Digitalization and Energy in Attaining Sustainable Development

Subjects: Economics

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Digitalization significantly impacts energy consumption patterns, energy infrastructure, and the overall intensity of energy use. It represents a transformative force that can either increase energy demand through the proliferation of digital devices and data centers or decrease it through efficiency gains and smart energy management. The relentless advancement of digital technologies has the potential to significantly reshape the energy landscape as digital technologies become increasingly integrated into diverse sectors of the economy.

Keywords: consumption ; green energy ; environmental regulations ; green investments

1. Introduction

Achieving sustainable development goals (SDGs) [1][2][3][4][5][6] requires the development and implementation of new and effective instruments that consider ongoing trends in world development [7][8][9][10][11], such as digitalization, integrating sustainable development into all economic activities and levels [12][13][14][15]. It should be noted that sustainable development is a multifaceted concept that, at its core, seeks to balance environmental stewardship, economic growth, and social equity for current and future generations [16]. It provokes the transformation of the world through innovative approaches to solving complex challenges related to climate change, resource depletion, and social disparities. This concept encourages us to rethink economic models and societal structures to ensure a livable planet for future generations. Digitalization, as a multifaceted process, significantly shapes the contemporary landscape by intertwining with various aspects of our environment and society. Studies [17][18][19] underscore the complexity of this transformation, outlining the diverse array of both the positive and negative effects it evokes. On the positive side, digitalization has the potential to enhance efficiency and streamline processes across various sectors [20][21][22][23]. The integration of digital technologies often leads to a reduction in energy consumption [24][25][26][27][28][29][30], offering opportunities for sustainability and resource optimization [26][27][28][29][30]. Additionally, it can foster innovation, provide novel solutions to environmental challenges, and contribute to the development of cleaner, more sustainable technologies [31][32][33][34]. However, it is crucial to acknowledge the potential negative repercussions of digitalization, especially concerning its impact on the environment [35][36][37][38]. The increased reliance on digital technologies has resulted in a surge in energy consumption [36][37], contributing to concerns about energy intensity and the carbon footprint [39][40]. Additionally, the accelerated pace of technological advancements has provoked the generation of electronic waste (e-waste) [41][42], posing challenges for proper disposal and recycling. As societies worldwide navigate the complexities of digitalization, finding a delicate balance becomes imperative. Efforts to harness the positive aspects while mitigating the negative consequences involve implementing policies and practices that promote sustainable development. This includes investing in green technologies [43][44][45][46][47][48], developing efficient waste management systems [49][50][51], enhancing green logistics [52][53], and fostering a culture of responsible digital consumption [54]. However, digitalization is conducive to extending new management approaches [55][56][57][58][59][60][61] and requires developing relevant infrastructure [62][63][64][65][66][67][68], knowledge, and competencies [69][70][71][72][73].

The diverse perspectives on the impact of digitalization on the energy sector underscore the need for a comprehensive analysis of the relationship between digitalization and energy in EU countries. The EU has developed a comprehensive set of strategies aimed at addressing the escalating energy prices, as detailed in [74]. These strategies encompass a dual approach: on the one hand, they focus on the supply side by ensuring an adequate supply of natural gas and accelerating the transition towards renewable energy sources through policy instruments. On the other hand, the Commission's measures target the demand side, aiming to reduce the energy consumption of both households and businesses. However, a critical aspect that appears to have been overlooked in this framework is the role of digitalization. Digitalization significantly impacts energy consumption patterns, energy infrastructure, and the overall intensity of energy use. It represents a transformative force that can either increase energy demand through the proliferation of digital devices and data centers or decrease it through efficiency gains and smart energy management. Therefore, it should have been a key consideration for the European Union's authorities in formulating their energy strategy. By integrating digitalization into their approach, the European Commission could better address the complexities of energy consumption, structure, and intensity, and thus develop a more holistic and effective response to the ongoing energy crisis. This examination should concentrate on both the direct and indirect effects of digitalization on energy consumption, structure, and intensity. Understanding the character of this influence is crucial for policymakers, industry stakeholders, and researchers alike, as it allows for informed decision making in steering energy systems toward greater resilience and environmental sustainability.

2. Relationship between Digitalization and Energy Consumption

Scientists hold diverse perspectives on the interplay between digitalization and energy consumption. Researchers [75][76][77][78][79][80][81] envision enhanced efficiency through smart technologies [75][76][77], smart grids [78], and AI-driven optimizations in industrial processes [79][80][81]. However, scholars [82][83][84][85][86][87] have focused on the energy intensity of digital technologies, with high-performance computing and data centers being potential culprits. Studies [88][89][90][91][92] have shown that digitalization facilitates the better integration of renewable energy into grids, promoting sustainability. Nevertheless, scholars [93][94][95][96] have highlighted that the environmental impact of e-waste and the extraction of rare minerals from electronics cannot be ignored. One study [97][98][99] outlined that behavioral changes induced by digitalization, such as increased device usage and the adoption of smart technologies, alter energy consumption patterns. Moreover, the proliferation of data centers and cloud computing has raised concerns about centralized energy consumption [100][101][102]. However, Aithal [103] and Mishra and Singh [104] showed that ongoing technological innovations and solutions, including energy-efficient hardware and quantum computing, offer potential avenues for mitigating these challenges [105]. Analyzing the situation in EU countries reveals a discernible gap in investigations into the relationship between digitalization and energy consumption for EU countries considering energy consumption, the energy structure, and energy intensity.

3. Relationship between Digitalization and the Structure of Energy Usage

Xu et al. [106] noted that digitalization allows for the optimization of energy structures in China. In addition, Xu et al. [106] highlighted that the impact of digitalization on energy consumption is most significantly mediated by technological innovation, while the influence of digitalization on energy intensity is primarily mediated by human capital. In contrast, the distortion of the industrial structure plays the most substantial mediating role in shaping the impact of digitalization on energy structure. Ren et al. [98] concluded that the correlation between internet development and the energy consumption structure is notably negative. Internet development influences the energy consumption structure by way of economic growth, research and development (R&D) investment, human capital, financial development, and the industrial structure. Scholars [107] have confirmed that extending digital technology has provoked a decrease in the impact of the energy structure on carbon dioxide emissions. Zhang et al. [108] noted that digitalization provoked changes in the structure of energy usage in China. Moreover, the energy consumption structure impacts the attainment of sustainable development goals, particularly for carbon dioxide emissions. Noussan and Tagliapietra [109] argue that digital technologies lead to opposite effects on energy consumption and emissions in EU countries. The authors emphasize that an effective strategy is "responsible" digitization, which involves the development of sustainable mobility. In contrast, "selfish" digitization results in maximizing the benefits for the end consumer. Scholars [110] empirically justify that digitalization plays a moderating role, alleviating the impact of a 3.654% increase in energy consumption resulting from income inequality. This moderating influence is particularly noticeable in middle- and high-income countries spanning Europe, the Americas, and the Asia–Pacific region, and it remains effective in both free and nonfree economies. Through the use of dynamic SYS–GMM threshold panel models, this research uncovers a nonlinear connection between income inequality and energy consumption influenced by digitalization, offering international evidence of the interconnected dynamics involving digitalization, income inequality, and energy consumption. Ren et al. [98] examined the influence of internet development on energy consumption in China, with a focus on the mechanisms of transmission. The findings reveal a noteworthy positive association between internet development and overall energy consumption, as the internet contributes to increased energy usage through economic growth. On the other hand, there is a negative relationship between internet development and the structure of energy consumption, indicating that the internet shapes the energy consumption structure through factors such as economic growth, R&D investment, human capital, financial development, and the industrial structure. Additionally, empirical evidence demonstrates a substantial negative correlation between internet development and energy consumption intensity, suggesting that the internet facilitates a decrease in energy consumption intensity through similar influencing factors. Lange et al. [111] suggested that the growth of digitalization is conducive to increasing energy consumption.

4. Relationship between Digitalization and Energy Intensity

Scholars [112][113][114][115][116][117][118][119][120][121] argue that digitalization, by fostering technological advancements and efficiency improvements, lead to a reduction in energy intensity. This viewpoint suggests that smart technologies [122][123][124][125], data analytics [126][127][128][129][130][131][132], and automation can optimize energy consumption in various sectors, ultimately contributing to more sustainable practices. In contrast, skeptics [133][134][135] emphasize the potential for increased energy consumption associated with the growing demand for digital technologies. The proliferation of devices and data centers and the overall expansion of digital infrastructure may offset the gains achieved through efficiency measures. This perspective highlights the need for a holistic assessment that considers both the positive and negative aspects of digitalization on energy intensity. Another viewpoint [136][137][138][139] acknowledges the complex and nuanced relationship between digitalization and energy intensity, emphasizing that the impact is context-dependent. Factors such as the type of digital technology implemented, the overall energy mix in a region, and specific industry practices play crucial roles. This perspective suggests that a one-size-fits-all approach may not be suitable, and tailored strategies are necessary to optimize the balance between digitalization and energy intensity based on the unique circumstances of each situation.

One study [140] showed that digitization contributes to the economic growth of South Asia. Moreover, there is a negative correlation between energy intensity and economic growth [140]. The empirical results [141] indicate a predominantly positive asymmetric relationship between digital innovation, energy intensity, demographic change, and economic growth in Vietnam. Although minor distinctions are observed across different quantiles of the chosen indicators, the overall impact is favorable. Furthermore, the Granger causality analysis of quantiles reveals a bidirectional connection between digitalization, demographic dividends, and economic growth over the sample period. Moreover, unidirectional causality is identified from energy intensity to economic growth [141]. Scholars [141] have discovered a noteworthy adverse correlation between digitalization and energy intensity. Additionally, they identify a significant positive correlation between digital capital intensity and energy intensity. Lan and Wen [142] showed that the industrial digitalization of the manufacturing sector leads to a notable increase in energy intensity. Throughout the process of digital transformation, there is an initial increase followed by a subsequent decrease, forming an inverted U-shaped relationship. As of 2019, more than 80% of industries exhibited a level of digitalization below the inflection point [142].

The perspectives on the link between digitalization and energy intensity vary, encompassing optimistic views on efficiency gains, concerns about increased energy demand, and recognition of the context-specific nature of this relationship.

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