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Examining the role of digitalization and gig economy in achieving a low carbon society: an empirical study across nations

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Introduction: This paper investigates the international relationship between digitalization, the gig economy, and low carbon development, providing valuable insights for governments and stakeholders seeking to advance sustainable development and a low-carbon society.

Methods: A large dataset comprising countries with varying degrees of digitalization and gig economy prevalence was analyzed to assess the impact of digitalization on the gig economy and its subsequent effects on greenhouse gas emissions.

Results: The study reveals that the impact of digitalization on the gig economy varies by income level, exhibiting a positive relationship in high-income countries and a negative relationship in low-income countries. Furthermore, the gig economy demonstrates a significant negative impact on greenhouse gas emissions, particularly CO2 emissions, indicating that its growth may support emissions reduction and facilitate the transition to a low-carbon society. The gig economy also mediates the connection between digitalization and low-carbon development.

Discussion: These findings carry substantial policy implications for governments and stakeholders working towards sustainable development and a low-carbon society. Moreover, the study highlights potential areas for future research, such as investigating the heterogeneous effects across income levels, exploring sectoral differences in the gig economy, and examining the dynamic nature of the gig economy and digitalization.

KEYWORDS

digitalization, gig economy, low carbon society, greenhouse gas emissions, CO2 emission

1 Introduction

The ongoing digital revolution, characterized by rapid technological advancements and the widespread adoption of digital platforms, has fundamentally transformed the way we live, work, and interact (Sutherland and Jarrahi, 2017; Chinoracký and Čorejová, 2019; Schor and Vallas, 2021). This transformation has also led to the development and expansion of e-government services, which have the potential to combat corruption in public sector service delivery in developing and transition economies (Sadik-Zada et al., 2022). Moreover, e-government initiatives have been shown to contribute to socio-economic development and offer solutions for the improvement of the efficiency and effectiveness of public administration (Niftiyev, 2022). In this context, various studies have shed light on the

role of digitalization in achieving a low carbon society across different domains, such as agriculture, finance, and manufacturing (Shen et al., 2022; Yang and Masron, 2022; Ma et al., 2022; Wang et al., 2022; Hao et al., 2023). Research has also emphasized the potential contributions of digital transition technologies, like AI, IoT, and big data analytics, to environmental, economic, and social sustainability (Rosário and Dias, 2022), as well as the influence of digital entrepreneurship on sustainable development goals (Herman, 2022; Wei et al., 2022). The South Caucasus region, as a rapidly developing post-Soviet area, has been gaining importance in international economic agreements due to increased partnerships between Eastern and Western countries, providing an interesting context to explore innovativeness trends (Niftiyev et al., 2021). This transformation has given rise to the gig economy, which refers to a labor market characterized by the prevalence of short-term contracts, flexible employment, and freelance work, as opposed to traditional long-term, full-time jobs (De Stefano, 2015; Graham et al., 2017; Thompson, 2018). Concurrently, there is growing global awareness and urgency to address the challenges posed by climate change and transition towards a low carbon society (Andersen et al., 2021; De las Heras et al., 2021). The Intergovernmental Panel on Climate Change (IPCC) has emphasized the need for immediate action in reducing greenhouse gas emissions to mitigate the impacts of climate change (IPCC, 2018).

Given these developments, there has been increasing interest in understanding the interplay between digitalization, the gig economy, and the pursuit of a low carbon society (Berg et al., 2018; Light and Miskelly, 2019). Several scholars have begun to explore the potential synergies and trade-offs between these phenomena, examining how digital platforms and the gig economy may contribute to reducing carbon emissions and fostering sustainable development (Zhang et al., 2022). In particular, digital platforms have been found to reduce transaction costs and facilitate decentralized and flexible work arrangements, which can lead to a more efficient allocation of resources, decreased commuting, and reduced environmental impact (Cohen and Kietzmann, 2014; Esposito De Falco et al., 2017; Asadullah et al., 2018). Moreover, the gig economy, enabled by digital platforms, has the potential to optimize the use of resources by promoting asset-sharing and more efficient logistics (Acquier et al., 2017; Frenken and Schor, 2019). For instance, sharing economy platforms like Uber and Airbnb have been suggested to improve resource utilization and reduce emissions (Bucher et al., 2016; Zervas et al., 2017). Research on the asymmetric and heterogeneous global impact of the digital economy on energy transition (Shahbaz et al., 2022) highlights the varying effects of digitalization across different regions. Additionally, studies have established connections between digital and green factors for green competitive advantage (Rehman et al., 2023) and demonstrated the significant improvement of green transition by "Internet plus" in various sectors (Li et al., 2023). The relationships between digital transformation and sustainability adoption in companies have also been explored (Pînzaru et al., 2022), while research has developed a combined conceptual framework of the digital sustainable value cycle (Baranauskas and Raišienė, 2022). Furthermore, the role of technological innovation and city bank loans in driving clean energy development through the digital economy has been emphasized (Chen, 2022).

However, the relationship between digitalization, the gig economy, and sustainability is complex and multifaceted, and the potential environmental benefits of these phenomena should not be taken for granted. Some studies have raised concerns about the rebound effects of digitalization and the gig economy, whereby increased resource efficiency may lead to higher consumption levels and offset potential environmental gains (Wosskow, 2014; Pohl et al., 2019). Furthermore, there is a growing body of research examining the social and economic dimensions of digitalization and the gig economy, such as labor rights and income inequality (Wood et al., 2019; Healy et al., 2020; Keith et al., 2020; Smith et al., 2021). These aspects are crucial to consider when assessing the overall sustainability of digitalization and the gig economy, as they may have indirect implications for environmental outcomes (Van Doorn, 2017; Mazzucato, 2018).

In light of these debates, this paper aims to contribute to the existing literature by providing a cross-national empirical study that examines the role of digitalization and the gig economy in achieving a low carbon society. Specifically, we aim to address the following research questions.

- What impact does digitalization have on the labor market, particularly with regard to the gig economy?
- How does digitalization, through its influence on the labor market and the gig economy, affect low-carbon society development?

To achieve this, we will first review the relevant literature on digitalization, the gig economy, and low carbon societies, focusing on the theoretical mechanisms that link these phenomena. Next, we will present our research methodology, including the data sources, variables, and analytical techniques employed in our empirical analysis. We will then discuss the results of our cross-national study, highlighting the key findings and their implications for policy and practice. Finally, we will conclude by summarizing the main contributions of our research and outlining potential avenues for future research in this area.

2 The logical mechanism of digitalization, gig economy, and low carbon society development

Figure 1 illustrates the logical mechanism of digitalization, gig economy, and low carbon society development. It shows how the digital economy contributes to reduced transaction costs and flexible employment patterns, which in turn lead to the emergence of the gig economy. The gig economy encompasses telecommuting, social logistics networks, and asset sharing, which have both positive and negative environmental impacts. Figure 1 demonstrates the interplay of these elements in shaping the development of a low carbon society.

2.1 Digitalization promotes gig work as mainstream employment mode

Primarily, employment models are classified as either employed or self-employed. The former is dependent on a business, whereas the latter is a model of self-employment in which an individual is not

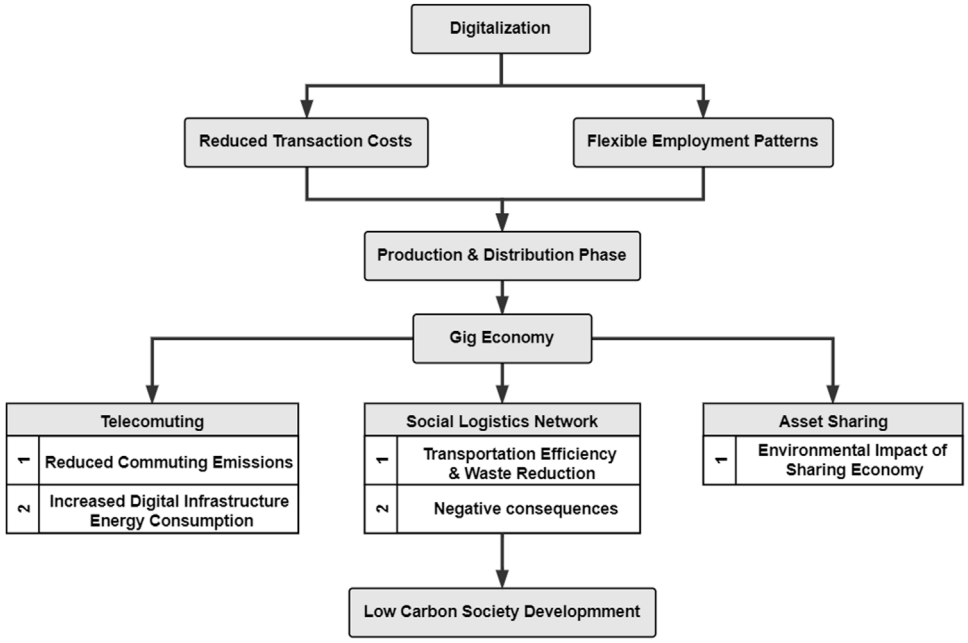

FIGURE 1
The theoretical framework of digitalization, gig economy, and low carbon society development.

reliant on an employer and forms the basis of the contingent labor economy. The selection of an employment model largely depends on whether a company is a significant organization type. Firms and markets are two options for economic organization, according to Coase's theory of the nature of the firm, a fundamental economic theory (Coase, 1991). This theory compares the transaction costs of the market with the administrative costs of the firm and argues that firms emerge to save on transaction costs when markets fail to perform their tasks efficiently (Figure 1 component: Digitalization - > Reduced Transaction Costs, Flexible Employment Patterns).

The rapid decline of market transaction costs, enabled by the growth of the digital economy, reduces the need for business organization and encourages more flexible employment patterns (Nagle et al., 2020). This can be discussed from both the production and distribution phases of economic production perspectives (Figure 1 component: Production & Distribution Phase).

The application of digital network platforms during the production phase can effectively reduce three types of market transaction costs: ex ante communication costs, ex post supervision costs, and ex post tracking costs. Digital platforms provide all participants with comprehensive product and service information, automated interaction, digital evaluation systems, and online support, thereby reducing communication costs and enhancing the efficiency and convenience of transactions. By providing automated tools and technologies, the digital network platform can effectively reduce the cost of ex-ante supervision of production (Wisetsri et al., 2022). Reducing the need for manual supervision, automated monitoring systems, supply chain management systems, and integrated digital tools can monitor the production process in real time (Pryanikov and Chugunov, 2017). Last but not least, digital web platforms reduce the cost of ex post tracking in production and play a crucial role in enhancing market oversight. Data collection and storage, automated production tracking systems, user-friendly data analysis tools, and real-time monitoring of production data can reduce the need for manual production supervision and tracking.

The growth of the digital economy and the expansion of telecommuting platforms has increased the employment opportunities available to self-employed individuals (Figure 1 component: Production & Distribution Phase - > Gig Economy). Telecommuting can reduce employees' commuting expenses, conserve office space resources, and improve their work efficiency and work-life balance (Gashi et al., 2022). Consequently, the gig economy is becoming an important labor market development trend. By providing a centralized communication and organization platform, digital network platforms enable a large number of flexibly employed individuals to access the production process quickly and efficiently (Rani and Furrer, 2021). This creates a social logistics network, which is extremely useful for physical transactions requiring specialized operations. Not only does the formation of this specialized production and distribution model significantly reduce operating costs for businesses, but it also enables them to enhance the quality and effectiveness of their services.

While digitalization and the gig economy can offer numerous benefits in terms of flexibility and employment opportunities, it is important to acknowledge their potential drawbacks as well. The gig economy has been criticized for fostering precarious work conditions, eroding labor rights, and perpetuating income inequality (Wood et al., 2019). Many gig workers lack job security, access to social protection, and collective bargaining power, which can lead to exploitation and vulnerability

(De Stefano, 2015; Graham et al., 2017). Additionally, the rise of digital platforms has led to protests and legal battles over the classification of gig workers as independent contractors rather than employees, further highlighting the need for a critical examination of this employment model (Aloisi, 2015; Cherry, 2019). It is essential to consider these aspects when assessing the overall impact of digitalization and the gig economy on employment, as they underline the fact that the gig economy is not a panacea for unemployment or a replacement for government and state institutions.

2.2 Gig economy and low carbon society development

The gig economy's contribution to low-carbon society development is multifaceted, with both positive and negative aspects that need to be considered.

In the production phase, the gig economy promotes telecommuting and independent contractor models, which can lead to a decrease in commuting expenses and contribute to low-carbon society development (Figure 1 component: Telecommuting - > Low-carbon society development). Telecommuting and flexible employment models enable businesses to reduce commuting-related costs and foster a sustainable, low-carbon environment. However, the literature tends to overlook the environmental costs of increased reliance on digital technologies and data centers for remote work (Malmodin and Lundén, 2018). More research is required to evaluate the net environmental impact of telecommuting, considering both reduced commuting emissions and increased energy consumption from digital infrastructure.

In the distribution stage, the gig economy's social logistics network streamlines traditional transactions, optimizing and organizing societal resources for economic and environmental improvements (Rani and Furrer, 2021) (Figure 1 component: Social logistics network - > Low-carbon society development). The network increases transportation efficiency and reduces waste, facilitating low-carbon society development and green economic growth (Geissinger et al., 2020). However, potential negative consequences, such as increased vehicle emissions and congestion in urban areas due to on-demand services, as well as a throwaway culture fostered by the gig economy's focus on convenience, warrant further investigation (Cohen and Kietzmann, 2014).

Lastly, the gig economy promotes efficient resource use by encouraging asset sharing, such as vehicles, tools, and workspaces, reducing the need for new production and associated carbon emissions (Martin, 2016) (Figure 1 component: Asset sharing - > Low-carbon society development). Sharing economy platforms can lower the environmental impact of consumption and waste generation, supporting low-carbon society development. However, concerns remain about the unintended consequences of the sharing economy, such as increased consumption due to lower access costs and the varying environmental impacts of different shared resources and user behaviors (Frenken and Schor, 2019).

Building upon the research questions, literature review, and theoretical analysis, we propose the following hypotheses.

H1: • Digitalization will lead to the transformation of a portion of a country's employed workforce into gig workers, influencing the structure and dynamics of the labor market.

H2: • The gig economy plays a pivotal role in mediating the impact of digitalization on low-carbon society development by promoting telecommuting, resource sharing, and more efficient logistics networks. However, this relationship may be influenced by various factors, such as the net environmental impact of telecommuting, potential negative consequences of on-demand services, and the diverse development levels and regulatory environments of different countries.

By analyzing a comprehensive dataset encompassing countries with varying degrees of digitalization and gig economy prevalence, we aim to identify patterns and relationships that can guide policymakers and stakeholders in their pursuit of sustainable development.

3 Data

3.1 Variables

Due to the significance of greenhouse gas emissions on a global scale, this paper utilizes panel data from the World Bank covering 185 countries. The World Bank provides extensive information on numerous economic, social, and environmental indicators compiled from countries around the world. These data resources include the World Development Indicators (WDI), which comprises more than 1,600 indicators on topics such as poverty, education, health, and the environment. In addition, the World Bank provides information on specialized subjects such as climate change, gender equality, and financial inclusion.

After excluding samples with missing values for the selected variables, the final dataset consists of 185 valid national samples, totaling 5,030 observations, from 1990 to 2019. This study's dependent variables are total greenhouse gas emissions (kt of CO2 equivalent), CO2 emissions (kt), Methane emissions (kt of CO2 equivalent), and Nitrous oxide emissions (kt of CO2 equivalent). These variables facilitate the assessment of low-carbon situations across countries and time periods. Climate Watch provides the greenhouse data, and the dependent variables are incorporated into the regression model after exponential transformation. All dependent variables are one period behind their respective independent variables.

In this study, the independent variables are a country's digitalization and gig economy status. Data from the International Telecommunication Union's (ITU) World Telecommunication/ICT Indicators Database is used to calculate a country's level of digitalization based on the proportion of its population that uses the internet (% of population). The gig economy is evaluated using the International Labour Organization (ILO) Database's self-employed (percentage of total employment) metric.

In addition, control variables such as national GDP, total national population, percentage of working-age population (ages 15–64) in total national population, sex ratio (male to female) in total national population, and countries' income level are included in this study. These time-varying control variables help to build our fixed-effects model.

TABLE 1 Variables statistics (*N* = 5,030).

	Mean	Std. Dev	Min	Max
Internet penetration (Percentage of population using the Internet)	22.763	28.678	0.000	99.701
Self-employed workers (as a percentage of total employment)	43.236	28.116	0.410	98.960
CO2 emissions (kt)	142958.000	654210.900	0.000	10700000.000
Total greenhouse gas emissions (kt of CO2 equivalent)	198530.600	801856.400	10.000	12700000.000
Methane emissions (thousand metric tons of CO2 equivalent)	38519.530	109332.200	0.000	1176140.000
Nitrous oxide emissions (thousand metric tons of CO2 equivalent)	13899.730	42454.650	0.000	552360.000
GDP (billion)	2556.750	11700.830	0.281	213810.000
Percentage of working-age population (ages 15–64) in total national population	61.988	7.137	46.097	86.079
National total Population	31300000.000	124000000.000	10408.000	1410000000.000
Sex ratio (male to female) in total national population	49.979	2.741	45.195	76.606
Low-income counties	0.238	0.426	0.000	1.000
Lower-middle-income counties	0.269	0.443	0.000	1.000
Upper-middle-income counties	0.206	0.405	0.000	1.000
High-income counties	0.287	0.452	0.000	1.000

Internet penetration, self-employed workers rates, greenhouse gas emissions, and economic factors vary significantly between countries, as shown by Table 1 descriptive statistics, which reflect diverse levels of development and environmental performance. The average percentage of the population that uses the internet is 22.760%, with a standard deviation of 28.680%, indicating a wide variation in Internet penetration across countries. Maximum value is 99.700%, minimum value is 0.000%. The mean rate of self-employment is 43.240 percent, with a standard deviation of 28.12 percent, indicating substantial variation in self-employment levels. Minimum value is 0.41 percent, and maximum value is 98.960 percent. Average CO2 emissions are 142,958 kt, with a large standard deviation of 654,210,9 kt, indicating that there are significant differences in emissions between countries. The minimum value is 0 kt, and the maximum value is 10,700,000 kt. The average total emissions of greenhouse gases are 198,530.6 kt, with a standard deviation of 801,856.4 kt. The minimum value is 10 kg, while the maximum value is 12,700,000 kg. The standard deviation of the average methane emissions is 109,332,2 thousand metric tons. Maximum value is 1,176,140, minimum value is 0. The standard deviation of the mean Nitrous oxide emissions is 42,454.65 thousand metric tons.

3.2 Methodology

In this study, we use a two-way fixed effects regression model to analyze the impact of digitalization on gig economy and the subsequent effects on low carbon emissions. The two-way fixed effects model helps control for unobserved individual and time-specific effects, enabling us to focus on the relationship between the variables of interest. The two-way fixed effects regression model can be mathematically specified as follows:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 Z_i + \beta_3 T_t + \beta_4 Z_i T_t + \varepsilon_{it}$$

where:

Y_{it} is the dependent variable, which can be either low carbon emissions or the impact of digitalization on self-employment. X_{it} represents the mediator variable, which is self-employment. Z_i is a vector of individual-specific fixed effects, which account for all time-invariant heterogeneity across individuals. T_t is a vector of time-specific fixed effects, which account for all time-specific heterogeneity across time periods. $Z_i T_t$ represents the interaction between the individual-specific fixed effects and the time-specific fixed effects, which captures unobserved time-varying factors affecting the dependent variable. β_0 is the intercept term. β_1 represents the direct effect of the independent variable (Internet penetration for the impact of digitalization on gig economy; self-employed workers for the impact of gig economy on low carbon emissions). β_2 represents the coefficient for the mediator variable (self-employed workers for the impact of digitalization on self-employment; Internet penetration for the impact of self-employment on low carbon emissions). β_3 represents the coefficient for the control variables, including GDP, Percentage of working-age population (ages 15–64), National total Population, and Sex ratio (male to female) in total national population. β_4 represents the coefficient for the interaction term (Internet penetration multiplied by self-employment). ε is the error term.

We divide our analysis into three parts: the impact of digitalization on gig economy, the impact of gig economy on low carbon emissions, and the mediation effect of gig economy on the relationship between digitalization and low carbon emissions. We further stratify the analysis by income levels (low income, lower middle income, upper middle income, and high income).

For the impact of digitalization on gig economy, we use the following independent variables: Internet penetration, GDP,

TABLE 2 Fix-effect model results of impact of digitalazation to gig economy.

	(1)	(2)	(3)	(4)	(5)
	Dependent variables: Self-employed workers				
	Total sample	Low-income counties	Low-middle-income counties	Upper-middle-income counties	High-income counties
Internet penetration	0.021***	−0.162***	0.0131	0.009	0.025***
	(0.004)	(0.037)	(0.015)	(0.011)	(0.006)
GDP (billion)	−4.59e-05***	−0.001	−9.90e-05	2.78e-05	3.83e-05
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Percentage of working-age population (ages 15–64) in total national population	−0.196***	−0.686***	−0.135**	0.046	0.042
	(0.024)	(0.062)	(0.062)	(0.065)	(0.027)
National total Population	−1.23e-08***	2.35e-09	−6.47e-08***	−1.19e-07***	−5.59e-08
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Sex ratio (male to female) in total national population	−0.042	−0.919***	−0.098	−1.904***	0.224***
	(0.083)	(0.290)	(0.343)	(0.264)	(0.063)
Lower-middle-income counties	−2.626***				
	(0.215)				
Upper-middle-income counties	−2.234***				
	(0.305)				
High-income counties	−2.083***				
	(0.425)				
Year	√	√	√	√	√
Constant	60.730***	160.400***	63.730***	127.100***	3.331
	(3.905)	(14.720)	(16.200)	(13.030)	(2.905)
Observations	5,030	1,312	1,441	997	1,280
R-squared	0.320	0.422	0.288	0.301	0.297

Note: Standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$; The reference of income level is low-income countries.

Percentage of working-age population (ages 15–64), National total Population, Sex ratio (male to female) in total national population, and dummy variables for different income levels. For the impact of gig economy on low carbon emissions, we use the independent variables self-employed workers and the same control variables as before. For the mediation effect of self-employment, we include both Internet penetration and self-employed workers as independent variables, along with an interaction term (Internet penetration multiplied by self-employment) and the same control variables as before.

4 Empirical results

4.1 Results of the impact of digitization on the gig economy

We use the R programming language to create the two-way fixed effect model. The impact of digitalization on the gig economy is illustrated in Table 2 by a fixed-effect regression analysis using the proportion of self-employed workers in total employment as the dependent variable. The analysis considers the total sample, low-income countries, low-middle-income countries, upper-middle-income countries, and high-income countries individually.

The coefficient for Internet penetration is positive and statistically significant at the 1% level (0.0214***) in the total sample (Model 1), indicating a positive relationship between Internet penetration and self-employment. As Internet penetration increases, the proportion of self-employed workers in the total labor force tends to rise as well. Other control variables, such as GDP, the proportion of the national population aged 15 to 64, the national total population, and the proportion of males in the national population, yield mixed results.

GDP and national total population coefficients are negative and significant at the 1% level, suggesting that an increase in GDP and population size results in a decrease in the proportion of self-employed workers. This could be due to the fact that as countries develop economically, more formal job opportunities are created, which may reduce the need for self-employment. Additionally,

larger populations may create more competition for self-employment opportunities, leading to a decrease in the proportion of self-employed workers.

The proportion of ages 15–64 and percentage of males coefficients are negative and significant at the 1% and 10% levels, respectively. This indicates that an increase in the proportion of working-age population and males in the national population leads to a decrease in self-employment. A possible explanation for this could be that countries with a higher proportion of working-age population have more opportunities for formal employment, making self-employment less appealing. Similarly, a higher proportion of males in the population might be correlated with more traditional employment opportunities, resulting in fewer self-employed workers.

In low-income countries (Model 2), the coefficient for internet penetration is negative and statistically significant at the 1% level (−0.162***), indicating that an increase in Internet penetration leads to a decline in self-employment. The proportions of people aged 15 to 64 and men in the national population are also negative and statistically significant at the 1% level, indicating similar effects as mentioned earlier. The coefficient for Internet penetration in low- and middle-income countries (Model 3) is positive but not statistically significant (0.013). This indicates that the relationship between Internet penetration and self-employment in these countries is not significant. Similar to low-middle-income countries, the coefficient for Internet penetration in upper-middle-income countries (Model 4) is positive but not statistically significant (0.009). At the 1% level, there is a negative and statistically significant relationship between the proportion of males in the national population and the national population. In high-income countries (Model 5), the coefficient for Internet penetration is positive and statistically significant at the 1% level (0.025***), indicating a robust positive association between Internet penetration and self-employment. This may be attributed to the greater availability of digital platforms, more advanced digital infrastructure, and the prevalence of digital skills among the workforce in high-income countries, which facilitate the growth of the gig economy. At the 1% level, the proportion of males in the national population has a positive and statistically significant relationship. This suggests that in high-income countries, an increase in the proportion of males in the population is associated with an increase in self-employment. This could be due to the fact that high-income countries offer more diverse self-employment opportunities, which might appeal to a larger portion of the male population.

In general, the empirical analysis reveals that the impact of digitalization on the gig economy is dependent on a country's income level. The relationship between internet use and self-employment is positive and statistically significant for the entire sample and high-income countries. However, it is negative and statistically significant for low-income countries. For countries classified as lower-middle-income and upper-middle-income, the impact of digitalization on the gig economy is not statistically significant.

Several factors, such as differences in economic development, labor market structures, access to technology, and the nature of self-employment, contribute to the varying outcomes in countries with different levels of income. Higher-income nations typically have more advanced economies with a higher degree of digitalization, in terms of economic development. This creates a more favorable environment for the success of the gig economy. In contrast, economies in low-income countries are less developed, with traditional industries and informal labor markets dominating, limiting the growth potential of the gig economy (Anwar and Graham, 2020). Labor market structures in high-income countries are frequently characterized by greater flexibility and a greater number of opportunities for self-employment. These markets foster the expansion of the gig economy more than others (Katz and Krueger, 2019). In contrast, labor markets in low-income countries may be more rigid and offer fewer opportunities for self-employment, thereby impeding the development of the gig economy. Access to technology: In terms of Internet penetration, digital infrastructure, and access to digital tools and services, countries with a higher *per capita* income are typically more advanced. This promotes the adoption of digital platforms that facilitate the gig economy. In low-income nations, limited access to technology and lower Internet penetration rates can impede the expansion of the gig economy. The nature of self-employment can vary depending on a person's income level. Self-employment opportunities in high-income countries frequently include freelance work, digital platforms, and small businesses that benefit from digitalization. Self-employment opportunities in low-income countries are more likely to be concentrated in the informal sector, where digitalization may have a smaller impact. Education and skills: In general, high-income countries have a more educated labor force with advanced digital skills, allowing individuals to leverage digital technologies for self-employment (OECD, 2019). In low-income countries, the workforce may lack the skills and education necessary to capitalize on digitalization, thereby limiting the expansion of the gig economy. Government policies and regulations: Government policies and regulations in high-income countries may be more conducive to digitalization and the expansion of the gig economy (World Bank, 2018). In contrast, low-income nations may lack the required regulatory framework or implement policies that discourage self-employment and digitalization. Digitalization is likely to have a greater impact on the gig economy in countries with higher levels of economic development, better access to technology, more flexible labor markets, and a supportive regulatory environment.

4.2 Results of the impact of gig economy on the low carbon development

Table 3 displays the impact of the gig economy on low-carbon development as determined by a fixed-effect regression analysis. The results indicate that a significant correlation exists between an increase in the proportion of self-employed individuals and a decrease in total greenhouse gas emissions, CO2 emissions, methane emissions, and nitrous oxide emissions. In all four models, this negative relationship is statistically significant at the 1% level.

Other control variables, such as GDP, the proportion of the national population between the ages of 15 and 64, the national total population, and the proportion of males in the national population, are also significantly correlated with the dependent variables. The

TABLE 3 Fix-effect model results of impact of Gig economy to low carbon society development (*N* = 5030).

	(6)	(7)	(8)	(9)
	ln (Total greenhouse gas emissions)	ln (CO2 emissions)	ln (Methane emissions)	ln (Nitrous oxide emissions)
Self-employed workers	−0.016***	−0.028***	−0.009***	−0.006***
	(0.001)	(0.001)	(0.001)	(0.001)
GDP (billion)	−2.02e-06***	−5.86e-06***	−2.64e-06***	−3.56e-06***
	(0.000)	(0.000)	(0.000)	(0.000)
Percentage of working-age population (ages 15–64) in total national population	0.030***	0.036***	0.015***	0.023***
	(0.001)	(0.002)	(0.001)	(0.001)
National total Population	1.91e-09***	2.15e-09***	1.16e-09***	1.57e-09***
	(0.000)	(0.000)	(0.000)	(0.000)
Sex ratio (male to female) in total national population	0.060***	0.032***	0.068***	0.054***
	(0.005)	(0.008)	(0.006)	(0.004)
Lower-middle-income counties	0.053***	0.143***	−0.001	0.053***
	(0.012)	(0.020)	(0.015)	(0.012)
Upper-middle-income counties	0.052***	0.086***	−0.038*	0.033*
	(0.018)	(0.029)	(0.021)	(0.018)
High-income counties	0.027	−0.048	−0.097***	−0.037
	(0.025)	(0.041)	(0.029)	(0.025)
Year	√	√	√	√
Constant	6.070***	6.521***	5.076***	3.973***
	(0.235)	(0.389)	(0.276)	(0.235)
R-squared	0.516	0.495	0.190	0.314
Number of countries	185	185	185	185

Note: Standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$; The reference of income level is low-income countries.

income level of countries, which is represented by lower-middle-income, upper-middle-income, and high-income countries, also has varying effects on the various emission reduction measures. Different R-squared values for the models suggest varying levels of explanatory power. Model (6) demonstrates the highest R-squared value at 0.516, followed by Model (7) at 0.495, Model (9) at 0.314, and Model (8) at 0.190.

In comparison to total greenhouse gas emissions, methane emissions, and Nitrogen oxide emissions, the impact of the gig economy on low carbon gas emissions is most pronounced for CO2 emissions. The effect is measured by the self-employed (percentage of total employment) variable's coefficient values, which are −0.016, −0.028, −0.009, and −0.006, respectively. This indicates that the gig economy has the greatest impact on CO2 emissions, as the coefficient's magnitude is the greatest.

Among the various types of greenhouse gas emissions, gig economy may have the greatest impact on CO2 emissions for several reasons. (i) Self-employment is a defining characteristic of the gig economy, which frequently includes sectors with lower CO2 emissions than traditional, full-time employment sectors. Self-employed individuals may, for instance, work primarily in the service industry or on digital platforms (Lehdonvirta, 2018), which tend to have a smaller carbon footprint than the manufacturing and heavy industries, which emit more CO2. (ii) Individuals who are self-employed frequently have flexible working hours and locations, resulting in distinct energy consumption patterns. For instance, working from home can reduce the need for daily commuting, thereby reducing CO2 emissions from transportation. Additionally, self-employed people may have a greater incentive to invest in energy-efficient technologies or adopt sustainable practices to reduce their operational costs, which can lead to a reduction in CO2 emissions. (iii) Gig economy workers typically operate on a smaller scale compared to employees of large organizations. Due to the decreased demand for resources and infrastructure, smaller-scale operations typically result in lower energy consumption and CO2 emissions. (iv) Governments may implement policies that encourage low carbon emissions in industries with high rates of self-employment. For instance, tax credits or subsidies for using energy-efficient technologies or promoting renewable energy sources can

TABLE 4 Results of Mediation effect of gig economy for impact of digitalazation to low carbon society development (*N* = 5030).

	(10)	(11)	(12)
	Dependent variable: Total greenhouse gas emissions after logarithmic transformation		
Internet penetration	−0.004***		−0.004***
	(0.000)		(0.000)
GDP (billion)	5.68e-07	−2.02e-06***	9.42e-08
	(0.000)	(0.000)	(0.000)
Percentage of working-age population (ages 15–64) in total national population	0.030***	0.030***	0.026***
	(0.001)	(0.001)	(0.001)
National total population	1.48e-09***	1.91e-09***	1.31e-09***
	(0.000)	(0.000)	(0.000)
Sex ratio (male to female) in total national population	0.082***	0.060***	0.083***
	(0.005)	(0.005)	(0.005)
Lower-middle-income counties	0.077***	0.053***	0.018
	(0.013)	(0.012)	(0.012)
Upper-middle-income counties	0.085***	0.052***	0.026
	(0.018)	(0.018)	(0.018)
High-income counties	0.143***	0.0271	0.069***
	(0.026)	(0.025)	(0.025)
Year	√	√	√
Self-employed (percentage of total employment)		−0.016***	−0.015***
		(0.001)	(0.001)
Interaction term: Internet penetration multiplied by self-employment			4.19e-05***
			(0.000)
Constant	3.898***	6.070***	5.102***
	(0.240)	(0.235)	(0.241)
R-squared	0.503	0.516	0.543
Number of countries	185	185	185

Note: Standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$; The reference of income level is low-income countries.

encourage self-employed individuals to adopt sustainable practices, thereby reducing CO2 emissions (Gillingham and Palmer, 2014).

For the control variables such as the impact of sex ratio, national total population, and country income classification on low carbon development, our analysis reveals interesting patterns. The sex ratio demonstrates a significant positive relationship with greenhouse gas emissions, CO2 emissions, methane emissions, and nitrous oxide emissions. This finding implies that countries with a higher proportion of males in the population might experience increased emissions levels, potentially due to differences in occupational choices or energy consumption patterns between genders. As anticipated, a larger population size correlates with higher emissions levels. This relationship can be attributed to the increased demand for resources, energy, and infrastructure, which subsequently results in elevated levels of emissions. Regarding country income classification, lower-middle-income and upper-middle-income countries exhibit a positive relationship with greenhouse gas emissions, CO2 emissions, and nitrous oxide emissions. In contrast, for methane emissions, the relationship is not significant in lower-middle-income countries and is negative in upper-middle-income countries. High-income countries display no significant relationship with total greenhouse gas emissions, but they do exhibit a negative relationship with both CO2 and methane emissions. These mixed results suggest that the impact of economic development on emissions levels can be intricate, depending on factors such as industrial composition, energy consumption patterns, and environmental policies. This highlights the importance of considering the diverse factors at play when examining the relationship between control variables and low carbon development.

4.3 Results of gig economy mediates the impact of digitalization on low-carbon development

Table 4 displays the results of the mediation effect of the gig economy on the effect of digitalization on low carbon development. The dependent variable is total greenhouse gas emissions after logarithmic transformation (kt of CO2 equivalent), the principal independent variable is internet use (percent of population), and the mediation variable is self-employment (percentage of total employment). The interaction term used to test for the mediating effects of self-employment is the product of Internet penetration (percentage of the population) and self-employment (percentage of total employment).

In all three models (10), (11), and (12), the effects of internet use on total greenhouse gas emissions are negative and statistically significant. The coefficient remains negative and significant when introducing self-employment as a mediator (model 11). In model (12), the interaction term between internet use and self-employment is highly significant and positive, indicating that the gig economy, as represented by self-employment, does indeed act as a mediator between internet use and low carbon development.

The negative coefficients for internet use in models (10) and (12) indicate that as Internet penetration rises, total greenhouse gas emissions tend to decrease. This could be attributed to the fact that increased Internet penetration encourages more efficient and environmentally friendly solutions, such as remote work, virtual meetings, and smart technologies, which can result in energy savings and reduced emissions. The negative and significant coefficients for self-employment in models (11) and (12) imply that an increase in the gig economy, as represented by self-employed individuals, reduces total greenhouse gas emissions. This may be due to the fact that gig economy workers are more likely to rely on flexible working arrangements, such as remote work or part-time schedules, which could contribute to lower emissions through reduced commuting and energy consumption. In addition, the positive and significant interaction term in model (12) indicates that the effect of internet use on greenhouse gas emissions is moderated by the level of gig economy self-employment. This indicates that when both Internet penetration and self-employment increase, their combined impact on low-carbon development is amplified.

Regarding the control variables, the results suggest that the relationship between GDP and emissions is intricate, influenced by factors such as industrial composition and government policies. In model (11), we identified a negative and significant association, implying that higher GDP might lead to reduced emissions due to the adoption of cleaner technologies and practices. Nevertheless, this relationship was not significant in models (10) and (12). In all models, the positive and significant coefficients highlight that a larger working-age population is linked to increased greenhouse gas emissions, possibly driven by a greater demand for resources and energy. We also discovered a positive and significant correlation between national population size and emissions levels, signifying that larger populations produce higher emissions as a result of heightened demand for resources, energy, and infrastructure. Furthermore, we found that countries with a higher male-to-female ratio in their population tend to have increased emissions levels. This could be attributed to gender-based differences in occupational choices or energy consumption patterns. Lastly, the coefficients for lower-middle-income, upper-middle-income, and high-income countries display mixed results across the models, indicating that the impact of economic development on emissions levels is multifaceted and reliant on factors such as industrial composition, energy consumption patterns, and environmental policies.

In conclusion, the mediation analysis presented in Table 4 reveals that the gig economy, exemplified by self-employment, plays an important role in mediating the effect of digitalization on low carbon development. This suggests that policies encouraging the expansion of the gig economy and Internet penetration may have positive environmental effects by lowering total greenhouse gas emissions.

5 Conclusion and discussion

In recent years, the global community has increasingly recognized the urgent need to address climate change and transition to a low-carbon society. As digitalization and the gig economy continue to reshape the economic landscape, it becomes vital to understand how these trends interact with environmental sustainability. This study was driven by the desire to explore the role of digitalization and the gig economy in facilitating a low-carbon society across countries with diverse income levels. Utilizing panel data from 185 countries between 1990 and 2019, we employed a fixed effects model to investigate the impact of digitalization on the gig economy and its subsequent implications for greenhouse gas emissions. This research provides crucial insights for policymakers and stakeholders striving to advance sustainable development and the transition to a low-carbon society. Understanding these relationships is critical for designing effective policies and strategies that can harness the potential of digitalization and the gig economy to promote environmental sustainability and combat climate change. The results demonstrate that the influence of digitalization on the gig economy varies by country, with a positive and significant relationship in high-income countries and a negative and significant relationship in low-income countries. Furthermore, the gig economy has a significant negative impact on greenhouse gas emissions, especially CO2 emissions, suggesting that the growth of the gig economy may support the reduction of greenhouse gas emissions and the transition to a low carbon society. The mediation analysis highlights the crucial role of the gig economy in mediating the connection between digitalization and low carbon development. The positive and statistically significant interaction term between Internet penetration and self-employment indicates that the combined effect of both variables on low-carbon development is amplified when both variables increase simultaneously. This indicates that policies designed to promote digitalization and the gig economy may have a positive effect on the environment by lowering greenhouse gas emissions.

While this study offers valuable insights, it is essential to recognize the limitations associated with the theoretical framework and methodological approach. The following paragraphs outline these limitations and suggest avenues for improvement in future research. Regarding the theoretical framework, the study's limitations lie in the simplification of the

relationships between digitalization, the gig economy, and low carbon development. The complex interplay between these factors may not be fully captured in the current analysis, as the study does not consider the various aspects of digitalization (e.g., e-commerce, automation, artificial intelligence) or the diverse nature of the gig economy (platform-based work, freelance work, informal labor). Furthermore, the study assumes a linear relationship between the variables, which may not accurately reflect the true dynamics between digitalization, the gig economy, and emissions reduction. Future research could expand the theoretical framework by incorporating a more nuanced understanding of digitalization and the gig economy and by exploring the possibility of non-linear relationships or threshold effects. In terms of methodology, the fixed effects model based on panel data employed in this study controls for unobserved time-invariant factors. However, there may still be issues with unobserved time-varying confounders that could affect both the outcome and the explanatory variables, leading to biased estimates of the relationships between digitalization, the gig economy, and low carbon development. To address these methodological concerns, future research could adopt more sophisticated panel data analysis techniques, such as dynamic panel models or difference-in-differences approaches, which can better account for unobserved time-varying confounders. Additionally, the potential endogeneity issue remains a concern. To address this challenge, future research could consider utilizing instrumental variables or employing two-stage least squares regression techniques, which can help account for endogeneity problems and provide more accurate estimates of the causal relationships between the variables of interest.

These findings have significant policy ramifications for governments and stakeholders seeking to advance sustainable development and the transition to a low-carbon society. Policymakers should consider supporting the growth of the gig economy and digitalization through the implementation of measures that improve access to technology, boost digital skills, and foster a supportive regulatory environment. Furthermore, targeted policies and incentives for low carbon practices in the gig economy, such as tax breaks or subsidies for using energy-efficient technologies or promoting renewable energy sources, can encourage the adoption of sustainable practices and contribute to the global effort to mitigate climate change.

The finding of this study raise a number of significant issues for further academic discussion. (i) Effects that vary across income levels. The relationship between digitalization and the gig economy varies across income levels, according to the study. Future research could examine how various aspects of digitalization (e.g., e-commerce, automation, artificial intelligence) and the gig economy (platform-based work, freelance work, informal labor) contribute to low carbon development in various contexts. (ii) Sector-specific variations in the gig economy. This study demonstrates that the gig economy may have different effects on greenhouse gas emissions depending on the industry. Additional research could examine the impact of gig economy work in various sectors (e.g., transportation, services, manufacturing) on greenhouse gas emissions and the potential for these sectors to transition to low carbon practices. (iii) The dynamic nature of the gig economy and the rise of digital technology. As the gig economy and digitalization continue to evolve at a rapid rate, it is essential for research to keep up. The dynamic interaction between digitalization, the gig economy, and low carbon development over time could be illuminated by longitudinal research.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://data.worldbank.org/.

Author contributions

The authors confirm contribution to the paper as follows: study conception and design: KL; data collection: KL; analysis and interpretation of results: KL and ZF; draft manuscript preparation: KL and QZ. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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