# The Double-Edged Sword: Unveiling the Impact of Digitalization on CO2 Emissions

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**Abstract:** Digitalization is a significant global trend aimed at optimizing business, society, and daily life to reduce carbon dioxide emissions. However, the connection between digitalization and carbon dioxide emissions remains unclear. To achieve sustainable development goals, it is crucial to significantly reduce fossil fuel consumption and greenhouse gas emissions. Despite growing research, the impact of digitalization on carbon emissions remains under researched. This study assessed the quantifiable impact of information and communication technology (ICT) use and access on carbon dioxide emissions in 90 countries in accordance with existing literature, and the results were compared based on the countries' level of development. The current study's independent and control variables include access to ICT, ICT use, country development level (CDL), GDP per capita, urbanization, and renewable energy use. Variance inflation factors were calculated to determine whether the used data series contains multicollinearity. The Levin-Lin-Chu constant test revealed that all variables are constant, and the PLM, PF, and PH tests demonstrated that the fixed effect model is the most appropriate method based on the data. The study found a significant effect of ICT use and access on CO2 emissions, with both having a positive relationship. The interaction of CDL with these variables was statistically significant, but the relationship between the two indicators of the use of ICT and carbon dioxide emissions depends on CDL. The relationship between access to ICT and CDL was not statistically significant, suggesting that the relationship remains constant at different levels of development in different countries. The generalizability of the study could be affected by the limited time period of 2007-2019 and should be replicated with a larger sample size. More research is needed to determine the effect of a country's ICT readiness index on environmental sustainability and carbon dioxide emissions. Other independent variables, such as emerging technologies like blockchain, AI, IoT, AR, and VR, should also be considered in future research.

**Keywords:** ICT, Carbon dioxide emission, fixed effect, countries development

## 1. Introduction

The 21st century is witnessing a digital revolution. Information and Communication Technologies (ICT) are rapidly transforming societies, promising a future of optimized resource use and sustainable practices. It can support sustainability by improving resource efficiency and promoting sustainable consumption and production patterns. We envision smart cities with efficient energy grids, remote work reducing commuting emissions, and paperless workflows minimizing waste.

However, this digital utopia faces a harsh reality: Incremental advances alone are insufficient to support sustainable futures since technology, particularly ICT, is currently not geared towards sustainability [1]. the very technology driving progress also leaves a growing environmental footprint. Increased energy consumption for data centers and electronic devices, coupled with the looming issue of e-waste, raises concerns about rising CO2 emissions.

While the concept of sustainable development emerged in the 1980s, with roots in earlier environmental movements, the precise impact of digitalization on achieving this goal remains unclear. The World Commission on Environment and Development defines sustainable development as "development that meets the needs of current generations without compromising the ability of future generations to achieve their needs and aspirations." To accomplish environmental objectives of sustainable development, fossil fuel use and greenhouse gas (GHG) emissions need to fall by roughly 45% by 2030. We could achieve net zero by 2050 if we could keep the temperature within 1.5 degrees Celsius [2]. Sustainable transition research is therefore providing comprehensive transformation toward new systems that provide suitable activities for GHG emissions reduction which will not only affect the environmental aspect of sustainability but also other 2 polars [3].

Recent studies in digitalization highlight the ambiguity surrounding digitalization's environmental impact. Chen, Despeisse and Johansson [4] acknowledges the lack of consensus on the issue. Understanding the role of ICT innovations, both intended and unintended, is crucial for developing effective mitigation strategies in the fight against climate change [5].

This intricate relationship between digitalization and environmental sustainability has become a point of contention. Some view ICT as a "fire accelerant," fueling environmental degradation through its energy demands. Others see it as a "game changer," with the potential to unlock pathways to a sustainable future by optimizing resource use [6, 7]. Existing literature often focuses on isolated elements of digitalization or specific sustainability aspects, failing to provide a holistic picture [8]. Therefore, this research seeks to bridge this gap by examining the overall impact of ICT use and access on CO2 emissions at the national level. Building on the uncertainty surrounding the environmental effects of digitalization, we speculate that a nation's economic standing may moderate the relationship between ICT and CO2 emissions. Developed nations with established infrastructure might experience different consequences from ICT growth compared to developing nations still building their digital foundation. By analyzing this interplay across development levels, we aim to move beyond simplistic views and gain a nuanced understanding. This study specifically addresses the question: Does digitalization act as a double-edged sword, promoting sustainability in some contexts while hindering it in others, depending on a nation's development level? Understanding this dynamic is crucial for policymakers and industry leaders seeking to harness the true potential of ICT for sustainable development across all levels. By exploring this question, we can unlock valuable insights that can inform strategies for harnessing the true potential of ICT for sustainable development across all levels. In the next parts of this article, after a brief review of the literature, we will describe the research methodology used in this article, and then we will discuss the results obtained and conclude and express future suggestions and limitations.

## 2. Literature review

Digital technology's rapid growth has undeniable environmental consequences[8]. The ever-increasing energy demands of data centers and ICT infrastructure raise concerns about exceeding sustainable limits. Studies predict that by 2030, digital technologies could account for 20% of total global electricity usage[4, 9, 10]. However, until recently, digitalization and sustainability were primarily studied individually and independently in top-tier journals; the relationship between digital technologies and climate change has gotten insufficient attention[8, 11]. The picture becomes even more complex when considering opposing viewpoints.

Some scholars argue that digitalization hinders sustainability efforts. Manufacturing and using ICT equipment generates electronic waste and relies on harmful materials. Furthermore, online activities and data storage contribute significantly to greenhouse gasses, approaching the emissions of the airline industry[10, 12-18]. On the other hand, digitalization presents opportunities for environmental progress[10, 12, 19]. ICT can facilitate the spread of environmental awareness and promote eco-friendly technologies. Digitalization can also improve efficiency in other sectors, potentially leading to an overall reduction in energy consumption. For instance, e-commerce and virtual meetings can replace physical activities that require travel and associated emissions [16]. The literature recognizes two main effects of ICT on CO2 emissions: the direct impact (footprint) and the indirect impact (enabling effects). Indirect effects arise from how ICT influences user behavior and alters existing processes. These indirect effects can be either positive, such as facilitating remote work and reducing commutes, or negative, such as increased reliance on personal delivery services [11, 12, 20, 21]. The overall impact of digitalization on CO2 emissions remains a subject of debate. While some studies find a positive correlation in developed nations, others highlight the negative environmental consequences of large-scale digital adoption, particularly in developing economies[5]. This ongoing debate underscores the need for further research. Understanding the various ways ICT can influence CO2 emissions, both directly and indirectly, is crucial for developing sustainable digitalization strategies. This study aims to contribute to this understanding by focusing on the potential of ICT to achieve environmental goals rather than the technical inner workings of the technology itself. By analyzing the existing arguments for and against digitalization's environmental impact, this research will explore how different contexts, developed versus developing countries, might influence this complex relationship.

For instance, Digital Economy and Society Index (DESI) 2021 mentions, Digital technologies are increasingly being adopted by industrialized countries, with countries like Denmark, Finland, Sweden, the Netherlands, and Estonia demonstrating advanced digitalization. The COVID-19 pandemic has accelerated the adoption of digital technology in developed countries, allowing businesses and citizens to adapt to remote work and digital communication. However, the level of digitalization in developing countries varies greatly, with some countries making significant strides but still facing challenges in infrastructure, affordability, and skill sets. Developing countries benefit less from digitalization in manufacturing and services trade than developed countries due to their comparative advantage in high-skilled labor, capital, and intangible assets. However, ongoing digitalization is likely to reduce costs of automation of low-skilled, labor-intensive routine tasks in high-income countries, reducing the incentive to outsource labor-intensive tasks and allowing developed countries to produce close to domestic markets [22]. Institutional barriers constrain digitalization of government budgeting in developing countries, such as outdated laws, paper document flows, nonuse of integrated system implementation approaches, and inadequate and unreliable online access[23]. The study by Majeed [24] explores the relationship between Information and Communication Technology (ICT) and environmental sustainability in developed and developing countries. The results show that ICT has the power to determine ecological future, but its favorable outcomes are observed only in developed countries, while adverse impacts prevail in developing countries. The study confirms the "Greening through ICT" hypothesis for developed countries and the "Environmental Kuznets" hypothesis, suggesting that the relationship between CO2 emissions and GDP per capita is non-monotonic. This research is the first of its kind to identify heterogeneous outcomes of ICT between developed and developing countries, suggesting that investment in ICT infrastructure is essential for environmental sustainability only in developed countries. Another research found that the prevalence of ICT is associated with low levels of CO2 emissions in low-income developing countries, but no clear relationship in high-income countries. ICT promotion can be a powerful tool to fight environmental degradation, particularly for least-developed countries [25].

## 3. Methodology

In this study, ICT data were utilized to quantify digitalization, as proposed by prior studies, and these data were retrieved and used from the International Telecommunication Union's database. According to the ITU, ICT-related data is divided into two categories: access and use. Data from the United Nations and the World Bank were used as the dependent and control variables, as well as the moderator. This study investigated data from 90 nations, 60% of which are developing countries and 40% of which are developed ones. These nations had the lowest missing rate among all countries with available data from 2007 to 2019, which was the common period of the data sets. The control variables included in the present study were gathered from previous studies [16, 26-31] Control variables used are GDP per capita PPP, urbanization, and the proportion of renewable energy use. There is a positive association between GDP per capita PPP and CO2 emissions, according to studies [13, 29, 32], but the relationship is not linear. Because of increasing energy demand and transportation needs, urbanization has been associated to higher CO2 emissions [14, 33, 34], however this effect is mitigated by the availability and use of renewable energy sources. Transitioning from fossil-fuel-based energy systems to renewable energy sources is critical for lowering CO2 emissions, however the success of renewable energy adoption varies by country and location. As a result, based on past research, it is essential to control the effect of these variables in our study [31, 35, 36]. To substitute missing numbers, we used extrapolation and interpolation techniques. Then, the unit root tests were carried out in order to use the appropriate panel data analysis method. Due to its capacity to manage cross-sectional dependence, heterogeneity, and provide valid inference in panel contexts, Levin-Lin-Chu unit root test method for panel data analysis was used in this study [37]. The panel data Fixed effect method is employed in this study, and we trained model using the R studio where we analyze impact of ICT use and access on CO2 emissions in model based on equation 1.

$$CO2_{i,t} = \beta_1 * ICT_{Use_{i,t}} + \beta_2 * ICT_{Access_{i,t}} + \beta_3 * CDL_{i,t} + \beta_4 * ICT_{Use_{i,t}} * CDL_{i,t} + \beta_5 * ICT_{Access_{i,t}} * CDL_{i,t} + \beta_6 * GDP_{i,t} + \beta_7 * URB_{i,t} + \beta_8 * REC_{i,t} + \varepsilon \,, i = 1, \dots, 90 \,,\ t = 2007, \dots 2019 \quad (1)$$

Using the aforementioned model, we compared the results of OLS, Random effect, and Fixed effect and decided which approach was superior based on related tests. Including the PLM (Lagrange Multiplier Test), PF (F test for individual effects) and Hausman Test, that determine Fixed effect method was the most effective method for existing model.

*Table 1. Variables and definitions.*

| Variable name | Abbreviation | Definition |
|---|---|---|
| Usage of information and communication technology | ICT Use | Percentage of individuals using the Internet |
| | | Fixed (wired) broadband Internet subscriptions |
| | | Active mobile broadband subscriptions |
| Access to information and communication technology | ICT Access | Fixed telephone subscriptions |
| | | Mobile cellular telephone subscriptions |
| | | International Internet bandwidth (Mbit/s) per Internet user |

| | | |
|---|---|---|
| Country development level | CDL | The fundamental criteria for this classification is based on meeting the thresholds defined by UN such as: per capita GNI, a human assets index and an economic and environmental vulnerability index |
| CO2 emission | CO2 | The amount of yearly CO2 emission by region. Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring. |
| Urban population | URB | Urban population refers to people living in urban areas as defined by national statistical offices. The data are collected and smoothed by United Nations Population Division. |
| Renewable energy consumption | REC | Renewable energy consumption is the share of renewable energy in total final energy consumption. |
| GDP per capita | GDP | GDP per capita based on purchasing power parity (PPP). PPP GDP is gross domestic product converted to international dollars using purchasing power parity rates. Data are in constant 2017 international dollars. |

## 4. Results and Discussion

Following empirical estimates, Table 2 indicates statistical summary of the data set and the Correlation. The finding suggests that the correlations between variables generally are weak while ICT use and ICT access are strongly correlated. The correlation value of 0.81 between ICT Use and ICT Access indicates that the two variables have a good association. This implies that improved access to ICT resources and infrastructure may lead to increased ICT utilization.

*Table 2. Statistical summary and Correlation matrix.*

High correlation may result in multicollinearity and cause problems with the model. Since multicollinearity problems among regressors might lead to erroneous estimations, we calculated variance inflation factors to quantify this issue. The VIF value expresses the degree of uncertainty in the coefficient estimates. High VIF values indicate a high correlation between a predictor variable and the other predictor variables, which can make it difficult to distinguish the individual effect of each predictor variable on the response variable. The VIF value in Table 3. indicates that the data series lacks potential multicollinearity because all values are less than 5.

*Table 3. The VIF result for model.*

*Table 4. Empirical result.*

As the results of model indicated in table4., Both access and use of ICT have a significant and positive effect on carbon dioxide emissions. And the normalized coefficients demonstrate that both have nearly the same effect on carbon dioxide emissions. However, the level of development of countries only moderates the relationship between the ICT use and the CO2 emissions. And the association of access to information and communication technology with CO2 is not regulated by the level of development of countries. This might be taken as the relation between access to information and communication technology and carbon dioxide emissions remains consistent at different degrees of development of countries. However, depending on a country's level of development, the relationship between the use of information and communication technology and carbon dioxide emissions varies, which can be attributed to differences in energy consumption or indirect effects on economic growth and industrial activities.

## 5.Conclusion

This study investigated the complex relationship between digitalization (ICT use) and CO2 emissions, considering the moderating effect of a nation's development level. While digitalization offers potential for sustainable development, its environmental footprint raises concerns. Our findings confirm the ambiguity surrounding this issue. We observed a positive impact of both ICT access and use on CO2 emissions, suggesting a potential conflict with sustainability goals. Interestingly, the level of development only moderated the relationship between ICT use and emissions, not access. This suggests that the environmental impact of using digital technologies is more nuanced and depends on a country's development stage. These findings resonate with recent research highlighting the inverted U-shaped relationship between the digital economy and CO2 emissions. While ICT can encourage energy-intensive practices initially, it might also lead to efficiency improvements in the long run [38]. Additionally, the varying impact of development levels aligns with studies suggesting benefits in high-ICT quality nations and drawbacks in others. These insights contribute to the ongoing debate on ICT's environmental impact [39]. Understanding how development moderates this relationship is crucial for policymakers. In developed nations, promoting clean energy infrastructure alongside digitalization might be key. Developing nations, on the other hand, could prioritize sustainable ICT adoption strategies to mitigate negative environmental effects. The impact of ICT on CO2 emissions is a major concern, however potential limitations include a small sample size and a scarcity of data sources. The study solely addresses the influence of ICT on CO2 emissions, neglecting the indirect consequences of digitalization and other environmental issues such as e-waste, resource depletion, and the other two aspects of sustainability. Future research could explore the specific mechanisms by which ICT use impacts CO2 emissions across different development levels. Additionally, investigating the role of policy interventions in shaping this relationship holds significant promise for achieving sustainable development through digitalization. In conclusion, there are some gaps that must be filled, and future research on this topic must be more extensive and nuanced.

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