

# THE IMPACT OF SMART TECHNOLOGIES ON THE 3E NEXUS: BENEFITS, RISKS AND MITIGATION STRATEGIES

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## ABSTRACT

*Smart technologies are increasingly reshaping the relationship between economic development, energy systems, and environmental performance. Their application creates new opportunities for improving resource efficiency, strengthening energy management, and supporting more sustainable economic activity. At the same time, the expansion of digital infrastructure generates additional technological, environmental, and managerial risks that may reduce the expected benefits of digital transformation. This study examines the impact of smart technologies on the Economy–Energy–Environment (3E) nexus, with particular attention to the balance between positive effects and associated risks. The analysis draws on recent scientific literature, comparative assessment, and the synthesis of international experience related to artificial intelligence, the Internet of Things, big data, digital twins, and automated management systems. The results show that smart technologies can improve productivity, optimise energy consumption, enhance environmental monitoring, and support more informed decision-making. However, these benefits are accompanied by higher electricity demand from digital infrastructure, growing cybersecurity exposure, increasing volumes of electronic waste, dependence on digital platforms, and new governance challenges. The study therefore argues that the contribution of smart technologies to sustainable development depends not only on the scale of their adoption, but also on the quality of risk management and the capacity to anticipate unintended consequences. The article proposes a set of mitigation strategies focused on energy-efficient digital solutions, stronger cybersecurity and data-governance practices, improved regulatory coordination, and the integration of technological risks into organisational risk-management systems. The findings provide a conceptual basis for evaluating smart technologies as a factor influencing the coordinated development of the 3E nexus.*

## KEYWORDS:

*smart technologies, 3E system, risk management, sustainable development*

## **1. Introduction**

Currently, global economic development is impossible without the use of digital data, the Internet of Things, and artificial intelligence. In 2026 the worldwide spending in the Internet of Things was forecast to exceed one trillion U.S. dollars (Thuy, 2026), demonstrating the sector's steady growth. It's also worth noting the new architecture of interactions between the key components of sustainable development, driven by the use of smart technologies. Thus, the interconnectedness of energy components, environmental sustainability, and economic growth (the 3E system) is becoming apparent.

The 3E system represents an integrated model of interactions between the economy, energy, and the environment, within which economic development shapes demand for energy resources, the energy sector ensures the functioning of the economy, and the environmental subsystem reflects the consequences of energy and industrial consumption. The interactions between the 3E components are two-way and cyclical: energy decisions influence economic efficiency and environmental performance, while environmental constraints and sustainable technologies transform economic and energy policy.

Within this 3E system, the use of smart technologies serves as a driver that enhances the overall effect (catalyst) of these interactions. Reducing the carbon footprint, increasing productivity, optimizing costs, and improving individual economic indicators through overall impact are the result of the implementation and effective use of digital technologies. However, along with the positive effects, a number of risks arise that negatively impact long-term development. These risks may include cyber threats, increased energy consumption, operational and social risks, and others. Thus, the need for a comprehensive analysis and development of a preventive risk management system for the integration and use of digital technologies at the micro- and macroeconomic levels is becoming clear.

This study examines how smart technologies affect the interconnected dimensions of the 3E nexus and identifies the principal risks arising from their implementation. Due to conceptual and qualitative nature of this study, the *following research propositions* were formulated:

1. The adoption of smart technologies generates favorable effects across the economic, energy and environmental dimensions of the 3E nexus;
2. The implementation of digital technologies transforms the structure of inherent risks, and new risks arise for the organization.

To achieve this goal, the *following objectives* were formulated:

1. Examine the theoretical approaches explaining the contribution of digital technologies to sustainable development;
2. Establish relationships within the 3E system's components;
3. Identify trends in the use of smart technologies;
4. Identify and systematize emerging risks;
5. Formulate practical recommendations for the implementation of smart technologies for sustainable development, taking into account the development of a risk management system for emerging risks.

## **2. Literature Review**

### **2.1. *The 3E Framework as a Basis for Sustainable Development***

Research on sustainable development increasingly addresses the links among economic performance, energy use and environmental quality. This relationship is commonly examined within the 3E (Economy- Energy - Environment) framework, which considers these three dimensions as an integrated system rather than independent components. Unlike traditional approaches that analyse economic growth, energy development or environmental protection separately, the 3E concept emphasises their mutual dependence and the need to achieve a balanced development trajectory.

One of the earliest comprehensive contributions to this field was made by Stern (2004), who argued that energy represents a fundamental production factor driving economic development. At the same time, increasing energy consumption is frequently associated with greater environmental degradation, indicating that long-term economic growth cannot be sustained without improvements in energy efficiency and environmental performance.

Subsequent studies have examined extensively the direction and strength of the link between energy use and economic expansion. Apergis and Payne (2010) demonstrated that this relationship is not universal but varies across countries according to their level of economic development, industrial structure and energy policy. Their findings suggest that energy policy should be considered an integral component of economic development strategies rather than an independent policy domain.

A comprehensive review conducted by Ozturk (2010) synthesised more than one hundred empirical research addressing the energy–economy relationship. The review distinguished four alternative interpretations of how energy use and economic performance may influence one another (the growth, conservation, neutrality and bidirectional perspectives), concluding that no single model can explain all national experiences. Nevertheless, most empirical evidence confirms that energy remains a key determinant of long-term economic performance.

Expanding the traditional energy–growth perspective, Omri (2014) argued that analysing total energy consumption alone is insufficient. According to the author, the composition of the energy mix should also be considered, as renewable and non-renewable energy sources produce different economic and environmental outcomes. Consequently, the effectiveness of the 3E system depends not only on the quantity of energy consumed but also on the quality and sustainability of energy production.

A broader synthesis of the literature was presented by Tiba and Omri (2017), who reviewed several decades of research devoted to the interactions among economic growth, energy consumption and environmental quality. Their analysis shows that the 3E system operates as a dynamic network of interdependent relationships rather than as a linear cause-and-effect mechanism. The authors also conclude that institutional conditions, technological development, energy structure and environmental policies substantially influence the performance of the 3E system, explaining why empirical findings often differ across countries.

### **2.2. *Smart Technologies as a Driver of the 3E System***

The rapid development of digital technologies has considerably expanded the scope of research on sustainable development. While earlier studies primarily focused on the interactions among economic performance, patterns of energy use and

environmental conditions, recent literature increasingly investigates how smart technologies reshape these relationships and contribute to the coordinated development of the 3E system.

Despite their widespread use, there is no universally accepted definition of smart technologies. Porter and Heppelmann (2014) associate smart technologies with smart connected products capable of collecting, processing and exchanging data through embedded sensors, software and communication networks. According to the authors, these technologies fundamentally change the logic of value creation by enabling continuous monitoring, predictive maintenance and data-driven decision-making.

A broader interpretation is proposed by Vial (2019), who considers smart technologies as the technological foundation of digital transformation. Rather than viewing digitalisation as the implementation of individual technologies, the author argues that it represents a profound organisational transformation affecting business models, operational processes and managerial decision-making. In this context, smart technologies create value only when integrated into organisational capabilities and strategic management.

The economic implications of smart technologies have been extensively discussed by Brynjolfsson and McAfee (2014). They argue that smart technologies have become the driving forces of the Fourth Industrial Revolution by improving labour productivity, accelerating innovation and increasing resource efficiency. Digital technologies are therefore viewed not only as operational tools but also as strategic assets capable of enhancing long-term competitiveness.

From the perspective of sustainable industrial development, Kamble, Gunasekaran and Gawankar (2018) conducted one of the first systematic literature reviews on Sustainable Industry 4.0. The authors concluded that smart technologies contribute to sustainability through three interconnected mechanisms: technological integration, process optimisation and sustainable outcomes. Their proposed framework demonstrates that digital technologies improve productivity while simultaneously supporting more efficient resource utilisation and environmental performance.

The contribution of Industry 4.0 technologies to sustainability has been further explored by Ghobakhloo (2020), who argues that digitalisation should be regarded as an enabler of sustainable development rather than merely a technological trend. According to the author, smart technologies support sustainable manufacturing by improving energy efficiency, reducing material waste, optimising production processes and facilitating circular economy practices. At the same time, the study emphasises that sustainability benefits can only be achieved through the integrated implementation of digital technologies rather than isolated technological solutions.

The analytical potential of smart energy systems has been highlighted by Wang et al. (2018) in review of smart meter data analytics. The authors demonstrate that the combination of smart technologies significantly improves electricity demand forecasting, load management and energy efficiency. At the same time, they identify several emerging challenges related to data quality, cybersecurity, privacy and the increasing complexity of digital energy infrastructures.

Beyond the energy sector, researchers increasingly examine the contribution of smart technologies to broader sustainability objectives. Vinuesa et al. (2020) conducted the first comprehensive assessment of the contribution of artificial intelligence to progress towards the UN Sustainable Development Goals. Their analysis indicates that AI can positively influence the majority of SDGs by improving

productivity, supporting environmental monitoring, enhancing resource management and increasing energy efficiency. Nevertheless, the authors also identify significant risks associated with growing electricity demand, digital inequality, algorithmic bias, transparency and governance, concluding that the sustainability effects of AI depend largely on appropriate regulatory and managerial frameworks.

More recent systematic reviews confirm these findings. Patrício and Varela (2025) conclude that IoT and artificial intelligence are the Industry 4.0 technologies most strongly associated with improvements in environmental and economic sustainability, whereas the social dimension remains comparatively underexplored. The authors further note that manufacturing and energy sectors demonstrate the highest level of digital transformation, while concerns regarding data privacy, cybersecurity and technology scalability continue to constrain wider implementation.

Similarly, Ejsmont, Gładysz and Kluczek (2020), based on a bibliometric review of Industry 4.0 and sustainability research, observe that most existing studies emphasise the technological benefits of digitalisation, whereas fewer investigate its long-term sustainability implications.

The use of smart technologies in the development of various 3E system components is reflected in reports from specialized agencies. According to the International Energy Agency (IEA) report “Energy and AI,” since 2022, companies linked to artificial intelligence have added approximately USD 12 trillion to their combined S&P 500 market value. (IEA, 2025). At the same time, the same report describes how a data center consumes as much electricity as 100,000 households, noting that there is a trend toward increasing this, and the largest data centers under construction will consume 20 times more energy (IEA, 2025). The most recent report from April 16, 2026, demonstrates that the field of artificial intelligence continues to grow significantly. The report noted that the capital expenditures of 5 technology companies exceed global investments in oil and natural gas production (IEA, 2025). Thus, the source demonstrates the widespread use of smart technologies (i.e., a current trend), but at the same time points to the negative consequences of this phenomenon.

Overall, the literature consistently demonstrates that smart technologies have evolved from instruments of process automation into strategic drivers of sustainable development. Their contribution extends beyond economic efficiency to encompass energy optimisation, environmental protection and resource management. However, despite the growing number of studies on digital transformation and sustainability, most existing research examines these effects separately. The integrated assessment of smart technologies as a driver of the 3E system, particularly considering the emerging technological, energy and environmental risks associated with digital transformation, remains relatively limited. This gap provides the conceptual basis for the present study.

### **3. Material and Methods**

To achieve the stated research objective, a conceptual analysis of the interactions between 3E system components was used, along with a literature synthesis. The literature review was used to identify the main concepts about smart technologies, including using of artificial intelligence, Internet of Things, automation, big data in different field. This demonstrates how smart technologies are described in academic resources and helps to understand their influence on the 3E system's components. A comparative analysis of the opportunities and risks associated with the use of smart technologies was also conducted to demonstrate the contrasting effects

of the same development tool. Existing examples of smart technology implementation were examined, their results were assessed, and conclusions were drawn regarding the feasibility of their implementation. In addition, method of synthesis allows to formulate the conclusions and recommendations regarding the implementation of smart technologies with the applying of relevant risk assessment and risk management policies.

#### 4. Results

In today's world, digital transformation of business processes is not an isolated external factor in the development of the economy, energy, and the environment, but rather an element of their interconnectedness. The study analyzed the impact of smart technologies on each aggregated component of the 3E system (economy, energy, and environment). It should be noted that the study did not decompose the aggregated system components into their individual components, identifying their interconnections and relative importance. For the purposes of the study, each component is assessed as a general area, with a corresponding impact assessment on the aggregated element.

To begin, it is needed to schematically represent the relationship between the components of the 3E system (Figure no.1).

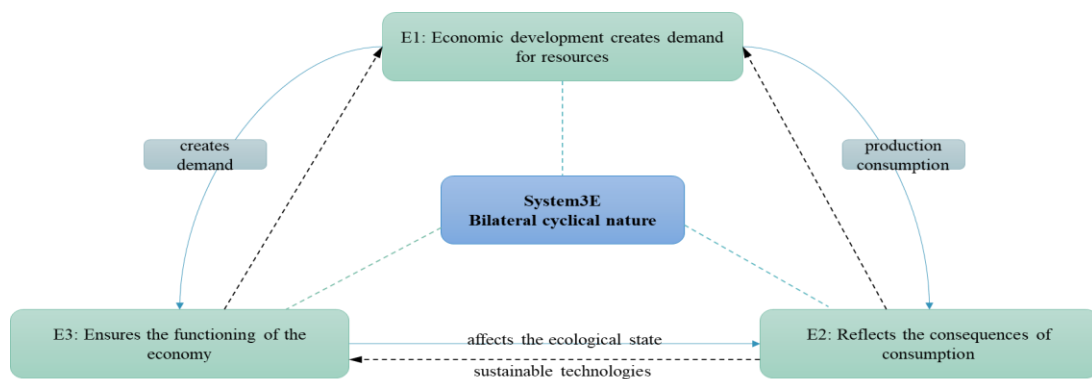


Figure no. 1: Relationship between the components of the 3E system  
(Source: Generated by the authors)

##### 4.1. Trends in the Use and Impact of Smart Technologies on the “Economy” component

Before analyzing the impact of smart technologies on economic components, it is worth noting that the implementation of smart technologies means not only the automation of certain operations, but also changes in management processes, forecasting, and determining the correlation between existing metrics, with the goal of influencing productivity and well-being. Thus, in the context of cost optimization and increased production reliability, smart technologies are being used through the development of a predictive maintenance system. This, in turn, helps reduce downtime, identify anomalies in the production process early, and identify potential failure indicators before they occur. To this end, factories use sensors that collect data on various parameters: temperature, maximum load level, humidity parameters, vibration, and other indicators characteristic of the current process or equipment. Using smart technologies capable of processing large amounts of data, as well as an artificial intelligence-based model, a forecast is generated regarding the likelihood of equipment failure.

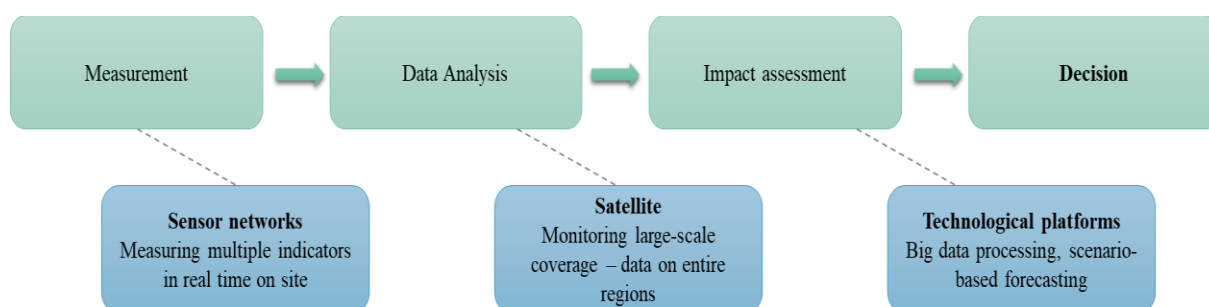
According to Organization for Economic Co-operation and Development (OECD Publishing, 2024), artificial intelligence acts as a general-purpose technology and has the potential to accelerate innovation in many sectors of the economy and become a driver of long-term sustainable development. At the same time, according to the report OECD Compendium of Productivity Indicators 2026, across all OECD countries, labour productivity increased by an average of 1.2% in 2024 which is twice the growth rate observed in 2023 (OECD Publishing, 2026).

When analyzing the risks that arise when implementing smart technologies, it is impossible not to note cyber threats expressed in attacks on technological infrastructure, data theft, dependence on IT giants, and dependence on IT infrastructure. According to the data presented in the EBA clearing report “Real-time transaction monitoring: The future of fraud fighting”, the use of various technologies such as generative artificial intelligence, image generation, deepfake, and the creation of clones of official websites lead to significant financial losses (EBA CLEARING, 2026). One example is a case of a 25 million USD transfer following a video conference attended by a fraudster posing as a CFO using deepfake technology. The problem is that the perception of material created by artificial intelligence is unable to distinguish natural reality from generative reality, which creates a number of risks in various areas.

The uneven distribution of investment in artificial intelligence and digital infrastructure between developed and developing economies is fueling digital inequality and creating the risk of further widening the economic development gap between countries. Achieving long-term positive economic impact is possible through a combination of technological innovation, effective risk management policies, human capital development, and inclusive digital transformation.

#### **4.2. Trends in the Use and Impact of Smart Technologies on the “Environment” component**

When analyzing the impact of smart technologies on an environmental component, it is important to note their role in shortening the assessment cycle and the corresponding decision-making based on multiple indicators, thereby shortening the assessment-decision cycle.

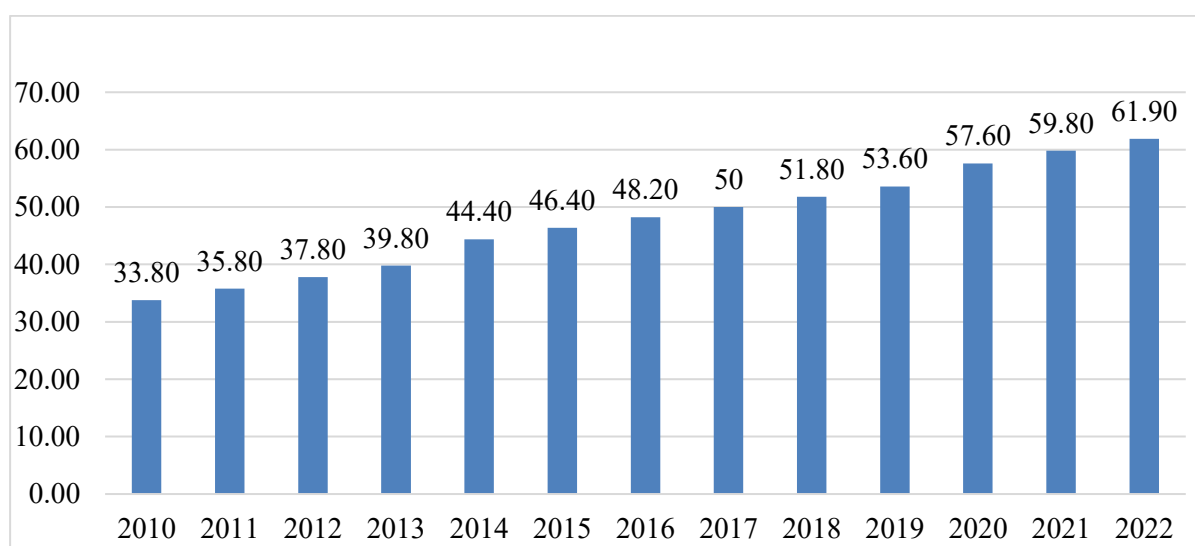


**Figure no. 2: The Evaluation-Decision cycle**  
(Source: Generated by the authors)

In Figure no. 2, the authors demonstrate a chain of interacting technologies: a network of sensors evaluates multiple indicators in real time, and through the use of data analysis, an impact assessment is performed, resulting in a decision being made based on the constructed scenarios. Analysis of practical cases of the application of smart technologies in the environment shows a significant positive impact.

According to Global Forest Watch (GFW, 2026), the use of smart monitoring technologies in Indigenous communities resulted in a 52% reduction in deforestation in the first year and a 21% reduction in the second year. Another example of the use of smart technology is the creation of Flood Hub, which covers basins in more than 150 countries, provides river flood forecasts up to 7 days in advance, and claims to reach approximately 700 million people; the expert layer includes approximately 250 000 forecast points (Flood Hub, 2026). As part of the study, the authors also examined the project *Destination Earth* - initiative of the European Commission to create a digital twin for forecasting various weather scenarios, hydrological, and air-quality extremes (EU, 2026).

At the same time, the use of technology leads to electrical emissions and the accumulation of toxic components (lead, mercury, cadmium). According to United Nations Institute for Training and Research (ITU, 2026), e-waste has nearly doubled since 2010, from 33.8 million metric tons to roughly 62 million tons in 2022. Figure no. 3 shows the growing trend of electrical waste, which proves the connection between the development of smart technologies and the negative impact on the environment.



*Figure no. 3: Global e-waste generation 2010-2022*

(Source: United Nations Institute for Training and Research; ITU, 2026)

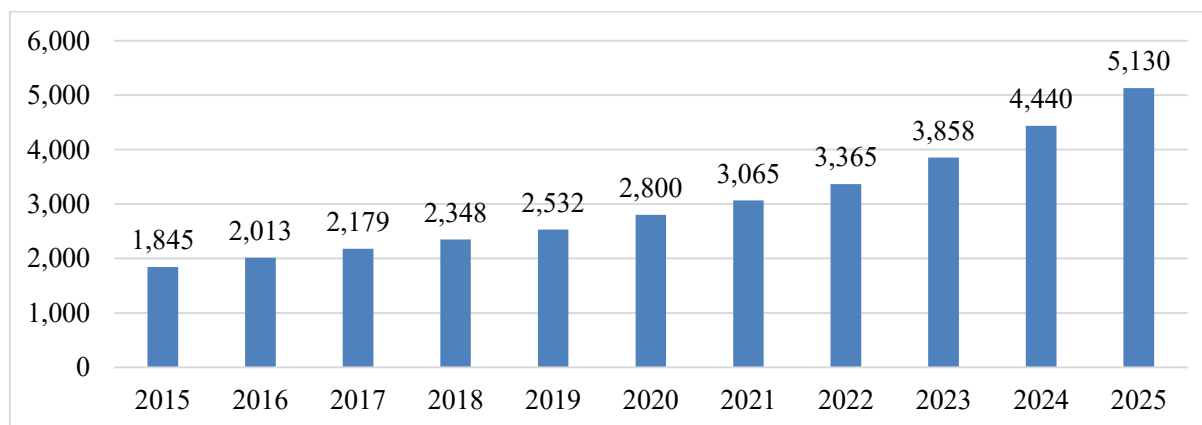
The authors note forecast, according to Schneider Electric report (Schneider Electric, 2023), for AI electricity use ranging from 14 (low forecast) to 18.7 (high forecast) gigawatts in 2028. Compared to 2023 data, in which this value was estimated at 4.5 gigawatts, the authors conclude that electricity use is growing at a significant rate.

#### **4.3. Trends in the Use and Impact of Smart Technologies on the “Energy” Component**

When analyzing the impact of smart technologies on the energy sector, it's insufficient to simply note the widespread adoption of renewable energy sources without assessing the transition to green energy. To manage a grid in which passive consumers are transformed into producers and consumers is necessary to use information and communication technologies to collect information on energy production and consumption. In other words, a two-way flow of not only electricity but also consumption data in real time is essential. Smart grids can mitigate the instability

of renewable energy sources through energy storage systems and self-healing processes, specifically by detecting fault zones and automatically rerouting power along a backup route, which in turn minimizes the overall outage time. Thus, the implementation of a Smart Grid solves problems that arise with traditional grids: peak load management, distribution optimization, and managing multiple generation and consumption points. Analyzing the energy sector in the context of smart technology, the authors note changes in the electric transport sector - as one example of the use of technology. For example, the EU's AFIR (Alternative Fuels Infrastructure Regulation), which has been in effect since April 2024, requires all public charging points built after April 13, 2024, to be capable of smart recharging (European Commission, n.d). This requirement changes the perception of charging stations and leads to a transition to a digital energy infrastructure. Further development of this approach will enable a bidirectional charge flow, in which the vehicle simultaneously serves as the battery for energy distribution. To connect the market to the grid, generate forecasts, identify threats, and ensure timely monitoring, a strategic initiative was adopted to create a digital twin of the European electricity grid. The TwinEU project involves 15 countries, 75 partners, and a €20 million fund. It aims to ensure the safe operation of infrastructure and the deployment of renewable energy sources (ITU, 2026).

In analyzing the impact of smart technologies on the energy sector, the authors note that the renewable energy market has been trending upward in recent years due to the emergence of more affordable technologies. Figure no. 4 demonstrates this trend.



*Figure no. 4: Cumulative renewable energy capacity worldwide from 2010 to 2025 (in TW)*

(Source: IRENA, Statista, 2026b)

At the same time, it is worth noting the emerging risks, primarily resulting in increased vulnerability to cyber threats on the critical grid and the shutdown of strategic power plants. Also, the use of the Internet of Things as a single point of entry for parameters makes it clear that peripheral zones are limited and ubiquitous accessibility via satellites is essential.

It's worth noting that researchers also note a "rebound effect", which is reflected in the fact that improving the energy efficiency of digital technologies leads to an increase in their actual use, which ultimately leads to an increase in total energy consumption instead of a decrease, Mhlanga (2025).

#### 4.4. Recommendations for Managing Emerging Risks

To ensure that smart technologies enhance benefits and prevent the emergence of additional risks, or allow risks to be managed, a number of measures must be taken both at the initial stage of implementation and at the post-implementation stage. In the table below, the authors highlight key recommendations for managing emerging risks when using smart technologies in 3E system components.

**Table no 1**  
*Key recommendations for managing emerging risks*

| Component | Micro-                                                                                                                                                                                                          | Macro-                                                                                                                                                                                             |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Economy   | <i>Audit of automated functions</i><br>Automation of processes must be ensured by periodic audits that will allow for the identification of incorrect settings.                                                 | <i>International standards for AI systems</i><br>The development of international standards in the field of artificial intelligence will ensure a unified approach to the application of the tool. |
|           | <i>Diversification of technology providers</i><br>To ensure business continuity in the event of supplier unavailability.                                                                                        | <i>International technology transfer programs</i><br>Accelerating the implementation of new technologies.                                                                                          |
|           | <i>Own data as a strategic asset</i><br>Smart technologies require quality data to function effectively.                                                                                                        | <i>Mandatory cybersecurity standards</i><br>Helps ensure technology protection as exposure grows.                                                                                                  |
|           | <i>Digital inclusion within the organization</i><br>To avoid gaps between employees from different areas within company.                                                                                        | <i>Providing training in smart technologies at the national level</i><br>To avoid social gaps between the population, preventing social stratification and inequality in access to income.         |
| Energy    | <i>Segmentation and isolation of critical nodes</i><br>An attack on an isolated area will not bring down the entire network.                                                                                    | <i>Mandatory standards for power grid protection</i><br>Formation of a unified approach and standards, safe development of infrastructure                                                          |
|           | <i>Monitoring data center and equipment consumption</i><br>Early detection of incidents and financial losses, forecasting, and energy efficiency. Supporting sustainable development and attracting investment. | <i>Renewable energy requirements for new data centers</i><br>Reducing the environmental impact of digital infrastructure by powering it with renewable energy.                                     |
|           | <i>Energy efficiency as a development KPI</i><br>Increase operational resilience and reduce costs.                                                                                                              | <i>International exchange of cyber threat intelligence</i><br>Timely detection of cyber threats and collective defense at the state level.                                                         |

| Component   | Micro-                                                                                                                                                                                                 | Macro-                                                                                                                                            |
|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| Environment | <i>Extended device lifecycle</i><br>Although life cycle extensions may lead to a decline in sales, adherence to sustainable development policies will attract investment and increase competitiveness. | <i>Mandatory "Right to repair"</i><br>Reducing electronic waste and using resources rationally.                                                   |
|             | <i>Environmental reporting for IT infrastructure</i><br>Identifying opportunities for energy efficiency improvements and managing energy costs.                                                        | <i>Mandatory disclosure of carbon footprints</i><br>Climate risk management, assessment of the real situation, stimulation of emission reduction. |
|             | <i>Maximizing recycled materials</i><br>Increasing resource efficiency and building a sustainable supply chain                                                                                         | <i>International fund for ecosystem restoration</i><br>Biodiversity conservation, increasing climate resilience at the global level.              |

(Source: Generated by the authors)

## 5. Conclusions

The study's findings demonstrate that the use of smart technologies is a key factor in the transformation of the modern economy, energy, and the environment. According to the study's synthesis of current trends, the implementation of smart technologies significantly enhances the potential for achieving sustainable development within the 3E system by increasing productivity, resource efficiency, reducing emissions, and, consequently, enabling informed decision-making based on big data analysis. Thus, the literature analysis confirmed the first proposition and demonstrated the positive effect of the implementation of smart technologies.

At the same time, the emerging risks identified during the study support the second proposition that the implementation of smart technologies has a dual nature. The same technology can simultaneously act as a development accelerator, leading to economic growth, but also pose a threat. These include high implementation costs, increased energy consumption by digital infrastructure, electronic waste and unequal access to technological benefits which were demonstrated in the analysis of negative consequences.

The findings confirm the need for a comprehensive analysis of the impact of smart technologies, along with their development potential. Based on the study, recommendations were identified that can be implemented at the micro and macro levels to achieve a balance between positive impacts and risk management to ensure sustainable development within the 3E system.

At the same time, the study has several limitations. It was based on a review of secondary literature and does not include primary quantitative data for confirming the propositions. Consequently, its conclusions are based on a synthesis of available data and do not demonstrate the magnitude of the causal relationships of the identified effects. Differences between countries, sectors and types of smart technologies may also affect the generalizability of the results. Thus, future research should empirically examine the formulated relationships and develop measurable indicators of the positive and negative affects of smart technologies within each 3E dimension.

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## Author Contributions

Conceptualization, D.I., Ca.O., Ch.O.; methodology, D.I., Ca.O.; validation, Ca.O.; formal analysis, Ca.O.; investigation, D.I., Ca.O., Ch.O.; resources, Ca.O., Ch.O.; data curation, Ch.O., Ca.O.; writing: original draft preparation, Ca.O.; writing: review and editing, D.I.; visualization, Ca.O.; supervision, D.I. All authors have read and agreed to the published version of the manuscript.

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