2024) shows that systematic management of electronic waste enables up to 80% of recoverable materials to be recovered, thereby reducing environmental impact.

The organizational dimension plays an equally crucial role. The implementation of robust governance frameworks, such as the COBIT 5 framework analyzed by Patón-Romero et al. (2017), provides an indispensable structure for standardizing and evaluating Green IT initiatives. These institutional mechanisms gain in effectiveness when accompanied by comprehensive awareness-raising and training programs, as advocated by Hernandez (2020) and Oduor with Franklin (2024), making it possible to anchor good practices in organizations in the long term. Technological innovation is also opening up promising prospects. The concept of "green digital fusion" developed by Ye et al, (2024), integrating self-optimizing systems, illustrates the potential of emerging solutions. As noted by Ye et al. (2024) and Ainin et al. (2015), these advances benefit from the momentum created by regulatory pressures and growing market demands.

The convergence of these different dimensions - technical optimization, rigorous governance and innovation - enables a dual performance to be achieved: environmental, by reducing the ecological footprint, and operational, by improving efficiency. This integrated approach, which goes beyond one-off actions in favor of a systemic transformation, offers a particularly relevant framework for organizations and territories committed to a sustainable digital transition.

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