Energy Economics 114 (2022) 106315

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneeco

How does the digital economy accelerate global energy justice? Mechanism discussion and empirical test

Jianda Wang [a], Kun Wang [b], Kangyin Dong [a,*,1], Muhammad Shahbaz [c,d]

[a] School of International Trade and Economics, University of International Business and Economics, Beijing 100029, China
[b] Department of Industrial and Systems Engineering, the Hong Kong Polytechnic University, Hong Kong, China
[c] School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China
[d] Department of Land Economy, University of Cambridge, Cambridge CB2 1TN, UK

ARTICLE INFO

JEL classification:
C33
J24
L86
Q43

Keywords:
Just transition
Digital economy
Mediating effect
Human capital
Financial development

ABSTRACT

In the context of climate change, just transition is particularly significant, and digitalization as a possible solution for a just transition is considered in this paper. We construct an econometric model between the digital economy and just transition by using a balanced panel dataset of 72 economies from 2010 to 2019, and explore their dynamic relationship and mechanism impacts by applying a system-generalized method of moments (SYS-GMM) technique and a mediating model. The main results indicate that both the digital economy index and just transition index increase during the study period. Moreover, the digital economy not only promotes just transition, but also increases distributional justice, procedural justice, and restorative justice. In addition, the infrastructure and social impact of the digital economy also significantly increase the level of just transition; however, digital trade presents a negative effect on just transition. Finally, from the mechanism analysis, the digital economy indirectly improves just transition by increasing the level of human capital and financial development. This paper provides new ideas for realizing just transition in the future.

1. Introduction

Scholars and related organizations increasingly recognize that climate change has become an important factor affecting global economic development, social welfare, security, and stability (Ren et al., 2020; Schmidhuber and Tubiello, 2007; Spencer and Strobl, 2020). To reduce the greenhouse effect, the Paris Agreement sets global temperature rises at well below 2 °C above pre-industrial levels, and aims to achieve carbon neutrality by mid-century (UNFCCC, 2015; Zhao et al., 2022). This is an arduous task, and the most important means is to control the excessive consumption of fossil energy. At the COP26 conferences, at least 23 economies made new commitments to phase out coal power, and 25 economies and public finance agencies have committed to ending international public support for the unabated fossil fuel energy sector by the end of 2022 (COP26, 2021). Clean energy will become an important development goal in the low-carbon age in the future.

However, with the global transition to low-carbon energy, increasing problems have begun to emerge. As fossil fuels have always been central to the existence and development of modern economies, they have dominated the modern energy system, so barriers are limiting their use imposed by global public policies (Evans and Phelan, 2016; Unruh, 2000). Based on the strong dependence of the market on fossil energy and special interests, society urgently needs a "just transition." The concept of a "just transition" originated in the American labor movement in the late 1970s, and firmly introduced the application of fairness and justice in planning and implementing the transition of each society's energy system (Markard, 2018; Stevis and Felli, 2015). In the context of climate change and energy transition, just transition has been endowed with more connotations. It requires government organizations to redistribute job benefits and ensure adequate energy services, with a particular focus on benefit and risk sharing. The United Nations Framework Convention on Climate Change (UNFCCC) states that, in addition to a broad action plan to address climate change, it is necessary to "*take into account the imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally*

* Corresponding author.
E-mail addresses: wangjd1993@163.com (J. Wang), wqueenfox@gmail.com (K. Wang), dongkangyin@uibe.edu.cn (K. Dong), muhdshahbaz77@gmail.com (M. Shahbaz).

[1] Personal website: *https://scholar.google.com/citations?user=Ut15iYkAAAAJ&hl=en&oi=ao* or *https://www.researchgate.net/profile/Kangyin_Dong*.

https://doi.org/10.1016/j.eneco.2022.106315
Received 15 June 2022; Received in revised form 21 August 2022; Accepted 7 September 2022
Available online 17 September 2022
0140-9883/© 2022 Elsevier B.V. All rights reserved.

defined development priorities." (UNFCCC, 2015). The U.S. Green New Deal explicitly integrates equity and social justice into climate change mitigation goals and emphasizes a commitment to job training and economic development support for individuals and communities that may be adversely affected by transitioning to new energy sources (Markard, 2018). The European Union (EU) has also provided a €17 billion transition fund, which aims to channel funds into real economic activities aligned with social and development goals, improving social inclusion, community renewable energy, industrial training, and skills (Lowitt and Makgetla, 2021).

In this context, people are increasingly interested in the behavior of a just transition to a low-carbon economy and seek to realize "just transition" more clearly in a low-carbon society. This process involves multiple forces and factors, including political factors (Newell and Mulvaney, 2013), social movements (Evans and Phelan, 2016), and worker responses (Vatalis et al., 2022). In fact, an emerging cognition needs to be alerted to a subversive revolution, just as digitalization has brought new vitality and opportunities to the global energy industry. The emergence of digital industries and high technology has changed consumers' and suppliers' perceptions of the energy transition, and the way energy is delivered, providing more possibilities (Zhukovskiy et al., 2021).

So, we need to consider exactly what a just transition should expect from the digital economy. The International Energy Agency (IEA) points out that digitalization is already increasing the safety, productivity, accessibility, and sustainability of the energy system (IEA, 2017). Global investment in digital electricity infrastructure and software has improved by over 20% annually since 2014, reaching USD 47 billion in 2016 (IEA, 2017). The United Nations' 2030 Agenda states that digital solutions can increase job creation, regional development, and competitiveness, which are important actions in the fight against exclusion, poverty, inequality, and resource scarcity (Enciso-Santocildes et al., 2021). All of these give the digital economy the potential to achieve a just transition. However, the rapid adoption of the Internet in developed regions has also exacerbated social inequalities, and the digital divide has become more pronounced. This obscures the impact of the digital economy on just transition. Furthermore, according to McCauley and Heffron (2018), just transition is divided into distributional justice, procedural justice, and restorative justice, which summarizes its cause, process, and influence. But whether all three aspects of just transition are justified by the digital economy remains unclear. Thus, we construct a theoretical model between the digital economy and just transition by using a balanced panel dataset of 72 economies from 2010 to 2019, and explore their dynamic relationship and mechanism effects. Further, this paper will address two main questions: "What aspects of the just transition are affected by the digital economy?" and "What aspects of the digital economy affect just transition?"

The main research contributions of this paper are as follows. First, we evaluate the just transition and digital economy index of major economies around the world, which clearly shows readers the level of digitalization and just transition development in each economy. Second, we innovatively investigate the influence of the digital economy on just transition, which helps the government formulate a more just transformation plan in a low-carbon society, and provides a digital solution. Third, this paper also addresses the internal impact of the digital economy and just transition, so we can understand whether the digital economy further affects distributional justice, procedural justice, or restorative justice, which will be more instructive in the future. Finally, we provide a path for the digital economy to influence just transition, which provides a favorable reference for the government to explore how to formulate policies for just transition through digitalization.

The remainder of the paper is organized as follows. Section 2 provides a summary of the empirical literature. In Section 3, we propose the theoretical mechanisms and research hypotheses. In Section 4, we introduce the methodology and data. Section 5 investigates the relationship between the digital economy and just transition. Section 6 further discusses the impact mechanism. Section 7 concludes the whole paper.

2. Literature review

2.1. Studies of just transition

The world has made great efforts to achieve sustainable development goals and zero-carbon actions (Creti et al., 2012). The most important challenge is the transformation of fossil energy to clean energy, which involves the interests of climate justice, energy justice, and environmental justice (Vatalis et al., 2022). Only by solving the problem of just transition will it be possible to realize a low-carbon society in the future. Based on the above analysis, many scholars have carried out systematic research on just transition.

Just transition centers mainly around three subjects, namely environment, climate, and energy. Discussions on environmental justice focus on inequality and unfair distribution in society and the environment (Laurent, 2011; Schlosberg, 2004; Walker, 2009). These discussions originated in the mid-1980s, and pointed out that some communities and individuals will suffer more environmental risks, which will lead to inequalities (Schlosberg, 2013). Climate justice focuses on avoiding impacts on climate-vulnerable economies and groups (especially the global South) in the context of rapidly responding to climate change (Bulkeley et al., 2013; Fisher, 2015; Okereke and Coventry, 2016). Energy justice focuses on fairness and justice in the transition from fossil energy to low-carbon energy in the context of climate change (Heffron and McCauley, 2017; Jenkins et al., 2016; Sovacool et al., 2016). However, the issue of climate change has gradually attracted the attention of scholars and related organizations, and the associated interests of the environment, climate, and energy have gradually merged into a whole, so a unified framework is needed for in-depth analysis.

McCauley and Heffron (2018) provide an analytical framework for just transition that integrates just transitions in climate, energy, and environmental justice scholarships. In addition, they supplement restorative justice based on the original distributional justice and procedural justice, and provide a more complete framework for measuring a just transition. Based on this, this framework is widely used by scholars (Coggins et al., 2021; Diduck et al., 2021; Kalt, 2021; Lacey-Barnacle, 2020; McCauley et al., 2019; Scheuerman, 2018; Zhu and Lo, 2021). They analyze the dependence on fossil energy in the process of the energy transition, the justice of the realization process, and the reemployment after the transition. Just transition has also been widely discussed in a specific industry or a specific region. For example, Bastos and Mairon (2022) study bio-based production systems under just transition in Brazil, India, and Indonesia, and their results indicate that the bioeconomy promotes unfair production systems, causes damage to traditional communities and residents, and that there is no accountability and remediation. Cha (2020) focuses on the energy transition of the largest coal mining area in the United States, pointing out that the closure of coal mining areas has led to strong justice, but just transition is still the best way to prevent serious economic distress in this region. Vatalis et al. (2022) explore the impact of decarbonization projects on coal-dependent regions (a region in north-western Greece) through a questionnaire survey. Their results show that respondents do not believe decarbonization will have a positive impact on the sustainability of coal-dependent regions and that a just transition to coal requires the active participation of all stakeholder groups in effective public dialogue.

However, the above-mentioned scholarships do not have a clear framework to discuss the level of just transition in economies or industries around the world. McCauley et al. (2022) have collected public databases and ranked the level of just transition in major economies. Their study gauges which economies are most likely to take a leadership role in the global energy transition. Achieving a just transition in the Arctic, they noted, requires documenting economies' contributions to climate and commitments to equity and jobs. Therefore, based on the framework of McCauley et al. (2022), we will deeply explore the issue of just transition in major economies around the world.

2.2. Studies of the digital economy

The rapid development of the Internet, big data, artificial intelligence, and information and communication technology (ICT) industries has led scholars to think about the digital economy (Carlsson, 2004). First, many scholars have researched methods to measure the digital economy, because a unified measurement method of the digital economy has not been formed globally (Mesenbourg, 2001; Tranos et al., 2013), and the development of new forms of the digital economy also poses challenges to traditional economic measurements (Quiggin, 2014; Watanabe et al., 2018b). Second, some scholars have explored the influencing factors of the digital economy (Litvinenko, 2020; Wang et al., 2022c). For instance, Li and Liu (2021) explore the influence of input factors, technological progress, and institutional changes on China's digital economy based on economic growth theory and new economic geography. Third, more scholars are focusing on the impact of the digital economy, such as the influence of digital economy on economic development (Baxtiyarjon Bulturbayevich and Baxriddin Jurayevich, 2021; Mahmudov Baxriddin and Mullabayev Baxtiyarjon, 2020), international trade (Ahmedov, 2020), and welfare (Grigorescu et al., 2021).

At the same time, the process of digitalization has also affected energy and environmental changes. The digital economy, with information technology as the core, provides new solutions for intelligent environmental management, which is conducive to solving problems such as a declining environmental carrying capacity and scarce resources (Li et al., 2021). Therefore, the development of the digital economy will become an important solution for the development of clean energy in a low-carbon society. For instance, some scholars have pointed out that the digital economy or ICT industry is conducive to reducing greenhouse gas emissions (Murshed, 2020; Wang et al., 2022a, 2022b), decreasing fossil fuel consumption (Ishida, 2015; Lange et al., 2020), and improving the power of energy transition (Nijhuis et al., 2015). However, a few scholars seem to have paid attention to the influence of the digital economy on the post-transition society, particularly initiatives aimed at achieving a just transition. Pînzaru et al. (2022) point out that the digital transformation of enterprises can improve resilience and create conditions that enable these enterprises to adapt to fair transformation and achieve a measure of sustainable development. Qureshi (2019) points out that ICTs can help people create sustainable climate change resilience in their local communities and reduce their negative impacts. Gonzalez (2019) indicates that the lack of access to ICT will make it difficult for citizens to obtain important environmental justice mechanisms in the context of limited transportation and citizen poverty. King et al. (2021) also indicate that the application of ICT equipment is conducive to achieving environmental justice and promoting the healthy development of the local environment. Therefore, the relationship between the digital economy and just transition is also a topic worthy of attention.

2.3. Literature gaps

Although there are numerous studies on just transition and the digital economy, few scholars have measured their relationship. The literature review in Sections 2.1 and 2.2 highlights three reasons. First, few papers measure and analyze the multinational just transitions, which may be because the theory is still in its infancy. Second, the theoretical basis for the influence of the digital economy on the post-energy transition has not yet been established, which is not conducive to scholars following up with in-depth research. Third, although some studies mention the impact of the digital economy on energy justice and climate justice, few scholars have empirically analyzed the impact of the digital economy on just transition. Therefore, this paper will measure and discuss the relationship between the digital economy and just transition based on existing research.

3. Theoretical framework and hypotheses

3.1. The total effect of the digital economy on just transition

In the theoretical analysis, we try to find relevant evidence between the digital economy and just transition (especially distributional justice, procedural justice, and restorative justice).

First, the digital economy is conducive to a more equitable distribution model in the context of transition. Digitalization, artificial intelligence, and big data can help the government determine the best location of energy facilities to meet the interests of the majority while ensuring a supply of energy (Chen et al., 2022a; Gašparović and Gašparović, 2019). At the same time, digitalization has changed the traditional consumption concept, reduced the use of high-energy-consuming products, brought innovative devices with low energy efficiency, and decreased dependence on fossil energy (Huang et al., 2022; Ramzan et al., 2022). Digitalization has also increased social equity and inclusion, providing help to marginalized groups in society, and giving a voice to disadvantaged groups who may also express their opinions and suggestions on digital platforms (Agostino et al., 2021).

Second, digitalization will also affect procedural justice. On the one hand, digitalization provides people with a more convenient platform for making requests, and the government can understand the problems encountered in the energy transition faster and more directly, reducing community conflicts (Sindhu and Sangwan, 2017). On the other hand, digitalization has broken the original relationship between government personnel, making the transition process open and transparent, and reducing corruption (Merhi and Ahluwalia, 2018).

Third, digitalization also offers hope for restorative justice. On the one hand, digitalization is now recognized as an important path to employment (Enciso-Santocildes et al., 2021); it can provide the necessary skills training for laid-off workers by establishing models such as "air classrooms" and help them get back to work faster (Riddle, 2015). On the other hand, digitalization can reduce the cost of using renewable energy and improve the efficiency of clean energy, so that it can be quickly popularized in daily life (Ahmed et al., 2017). Thus, we propose the following hypothesis:

Hypothesis 1. The digital economy will positively affect just transition.

3.2. The mediating mechanism of human capital

The digital economy is an important way to promote human capital. First, the digital economy has given birth to the development of the Internet, which has a high promotion effect on the speed of information dissemination and accelerates people's acquisition of new technologies (Lee et al., 2022). Second, the digital economy provides people with more channels to acquire knowledge, enabling them to continuously learn new methods and technologies (Batjargal, 2007). Third, the digital economy has enhanced peoples' education level, facilitating the flow of labor to high-tech industries, and improving the level of human capital. The improvement of human capital is an effective attempt to achieve clean and green energy. Households with higher education levels consume less electricity and effectively reduce energy efficiency (Broadstock et al., 2016). A higher level of human capital enables households to consider green and low-carbon factors more when choosing energy (Salim et al., 2017). In addition, people with higher education levels tend to be more resilient to the negative impacts of transition; they can adapt to job changes and actively use alternative energy sources. Therefore, we propose the following hypothesis:

Hypothesis 2. The digital economy will indirectly improve just transition by increasing human capital.

3.3. The mediating mechanism of financial development

The digital economy has also brought vitality to the development of the financial sector. On the one hand, the deep integration of artificial intelligence, blockchain, cloud computing, and big data with the financial sector has spawned fintech, and the resulting mobile communication payment tools have promoted the flow of funds (Broadstock et al., 2021). On the other hand, the digital economy lowers the entry threshold for start-ups, enhances the level of technological innovation, and improves the quality of credit assets, thereby enhancing the development of the financial sector (Chen et al., 2022b). Moreover, financial development will effectively promote just transition. Under the same conditions, economies with higher levels of financial development may be more able to adjust their energy dependence and transition from fossil energy to renewable energy. In addition, a large amount of financial capital enables enterprises to obtain more sources of funds, expand the scale of enterprises, and then employ more workers to offset external risks (Sadorsky, 2010). Therefore, we propose the following hypothesis:

Hypothesis 3. The digital economy will indirectly improve just transition by increasing the level of financial development.

4. Method and data

4.1. Model specification

To assess the nexus between the digital economy and just transition, we construct a research framework for the main factors affecting just transition. Here we mainly consider the influence of economic factors, demographic factors, trade factors, and industrial structure factors (Evans and Phelan, 2016; McCauley and Heffron, 2018). The basic model is shown in Eq. (1).

$$JUST_{it} = f(DIG_{it}, GDP_{it}, POP_{it}, TRADE_{it}, IND_{it}) \tag{1}$$

where $f(\cdot)$ is a function, i represents the economy, t represents the year, *JUST* represents the just transition index, *DIG* represents the digital economy index, *GDP* represents economic growth, *POP* represents the population, *TRADE* represents trade openness, and *IND* represents industrial structure. Further, we log Eq. (1) to obtain Eq. (2):

$$lnJUST_{it} = \alpha_0 + \alpha_1 lnDIG_{it} + \sum_{k=2}^{5} \alpha_k lnX_{it} + \varepsilon_{it} \tag{2}$$

where ε_{it} represents the random error term, X represents the control variables (i.e., *GDP*, *POP*, *TRADE*, and *IND*), α_0 represents the constant term, and $\alpha_1, \cdots, \alpha_5$ represent the estimated coefficients. Among them, α_1 represents the elasticity of the digital economy on just transition. If α_1 is significantly greater than 0, then hypothesis 1 is confirmed; in other words, the digital economy significantly promotes just transition. However, Eq. (2) can only assess the static impact of the digital economy on just transition. Since just transition involves multiple factors of energy, climate, and the environment, the impact of just transition may have inertia; in other words, the conditions of past just transition may affect the current just transition process. Furthermore, the dynamic model estimation can reduce the effects of endogeneity and omit variable bias. Therefore, we add the lag term of just transition ($lnJUST_{i,\,t-1}$) to Eq. (2).

$$lnJUST_{it} = \beta_0 + \beta_1 lnJUST_{i,t-1} + \beta_2 lnDIG_{it} + \sum_{k=3}^{6} \beta_k lnX_{it} + \varepsilon_{it} \tag{3}$$

In this paper, we apply the system-generalized method of moments (SYS-GMM) technique to estimate Eq. (3), which has been investigated by Blundell and Bond (1998). Compared with the traditional static model, the SYS-GMM technique can solve the dual causal effects and endogeneity between independent variables and dependent variables, and improve the accuracy of estimation.

4.2. Mediation effect model

According to hypothesis theory, we believe there are conduction paths between the digital economy and just transition. Referring to the theory of Baron and Kenny (1986), we construct the following theoretical model:

$$lnM_{it} = \eta_0 + \eta_1 lnDIG_{it} + \sum_{k=2}^{5} \eta_k lnX_{it} + \nu_{it} \tag{4}$$

$$lnJUST_{it} = \delta_0 + \delta_1 lnM_{it} + \delta_2 lnDIG_{it} + \sum_{k=3}^{6} \delta_k lnX_{it} + \varsigma_{it} \tag{5}$$

where lnM_{it} represents the mediating variables, including human capital ($lnHCI_{it}$) and financial development ($lnFD_{it}$). η_0 and δ_0 are the constant terms, $\eta_1, \cdots, \eta_5$ and $\delta_1, \cdots, \delta_6$ are the estimated coefficients, ν_{it} and ς_{it} represent the random error terms. The coefficient of δ_2 represents the indirect effects between the digital economy and just transition.

Further, we will use the Sobel test to verify whether the mediating effect is established. The Sobel test was proposed by Sobel (1982), and its purpose is to test whether adding a mediating variable greatly reduces the effect of the independent variables on the dependent variable. The basic equation of the Sobel test is as follows

$$z = \frac{\eta_1{}^{*}\delta_1}{\sqrt{\left(\delta_1^2 {}^{*} S_{\eta_1}^2 + \eta_1^2 {}^{*} S_{\delta_1}^2\right)}} \tag{6}$$

where S represents the standard error of the corresponding estimated coefficient. If the z statistic of the Sobel test is significant and the coefficients of η_1 and δ_1 are all significant, the mediating effect is confirmed.

4.3. Variable measures and data sources

4.3.1. Dependent variable

According to a definition by McCauley and Heffron (2018), just transition is generally divided into three main components, namely distributional justice, procedural justice, and restorative justice. Therefore, we construct a comprehensive index of just transition as the dependent variable from the above three aspects.

First, there is distributional justice, which is defined as the level of fairness across a group or geographic location (McCauley et al., 2022). It considers mainly the differences in transition equality across economies in terms of energy endowments, climate change perceptions, and social conditions. Here we consider six dimensions of information: (1) Fossil energy dependence: Since the economy's infrastructure and technical equipment are all constructed following existing fossil energy standards (Mirza et al., 2009), it is possible to achieve a more difficult transition process; (2) Fossil energy financial dependence: the higher the economy's income dependence on fossil energy, the more dependent the financial system will be on fossil energy products, and the more difficult it will be to achieve a just transition; (3) Social inequality: this is also an important part of achieving distributional justice, as people's rights may be violated as we transition to a post-carbon society (Tomain, 2017). Here we use the Gender Inequality Index instead; (4) Climate change vulnerability: economies with more severe climate vulnerability usually receive less energy transition attention, and justice is difficult to be satisfied; (5) Climate change risks: the distribution of risks and responsibilities involved in climate change is unequal, with the global North responsible for most of the negative consequences of climate change, but the least affected (Khan et al., 2021b; Ren et al., 2022). Conversely, the global South is less responsible for these consequences, but suffers the severe negative impacts of the injustice of the transition (McCauley and Heffron, 2018); (6) Energy poverty: this represents another form of injustice in the distribution of energy, and for communities with more difficult access to energy, just transitions are often not well met.

The second category is procedural justice, which is defined as ensuring maximum inclusivity in a just transition. In other words, it aims to get all the stakeholders involved in climate reduction actions to reach a consensus on decarbonization (McLaren, 2012). It is concerned primarily with the process of achieving just transition, rather than distributive outcomes. It provides a platform for the realization of just transition and promotes the positive development of just transition (Hess, 2016). This can also be described as a process from protest to reception in the realization of transformation, measured here by three indicators: corruption control, voice and accountability, and rule of law. Moreover, climate change resilience and adaptive capacity ensure the resilience of communities in coping with climate change shocks and the successful implementation of just transition (Archer and Dodman, 2015). In addition, the process of achieving positive transition tends to focus on production-related activities, and energy efficiency is an important measure, which points out the balance between energy and economic activities, and is therefore considered by procedural justice.

The third category of just transition is restorative justice, which is defined as the impact of people in the process of achieving just transition. Many scholars believe the transition to a low-carbon society will result in the loss of many jobs, which has created obstacles to the transition (Berger et al., 2020; Green and Gambhir, 2020). The positive impact of the development of renewable energy on society must include a commitment to fairness, such as employment, which is the key to achieving a just transition. Referring to McCauley et al. (2022), we measure restorative justice in terms of fair jobs, green jobs, and renewable energy generation per capita.

Table 1 shows the proxy indicators and data sources for each dimension of just transition. We calculate the 21 sub-indices into a just transition index and three sub-indices by using entropy method, namely distributional justice ($lnJUST1_{it}$), procedural justice ($lnJUST2_{it}$), and restorative justice ($lnJUST3_{it}$).

4.3.2. Key independent variable

The key independent variable in this paper is the digital economy. Previous studies have used a single indicator to represent the digital economy or the ICT industry, which cannot fully express the true level of the digital economy. Therefore, referring to the indicator settings of Pan et al. (2022), Wu et al. (2021), and Lin and Zhou (2021), and the collection of major open databases around the world, we construct a comprehensive indicator of the digital economy by using the entropy method, which comprises four parts: infrastructure, social impact, digital trade, and social support (Shahzad et al., 2022). Among them, infrastructure includes the development of infrastructure related to the digital economy, such as fixed broadband, telephone, and telecommunications; social impact refers mainly to the changes in social life brought about by the digital economy, such as the popularization of the Internet, e-commerce, and changes in the value added of related industries; digital trade includes the import and export of ICT products; and social support refers mainly to the value added of the service industry per capita, and the higher the value, the greater the investment in the digital economy. Table 2 shows the specific indicators and data sources included in each dimension. Among them, the sub-indicators of infrastructure ($lnDIG1_{it}$), social impact ($lnDIG2_{it}$), and digital trade ($lnDIG3_{it}$) are also calculated using the entropy method.

4.3.3. Control variables

This paper includes four control variables - economic growth ($lnGDP_{it}$), population ($lnPOP_{it}$), trade openness ($lnTRADE_{it}$), and industrial structure ($lnIND_{it}$).

First, favorable economic conditions ensure that the economy is more focused on shifting energy from fossil fuels to low-carbon energy systems; while focusing on high economic growth also undermines social equity and the public interest, driving societies into greater inequality in terms of wealth, resources, and income (Barry, 2021). Second, population size is also a major factor affecting just transition, because a higher population base may generate more powerful trade unions, increase calls for just transition, and may also lead to more difficult employment issues. Third, the increase in trade openness will

Table 1
Index system for the just transition.

Category	Indicator	Measurement	Unit	Data sources	Attributes
Distributional justice	Fossil energy dependence	Electricity generation from oil	GWh	IEA (2022)	−
		Electricity generation from natural gas	GWh	IEA (2022)	−
		Electricity generation from coal	GWh	IEA (2022)	−
	Fossil energy financial dependence	Coal rents (% of GDP)	%	World Bank (2022)	−
		Oil rents (% of GDP)	%	World Bank (2022)	−
		Natural gas rents (% of GDP)	%	World Bank (2022)	−
	Social inequality	Gender Inequality Index		UNDP (2022)	−
	Climate change vulnerability	ND-GAIN Country Index		ND-GAIN (2022)	+
	Climate change risks	Global Climate Risk Index		Eckstein et al. (2021)	+
	Energy poverty	The proportion of the population with access to electricity	%	UN (2022a)	+
Procedural justice	Transition process	Control of Corruption		WGI (2022)	+
		Voice and Accountability		WGI (2022)	+
		Rule of Law		WGI (2022)	+
	Climate change adaptation and mitigation	The proportion of the population with primary reliance on clean fuels and technology	%	UN (2022a)	+
	Energy efficiency	GDP/Primary energy consumption	billion USD/EJ	World Bank (2022); BP (2022)	+
Restorative justice	Fair jobs	Labor share of GDP, comprising wages and social protection	%	ILOSTAT (2022)	+
	Green jobs	Employment in services (% of total employment)	%	World Bank (2022)	+
	Renewable energy electricity output per capita	Hydro generation per capita	GWh/million person	IEA (2022); World Bank (2022)	+
		Solar generation per capita	GWh/million person	IEA (2022); World Bank (2022)	+
		Wind generation per capita	GWh/million person	IEA (2022); World Bank (2022)	+
		Geothermal and biomass generation per capita	GWh/million person	IEA (2022); World Bank (2022)	+

Table 2
Index system for the digital economy.

Primary indexes	Secondary indexes	Units	Data sources	Attributes
Infrastructure	Fixed broadband subscriptions	per 100 people	ITU (2022)	+
	Fixed telephone subscriptions	per 100 people	ITU (2022)	+
	Mobile cellular subscriptions	per 100 people	ITU (2022)	+
	Telecommunication Infrastructure Index		UN (2022b)	+
Social impact	Individuals using the Internet	% of population	ITU (2022)	+
	Online Service Index		UN (2022b)	+
	E-Participation Index		UN (2022b)	+
	Medium and high-tech manufacturing value added	% of value added of manufacturing	World Bank (2022)	+
Digital trade	ICT goods exports	% of total goods exports	World Bank (2022)	+
	ICT goods imports	% of total goods imports	World Bank (2022)	+
Social support	Per capita value added of service industry	$US/person	World Bank (2022)	+

lead to a large inflow of foreign capital, destroying environmental quality, which in turn will affect just transition. Fourth, the adjustment of the industrial structure will also affect the fairness and redistribution of interests. For example, the increase of secondary industry will lead to many lower jobs, which will affect just transition.

The data of the above control variables are all from the World Bank (2022).

4.3.4. *Mediating variables*

According to the introduction of the theoretical hypothesis, this paper applies two mediating variables, human capital ($lnHCI_{it}$) and financial development ($lnFD_{it}$). Referring to Lee et al. (2022), we use the human capital index for years of education and return on education as the proxy variable for human capital (Feenstra et al., 2015; PWT 10.0, 2022); we also select domestic credit to the private sector (% of GDP) as the proxy variable for financial development (World Bank, 2022).

The research period of this paper is 2010–2019, and the research objects are 72 economies. Table 3 presents the descriptive statistics for all the above variables.

5. Empirical results and discussion

To explore the potential nexus between the digital economy and just transition, this section analyzes it through the following four parts. Section 5.1 shows the national characteristics of just transition and the digital economy; Section 5.2 presents the results of the correlation test; Section 5.3 shows the empirical results between the digital economy and just transition; and Section 5.4 is robustness checks.

5.1. *National characteristics of just transition and the digital economy*

5.1.1. *National characteristics of the just transition*

Fig. 1 shows the characteristics of the just transition indexes for each economy. From the perspective of the time trend, the just transition indexes of all economies show an obvious upward trend, which indicates that economies pay more attention to the balance of social equality, fair employment, and climate vulnerability indicators in the process of realizing low-carbon transition. From another point of view, as economies have been focusing more on renewable energy in recent years, their governments are also actively coordinating losses in the process of transformation. For example, in November 2020, the Prime Minister of the United Kingdom formulated a Ten Point Plan for a Green Industrial Revolution during which about 56,000 jobs were protected and created (House of Commons, 2021). Economies in Northern Europe have higher just transition indexes (e.g., Iceland and Finland). However, some economies in Asia and Africa have relatively lower just transition indexes (e.g., Pakistan and Bangladesh), because the economic development of these economies are highly dependent on fossil energy, and in the process of the low-carbon transition, their economic development, social stability, and climate risk present challenges that cannot be ignored.

In Fig. 2, we divide just transition into distributional justice, procedural justice, and restorative justice, and measure the index ranking of each economy under the above three dimensions. Overall, the rankings of all economies in the three justice indexes tend to be consistent, with developed economies in Europe ranking relatively high, while economies in Asia and Africa have lower rankings. The most notable of these is Iceland, which ranks in the top three of the three just transition indexes for the following reasons. First, Iceland's electricity generation relies mainly on hydropower and geothermal energy, which accounted for 68.79% and 31.16% of Iceland's total electricity generation in 2020, respectively (IEA, 2022). A higher reliance on renewable energy makes it easier for Iceland to achieve a just transition. Second, the government of Iceland has also been actively building itself into a "Nordic welfare government" in recent years, intending to protect vulnerable and low-income people, and share the burden fairly and equitably (Thorsdottir, 2013). In 2020, Iceland ranked 9th in the gender inequality index and 4th in the Human Development Index globally, reflecting a high degree of social equality (UNDP, 2022).

5.1.2. *National characteristics of the digital economy*

Fig. 3 shows the spatial characteristics of the digital economy indexes of various economies. Overall, the digital economy indexes of various economies are also improving significantly. During the study period, Singapore ranks first in the digital economy index. Studies have shown that Singapore has become a leader in the global ICT industry, developing the most advanced ICT technologies and services (Watanabe et al., 2018a).

Furthermore, Fig. 4 represents the average situation of the digital economy infrastructure, social impact, and digital trade across various

Table 3
Descriptive statistical results.

Variables	Definition	Units	References	Obs.	Mean	Std. Dev	Min	Max
lnJUST	Just transition	–	–	720	−2.153	0.532	−3.246	−0.442
lnDIG	Digital economy	–	–	720	−1.406	0.541	−3.613	−0.463
lnGDP	GDP	Constant 2015 US dollar	WDI	720	26.396	1.479	22.911	30.625
lnPOP	Population	people	WDI	720	16.809	1.657	12.670	21.065
lnTRADE	Imports and exports of goods and services	% of GDP	WDI	720	4.381	0.562	3.113	5.940
lnIND	The ratio of value added by a secondary industry to GDP	% of GDP	WDI	720	3.303	0.347	2.301	4.315
lnHCI	Years of education and return on education	–	PWT 10.0	680	1.093	0.182	0.560	1.471
lnFD	Domestic credit to the private sector	% of GDP	WDI	676	4.224	0.621	2.541	5.542

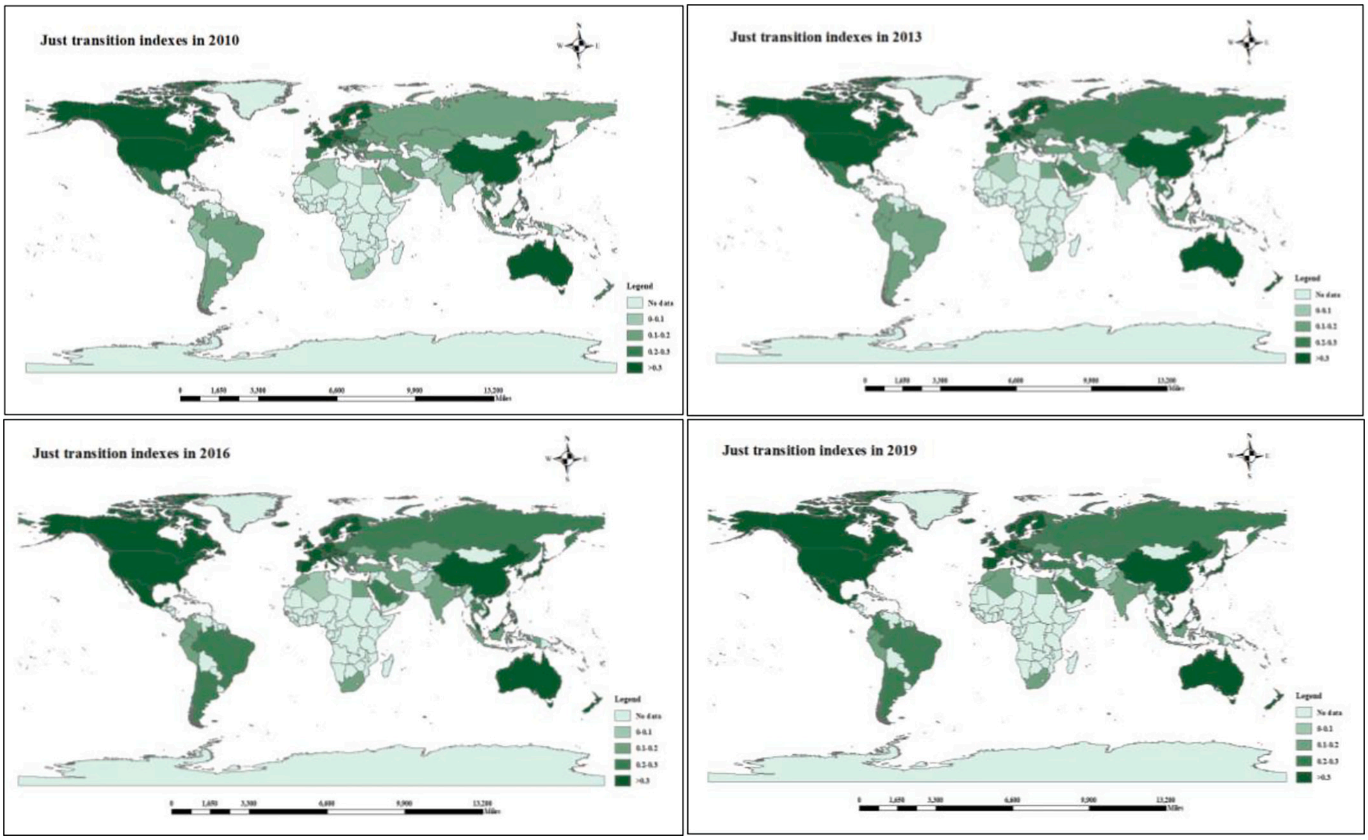

Fig. 1. Spatial distribution of just transition indexes in selected years.

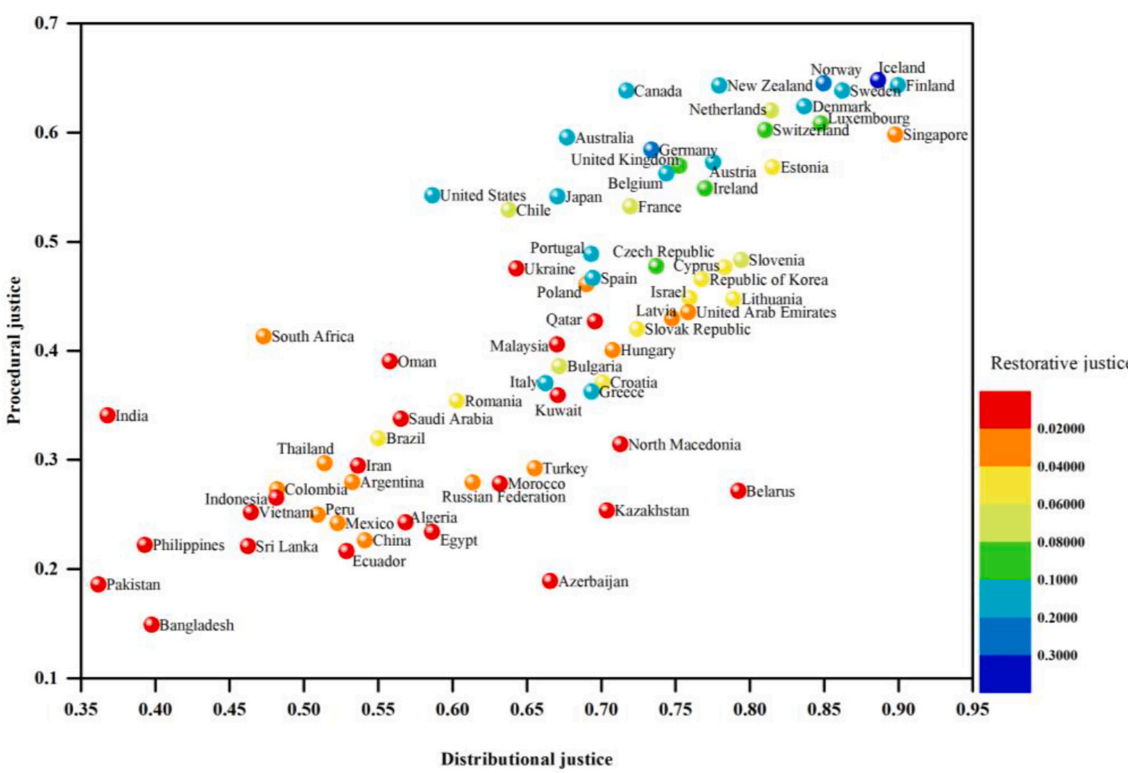

Fig. 2. The average of the three dimensions of just transition across each economy.

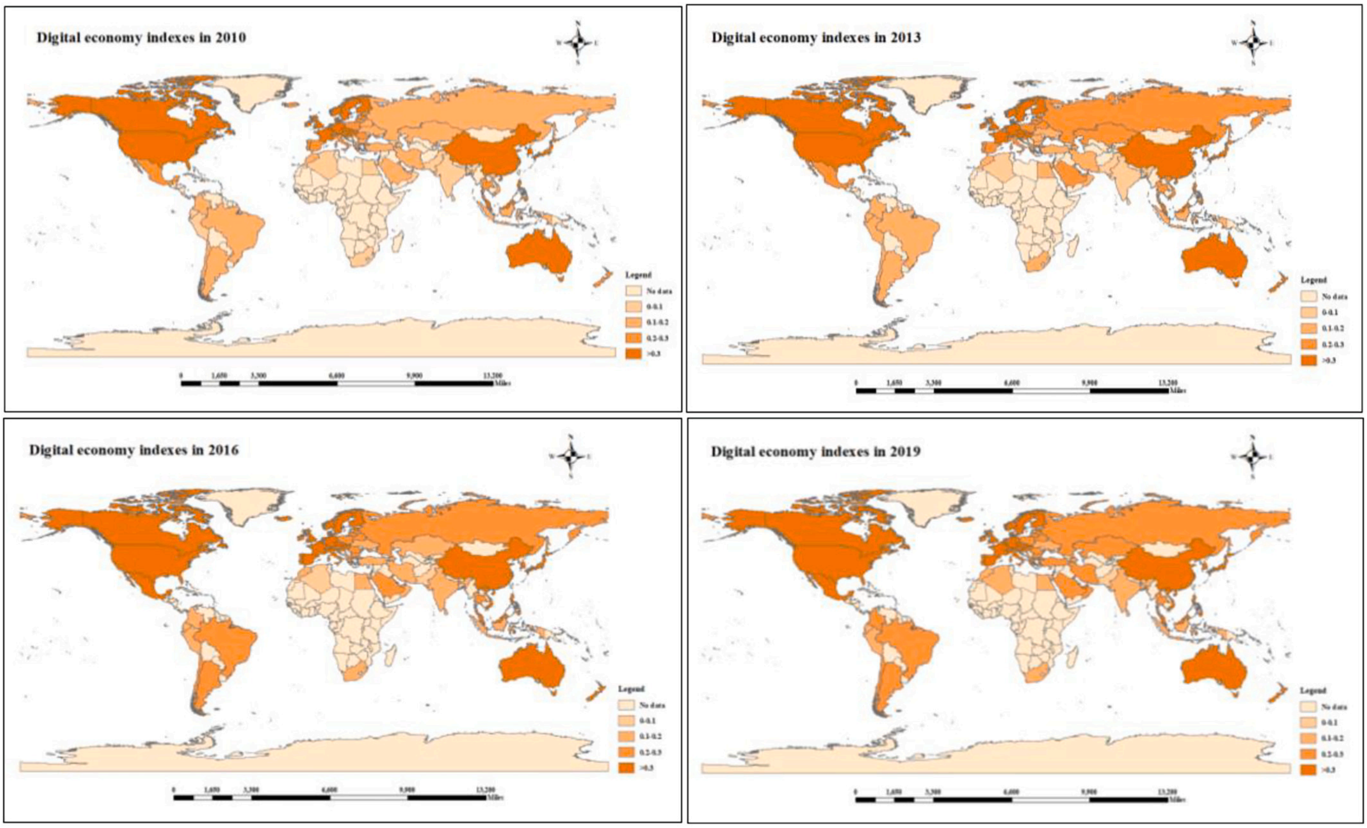

Fig. 3. Spatial distribution of digital economy indexes in selected years.

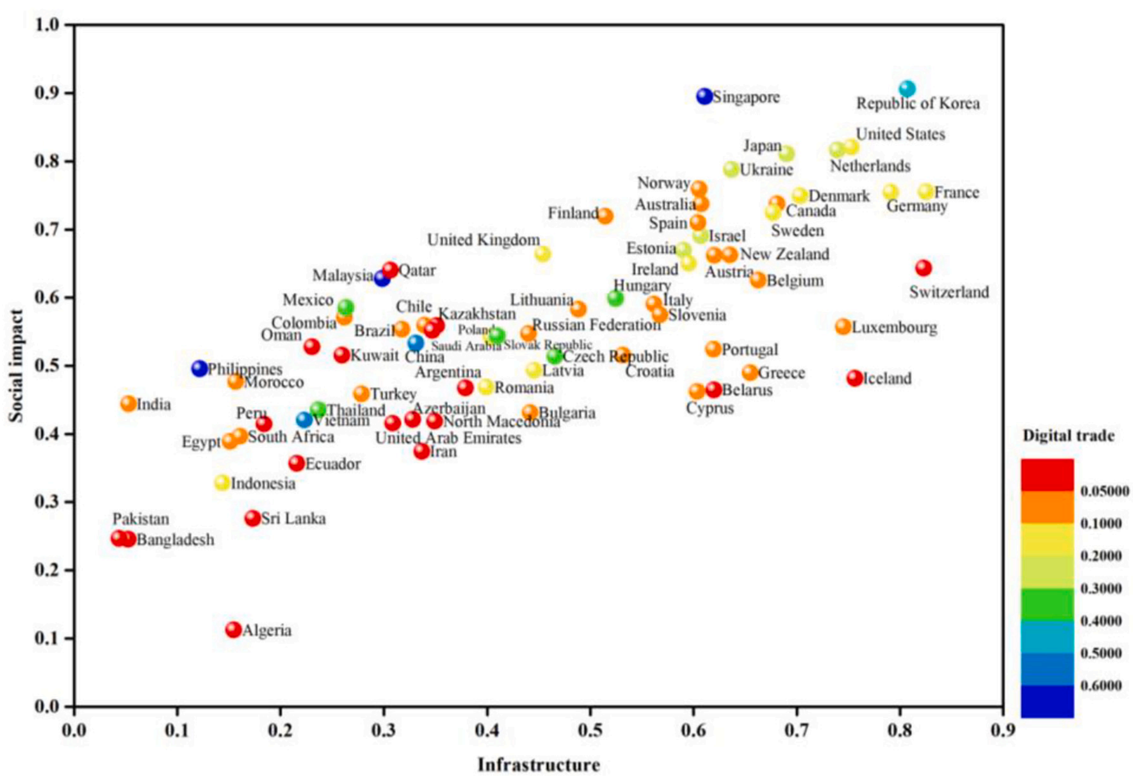

Fig. 4. The average of the three dimensions of the digital economy across each economy.

economies. Among them, France ranks highest in the infrastructure index, due to the high proportion of fixed broadband subscriptions (45.69% in 2019) and fixed telephone subscriptions (58.03% in 2019) in France (ITU, 2022). The social impact index of the Republic of Korea ranks highest, due to its higher online services index (0.9702 in 2019) and a higher proportion of medium and high-tech manufacturing value added to total manufacturing value added (63.83% in 2019) (UN, 2022b; World Bank, 2022). After the financial crisis, the Republic of Korea began to actively invest in the development of the information industry, realizing the establishment of an economy of science and technology. However, economies with higher digital trade indexes include Singapore, Malaysia, and the Philippines. This is mainly because these economies are principal exporters of the ICT industry, and many ICT basic products are exported and supplied to other economies for assembly and sales.

5.2. Pre-benchmark regression

Table 4 represents the results of the correlation test. All independent variables are significantly correlated with the dependent variable at the 5% significance level, which indicates that the control variables we selected are effective. In addition, most of the correlation coefficients between variables are significant at the 5% significance level and are all less than 0.8, which avoids the possibility of multicollinearity in the model. Further, to obtain a more precise relationship between the digital economy and just transition, we will use econometric models to estimate.

5.3. Benchmark regression

5.3.1. Does the digital economy accelerate the just transition?

In Table 5, we estimate the relationship between the digital economy and just transition by using pooled ordinary least squares (OLS), feasible generalized least squares (FGLS), and SYS-GMM techniques, respectively. In general, pooled OLS models estimate panel data with biased results. We set three tests for the panel data, which are the Wald test, the Wooldridge test, and the cross-sectional dependence (CD) test. Their results show that the null hypotheses are all rejected at the 1% level, indicating that the panel data has groupwise heteroskedasticity, first-order autocorrelation, and cross-sectional dependence (Shahzad et al., 2018). Therefore, the FGLS technique is usually a good estimation method. However, considering the bidirectional causal effects of independent and dependent variables, the dynamic model can eliminate potential endogeneity better than the static model. Therefore, we also use the SYS-GMM technique to estimate. For the SYS-GMM technique, we need to perform two tests (Dong et al., 2022). First, the Arellano-Bond (A-B) test is used to examine the autocorrelation characteristics of the difference term of the random disturbance term, and the estimates show that AR(1) is significant at the 1% significance level, and AR(2) is not significant. Therefore, we accept the null hypothesis that the disturbance term has no autocorrelation. Second, the result of the Sargan test shows that the *p*-value of the statistic is greater than 0.1, which indicates that the selected instrumental variable (IV) is effective.

Table 5
Estimated results of the impact of the digital economy on just transition.

Dependent variable: *lnJUST*			
Variables	OLS	FGLS	SYS-GMM
	(1)	(2)	(3)
$lnJUST_{i,t-1}$			0.827*** (24.37)
lnDIG	0.214*** (6.91)	0.150*** (4.69)	0.053*** (2.63)
lnGDP	0.275*** (18.40)	0.313*** (15.97)	0.039** (2.13)
lnPOP	−0.313*** (−23.97)	−0.325*** (−17.94)	−0.012 (−0.72)
lnTRADE	−0.104*** (−3.65)	−0.004 (−0.12)	0.084*** (3.37)
lnIND	−0.403*** (−13.10)	−0.257*** (−7.08)	−0.078** (−2.52)
_cons	−2.075*** (−5.40)	−3.894*** (−8.36)	−1.208*** (−3.85)
R2	0.7358		
Wald test		0.0000	
Wooldridge test		0.0000	
CD test		0.0000	
AR(1)			0.0000
AR(2)			0.2378
Sargan test			0.1607
Obs.	720	720	648

Notes: ***, **, and * indicates statistical significance at 1%, 5%, and 10% levels, respectively; the value in parentheses represent t-statistics or z-statistics.

In terms of the results of Table 5, the estimated coefficients of the digital economy are significantly positive in the static models and dynamic model, which indicates that the digital economy positively affects a just transition. For the results of the SYS-GMM technique, a 1% increase in the digital economy index will cause a 0.053% increase in the just transition index. This is because the digital economy has the potential to significantly promote the three aspects of just transition (i.e., distributional justice, procedural justice, and restorative justice). The digital economy has favorably promoted the development of renewable energy technologies, reduced unemployment, and achieved social equality. For example, with the rapid development of the digital economy, electric vehicles have ushered in vitality, and more and more digital charging piles have been established in cities (Fu et al., 2021), alleviating concerns about the transition to renewable energy transition. Moreover, the digital economy has created many green jobs. Digitalization helps enterprises make green transitions by creating a more advanced skills base and providing workers with greener employment opportunities (Angeliki, 2021). Specifically, we also analyze the impact of the digital economy on three aspects of just transition (distributional justice, procedural justice, and restorative justice; see Section 5.3.2). Therefore, hypothesis 1 is confirmed.

In terms of the control variables, economic growth and trade openness positively affect just transition due to a stronger economy that helps allocate resources in a post-carbon society for more equitable economic development. The industrial structure negatively affects just transition. A potential explanation is that the increase in the proportion of secondary industry will expand the consumption of fossil energy, which is not conducive to society getting rid of its dependence on fossil energy

Table 4
Results of the correlation check.

Variables	*lnJUST*	*lnDIG*	*lnGDP*	*lnPOP*	*lnTRADE*	*lnIND*	*lnHCI*	*lnFD*
lnJUST	1.0000							
lnDIG	0.6464*	1.0000						
lnGDP	0.1096*	0.1622*	1.0000					
lnPOP	−0.4333*	−0.3115*	0.7601*	1.0000				
lnTRADE	0.2633*	0.4926*	−0.4933*	−0.6506*	1.0000			
lnIND	−0.4574*	−0.2125*	0.0175	0.1701*	−0.0376	1.0000		
lnHCI	0.6719*	0.7242*	0.0750	−0.4074*	0.3454*	−0.2751*	1.0000	
lnFD	0.5848*	0.5391*	0.2764*	−0.1129*	0.1684*	−0.3144*	0.3870*	1.0000

Note: * indicates statistical significance at 5% levels.

sources, and it is not conducive to the development of green industries and the absorption of employment.

5.3.2. What aspects of the just transition are affected by the digital economy?

Further, we divide just transition into three components and explore the impact of the digital economy in three aspects of just transition - distributional justice ($lnJUST1_{it}$), procedural justice ($lnJUST2_{it}$), and restorative justice ($lnJUST3_{it}$). The estimated results are shown in columns (1)–(3) of Table 6, respectively. We find that the impacts of the digital economy on the three aspects of just transition are significantly positive. The digital economy has the most significant impact on distributional justice, with an estimated coefficient of 0.136. This indicates that the focus of the digital economy on promoting just transition is distributional justice. A potential reason is that the development of the digital economy can offset the national economy's dependence on fossil energy. On the one hand, the implementation of digitalization can improve the utilization efficiency of fossil energy, and reduce fossil energy reserves by managing national energy demand by implementing smart grids and creating distributed generation points (Ma et al., 2022). On the other hand, the digital economy also promotes equality of social distribution, narrows the digital divide, reduces production costs, and digitally spreads the benefits of the energy transition to the poor and those more vulnerable to climate change.

The digital economy also has a positive impact on restorative justice (column (3) of Table 6), but its estimated coefficient (0.066) is only half of the estimated coefficient value of the digital economy on distributional justice (0.136). The digital economy can also increase the active deployment of renewable energy and increase employment levels. For example, digital technology is widely used in clean energy, and the substantial promotion of smart charging piles has accelerated the use of new energy electric vehicles, making people more dependent on renewable energy. In addition, e-commerce, artificial intelligence, and big data have created multiple jobs, and the platform economy has facilitated a just transition by helping laid-off workers acquire skills and seek jobs online more easily. In comparison, the digital economy has less impact on procedural justice. Column (2) of Table 6 shows that every 1% increase in the digital economy will cause the procedural justice index to increase by about 0.01% at the 10% significance level. The digital economy ensures the fair implementation of climate financing and climate justice actions and improves the fairness, inclusiveness, and sustainability of climate justice through unified digital management measures. The digital economy breaks the model of layer-by-layer transmission in the original policy implementation process. It makes policy implications more direct and efficient, provides services directly to the public, avoids corruption, and ensures fairness and transparency (Merhi and Ahluwalia, 2018).

Table 6
Estimated results of the impact of the digital economy on distributional, procedural, and restorative justice.

Dependent variable	*lnJUST1*	*lnJUST2*	*lnJUST3*
	(1)	(2)	(3)
$lnJUST_{i,t-1}$	−0.076*** (−2.91)	0.851*** (31.17)	0.862*** (32.87)
lnDIG	0.136*** (4.44)	0.010* (1.84)	0.066** (2.06)
lnGDP	0.100*** (4.13)	−0.005 (−0.46)	0.327*** (6.26)
lnPOP	−0.077*** (−4.00)	−0.032*** (−3.40)	−0.146*** (−2.94)
lnTRADE	0.070* (1.86)	0.005 (0.51)	0.071* (1.79)
lnIND	−0.098** (−2.27)	−0.041*** (−3.10)	−0.217*** (−4.58)
_cons	−1.606** (−2.25)	0.668** (2.47)	−6.034*** (−7.08)
AR(1)	0.0000	0.0001	0.0000
AR(2)	0.4345	0.6322	0.4519
Sargan test	0.1194	0.2259	0.1791
Obs.	648	648	648

Note: ***, **, and * indicates statistical significance at 1%, 5%, and 10% levels, respectively; the value in parentheses represent z-statistics.

5.3.3. What aspects of the digital economy affect the just transition?

In addition, we are also eager to know what aspects of the digital economy have affected just transition. Therefore, we separately estimate the impact of the digital economy's infrastructure, social impact, and digital trade on just transition, and produce the results in columns (1)–(3) of Table 7. First, infrastructure significantly promotes just transition in column (1) of Table 7. Specifically, every 1% increase in the infrastructure index will result in a 0.068% increase in the just transition index. This is mainly because the infrastructure of broadband and the Internet has ensured the necessary basic guarantees in the transformation process and the rapid flow and transmission of information. Second, the social impact of the digital economy has also significantly promoted just transition. A potential explanation is that the digital economy has promoted the rapid rise of industries such as e-commerce, big data, and the Internet of Things (IoT), which have promoted the high-quality development of energy, reduced employment pressure, and offset the negative social impact of a low-carbon transition.

However, digital trade harms just transition, as shown in column (3) of Table 7. According to what we learned in Section 5.1.2, economies with a high digital trade index are in the upper locations of the digital value chain (e.g., the Philippines, Malaysia, and Vietnam), and employ many laborers to produce components required by high-tech manufacturing industries. The increase in digital trade makes upstream economies more dependent on this production model, which is not conducive to social transformation and equitable development, and it is more difficult to switch from dependence on fossil fuels to renewable energy.

5.4. Robust analysis

5.4.1. Robustness check I: alternative control variables

We first re-estimate Eq. (3) by using GDP per capita as the proxy variable for economic growth, and list the results in column (1) of Table 8. The estimated coefficient of the digital economy is significantly positive, which is consistent with the results of the benchmark regression.

5.4.2. Robustness check II: alternative estimation technique

We further verify robustness by using the IV strategy proposed by Lewbel (2012). It is worth noting that this method explores mainly the causal relationship between the digital economy and just transition by constructing an IV based on heteroscedasticity in the random error term.

Table 7
Estimated results of the impact of three aspects of the digital economy on the just transition.

Dependent variable: *lnJUST*			
	(1)	(2)	(3)
$lnJUST_{i,t-1}$	0.858*** (18.57)	0.827*** (25.92)	0.894*** (22.99)
lnDIG1	0.068** (2.52)		
lnDIG2		0.027*** (2.59)	
lnDIG3			−0.007*** (−3.84)
lnGDP	0.041 (1.55)	0.054*** (3.06)	0.049** (2.50)
lnPOP	−0.026 (−0.97)	−0.027* (−1.76)	−0.017 (−0.89)
lnTRADE	0.048 (1.27)	0.080*** (3.29)	0.078** (2.30)
lnIND	−0.009 (−0.21)	−0.077*** (−2.60)	−0.062* (−1.78)
_cons	−1.030** (−2.09)	−1.379*** (−4.33)	−1.334*** (−3.05)
AR(1)	0.0000	0.0000	0.0000
AR(2)	0.2626	0.2515	0.2734
Sargan test	0.3895	0.1358	0.1497
Obs.	648	648	648

Note: ***, **, and * indicates statistical significance at 1%, 5%, and 10% levels, respectively; the value in parentheses represent z-statistics.

Table 8
Estimated results of the robustness check.

Dependent variable: *lnJUST*			
Variables	(1)	(2)	(3)
lnJUST$_{i,t-1}$	0.827*** (24.37)		0.811*** (23.68)
lnDIG	0.053*** (2.63)	0.214*** (7.23)	0.037*** (3.28)
lnGDP	0.039** (2.13)	0.275*** (18.51)	0.040** (2.04)
lnPOP	0.027*** (3.05)	−0.313*** (−20.42)	−0.013 (−0.73)
lnTRADE	0.084*** (3.37)	−0.104*** (−2.72)	0.083*** (3.27)
lnIND	−0.078** (−2.52)	−0.403*** (−12.48)	−0.068** (−2.28)
_cons	−1.208*** (−3.85)	−2.075*** (−4.10)	−1.309*** (−3.78)
AR(1)	0.0000		0.0000
AR(2)	0.2378		0.2465
Sargan test	0.1607		0.1127
Hansen J		0.000	
Obs.	648	720	648

Notes: ***, **, and * indicates statistical significance at 1%, 5%, and 10% levels, respectively; the value in parentheses represent z-statistics.

The estimated coefficient of the digital economy is significantly positive in column (2) of Table 8, confirming the robustness of the benchmark regression.

5.4.3. Robustness check III: alternative index calculation method

We construct another comprehensive digital economy index by using the fully arranged polygon graphical index method following Hao et al. (2020). The estimated results show that the digital economy positively affects just transition in column (3) of Table 8, and further confirm that the benchmark results are robust.

6. Mediation analysis

To explore the path of the digital economy affecting just transition, we test the mechanisms by using the mediating variables of human capital and financial development. Their results are listed in Table 9.

6.1. The mediating effect of human capital

In terms of human capital, the value of the Sobel test is 0.046, which is significant at the 1% level and underscores the effective mediating role of human capital. For the estimated coefficients, column (1) of Table 9 shows the benchmark results, which indicate that the digital economy promotes just transition. Columns (2) and (3) are estimated from Eq. (4) and Eq. (5), respectively. Among them, the estimated coefficient of the digital economy in column (2) is significantly positive, which indicates that the digital economy positively affects human capital. Lee et al. (2022) also confirmed the above conclusion using the ICT index as a proxy variable of the digital economy. For column (3) of Table 9, the estimated coefficient of human capital is 0.275, which is significantly positive; and the estimated coefficient of the digital economy is 0.167, which is significant and lower than its coefficient in column (1) of Table 9. The above results indicate that the digital economy indirectly promotes just transition by raising the level of human capital, and hypothesis 2 is verified. On the one hand, the improvement of human capital means people have more skills and educational backgrounds. Under the negative impact of the energy transition, they can find alternative jobs faster to avoid unemployment. New digital technologies will affect the workforce's demand for new skills, especially in renewable energy (Tsani, 2021). On the other hand, human capital will have obvious positive social impacts in the process of realizing a low-carbon transition (Khan et al., 2021a; Yao et al., 2019). For example, an improvement in the education level positively affects people's environmental protection awareness, avoids the injustice of transition, and takes greater account of disadvantaged groups when formulating strategies.

6.2. The mediating effect of financial development

In terms of financial development, the value of the Sobel test is 0.037, which is significant at the 1% level, and underscores the effective mediating role of financial development. Column (4) of Table 9 shows that the estimated coefficient of the digital economy is significantly positive, indicating that the digital economy positively affects financial development. The development of the digital economy has improved the financing and investment methods of the traditional financial sector and increased the speed of capital investment and the efficiency of capital flow (Lee et al., 2022; Park et al., 2018). For example, it is possible to apply for loan services through mobile communication devices, and artificial intelligence helps companies develop more accurate investment strategies. Moreover, the estimated coefficient of financial development is significantly positive, and the estimated coefficient of the digital economy is also significantly positive in column (5) of Table 9. The above results show that the digital economy indirectly promotes just transition by increasing the level of financial development, and hypothesis 3 is confirmed. Traditional financial investments to help the energy transition will not consider an additional burden and simply provide decarbonized climate action. But financial development, while supporting renewable energy projects, also helps vulnerable workers and communities in decarbonization efforts. Lowitt and Makgetla (2021) suggest that finance for just transition is focused on societal and developmental goals for those negatively impacted by climate action. In Fig. 5, we show the above transition mechanism, so readers can further understand the relationship between the digital economy and just transition.

Table 9
Estimated results of the mediating effects.

Dependent variables	Total effect	Human capital		Financial development	
	lnJUST	*lnHCI*	*lnJUST*	*lnFD*	*lnJUST*
Variables	(1)	(2)	(3)	(4)	(5)
lnDIG	0.212*** (6.55)	0.166*** (12.82)	0.167*** (4.63)	0.290*** (5.36)	0.178*** (5.66)
lnHCI			0.275*** (2.87)		
lnFD					0.126*** (5.74)
lnGDP	0.275*** (17.22)	0.053*** (8.29)	0.261*** (15.62)	0.246*** (9.28)	0.241*** (15.00)
lnPOP	−0.314*** (−22.77)	−0.063*** (−11.39)	−0.297*** (−19.81)	−0.146*** (−6.37)	−0.293*** (−21.72)
lnTRADE	−0.105*** (−3.57)	−0.029** (−2.42)	−0.097*** (−3.30)	0.071 (1.41)	−0.112*** (−3.88)
lnIND	−0.399*** (−11.72)	−0.053*** (−3.85)	−0.385*** (−11.23)	−0.371*** (−6.59)	−0.334*** (−10.09)
_cons	−2.063*** (−5.07)	1.276*** (7.84)	−2.414*** (−5.71)	1.513** (2.21)	−2.267*** (−5.79)
Sobel test		0.046***(2.802)		0.037***(3.915)	
Proportion of total effect that is mediated		21.53%		17.04%	
Obs.	680	680	680	676	676

Notes: ***, **, and * indicates statistical significance at 1%, 5%, and 10% levels, respectively; the value in parentheses represent t-statistics.

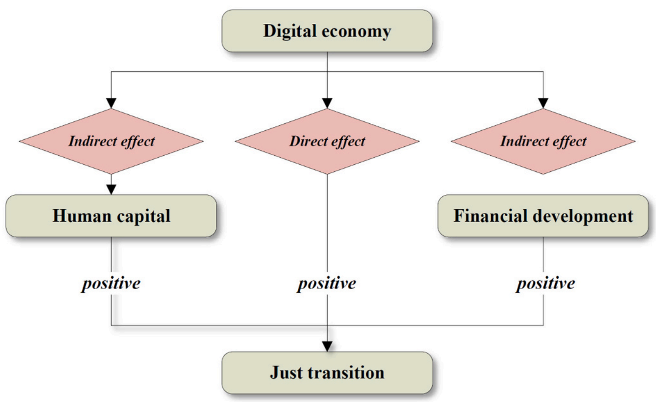

Fig. 5. The mechanism path between the digital economy and just transition.

7. Conclusions and policy implications

7.1. Conclusions

To explore the nexus between the digital economy and just transition, this paper estimates the impact of the digital economy on just transition and the mediating effect by constructing digital economy indexes and just transition indexes for 72 economies covering the period 2010–2019. We also estimate the impact of the digital economy on distributional justice, procedural justice, and restorative justice, as well as the impact of the digital economy infrastructure, social impact, and digital trade on just transition. Further, we also estimate the mediating mechanisms between the digital economy and just transition. This paper draws the following conclusions:

First, the just transition index and digital economy index of major economies in the world show a clear upward trend. Iceland has undergone the most prominent just transition due to its reliance on non-fossil energy. Second, the empirical results show that the digital economy not only positively affects just transition, but also has significant effects on distributional justice, procedural justice, and restorative justice. Third, the infrastructure and social impact of the digital economy significantly promotes just transition, while digital trade negatively affects just transition. Fourth, the digital economy indirectly promotes just transition by improving the level of human capital and financial development.

7.2. Policy implications

Based on the conclusions drawn above, this paper proposes the following policy implications:

First, digital development is conducive to the process of just transition. Therefore, digital participation should be included in the guidance of future low-carbon transitions. For example, digital participation guides unemployed workers to use Internet technology to obtain reemployment, and digital grids help to facilitate access to clean energy. Digitalization should also promote more equitable social services, deploying digital technologies in climate-vulnerable economies to help them improve technological innovation, civic awareness, access to low-cost energy services, and energy resilience.

Second, when formulating transition policies, digital concepts should be fully integrated into them. For example, the government uses digital means to gradually get rid of dependence on fossil energy, provide public advice services on digital platforms, and guide unemployed workers to reemployment. Moreover, the government should pay attention to improving the digital infrastructure in the process of responding to climate change to ensure the stable development of society and the economy.

Third, governments should pay special attention to promoting education in the process of developing the level of digitalization. The government should set up educational institutions to help unemployed workers acquire more needed skills by using digital technology. Furthermore, digitalization should provide more convenient financial services for transformed enterprises, such as lowering the threshold for loans, accelerating digital investment, and providing transition subsidies. Individuals affected by the transformation need to use digital financial platforms (e.g., Alipay or PayPal) to provide necessary financial assistance.

Inclusion and diversity

While citing references scientifically relevant for this work, we also actively worked to promote gender balance in our reference list. The author list of this paper includes contributors from the location where the research was conducted who participated in the data collection, design, analysis, and/or interpretation of the work.

Disclosure statement

No potential conflict of interest was reported by the authors.

CRediT authorship contribution statement

Jianda Wang: Data curation, Writing – original draft, Funding acquisition. **Kun Wang:** Validation, Writing – review & editing. **Kangyin Dong:** Conceptualization, Methodology, Software. **Muhammad Shahbaz:** Methodology, Conceptualization, Supervision.

Acknowledgements

The article is sponsored by "the Postgraduate Innovative Research Fund" of University of International Business and Economics (Grant No.202232). The authors acknowledge the useful comments from the editor and anonymous reviewers. Certainly, all remaining errors are our own.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2022.106315.

References

Agostino, D., Saliterer, I., Steccolini, I., 2021. Digitalization, accounting and accountability: a literature review and reflections on future research in public services. Financ. Account. Manag. 38, 152–176. https://doi.org/10.1111/faam.12301.

Ahmed, F., Naeem, M., Iqbal, M., 2017. ICT and renewable energy: a way forward to the next generation telecom base stations. Telecommun. Syst. 64, 43–56. https://doi.org/10.1007/s11235-016-0156-4.

Ahmedov, I., 2020. The impact of digital economy on international trade. Eur. J. Manag. Bus. Econ. 5 https://doi.org/10.24018/ejbmr.2020.5.4.389.

Angeliki, D., 2021. Digital Skills: A Catalyst for Green Transition, Huawei Blog. https://blog.huawei.com/2021/07/28/digital-skills-catalyst-green-transition/.

Archer, D., Dodman, D., 2015. Making capacity building critical: power and justice in building urban climate resilience in Indonesia and Thailand. Urban Stud. 14, 68–78. https://doi.org/10.1016/j.uclim.2015.06.007.

Baron, R.M., Kenny, D.A., 1986. The moderator–mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. J. Pers. Soc. Psychol. 51, 1173. https://doi.org/10.1037//0022-3514.51.6.1173.

Barry, J., 2021. Green republicanism and a 'just transition' from the tyranny of economic growth. Crit. Rev. Int. Soc. Pol. 24, 725–742. https://doi.org/10.1080/13698230.2019.1698134.

Bastos, L., Mairon, G., 2022. Just transition towards a bioeconomy: four dimensions in Brazil, India and Indonesia. For. Policy Econ. 136, 102684 https://doi.org/10.1016/j.forpol.2021.102684.

Batjargal, B., 2007. Internet entrepreneurship: social capital, human capital, and performance of internet ventures in China. Res. Policy 36, 605–618. https://doi.org/10.1016/j.respol.2006.09.029.

Baxtiyarjon Bulturbayevich, M., Baxriddin Jurayevich, M., 2021. The impact of the digital economy on economic growth. Int. J. Bus. Law Educ. 1, 4–7. https://doi.org/10.31149/ijie.v3i6.394.

Berger, L., Bréchet, T., Pestiaux, J., van Steenberghe, V., 2020. Case-study – the transition of Belgium towards a low carbon society: a macroeconomic analysis fed by a participative approach. Energy Strateg. Rev. 29, 100463 https://doi.org/10.1016/j.esr.2020.100463.

Blundell, R., Bond, S., 1998. Initial conditions and moment restrictions in dynamic panel data models. J. Econ. 87, 115–143. https://doi.org/10.1016/S0304-4076(98)00009-8.

BP, 2022. Statistical Review of World Energy. in: BP (Ed.). https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

Broadstock, D.C., Li, J., Zhang, D., 2016. Efficiency snakes and energy ladders: a (meta-)frontier demand analysis of electricity consumption efficiency in Chinese households. Energy Policy 91, 383–396. https://doi.org/10.1016/j.enpol.2016.01.009.

Broadstock, D.C., Cheng, L.T., Poon, J.S., 2021. Fintech Unicorns, The Palgrave Handbook of FinTech and Blockchain. Springer, pp. 109–170.

Bulkeley, H., Carmin, J., Castán Broto, V., Edwards, G.A.S., Fuller, S., 2013. Climate justice and global cities: mapping the emerging discourses. Global Envion. Chang. 23, 914–925. https://doi.org/10.1016/j.gloenvcha.2013.05.010.

Carlsson, B., 2004. The digital economy: what is new and what is not? Struct. Change Econ. Dyn. 15, 245–264. https://doi.org/10.1016/j.strueco.2004.02.001.

Cha, J.M., 2020. A just transition for whom? Politics, contestation, and social identity in the disruption of coal in the Powder River Basin. Energy Res. Soc. Sci. 69, 101657 https://doi.org/10.1016/j.erss.2020.101657.

Chen, J., Zhang, Q., Xu, N., Li, W., Yao, Y., Li, P., Yu, Q., Wen, C., Song, X., Shibasaki, R., Zhang, H., 2022a. Roadmap to hydrogen society of Tokyo: locating priority of hydrogen facilities based on multiple big data fusion. Appl. Energy 313, 118688. https://doi.org/10.1016/j.apenergy.2022.118688.

Chen, X., Yan, D., Chen, W., 2022b. Can the digital economy promote FinTech development? Growth Chang. 53, 221–247. https://doi.org/10.1111/grow.12582.

Coggins, S., Berrang-Ford, L., Hyams, K., Satyal, P., Ford, J., Paavola, J., Arotoma-Rojas, I., Harper, S., 2021. Empirical assessment of equity and justice in climate adaptation literature: a systematic map. Environ. Res. Lett. 16, 073003 https://doi.org/10.1088/1748-9326/ac0663.

COP26, 2021. End of coal in sight at COP26. In: UN Climate Change Conference 2021. https://ukcop26.org/end-of-coal-in-sight-at-cop26/.

Creti, A., Jouvet, P.A., Mignon, V., 2012. Carbon price drivers: Phase I versus Phase II equilibrium? Energy Econ. 34, 327–334. https://doi.org/10.1016/j.eneco.2011.11.001.

Diduck, A., Patel, K., Malik, A.K., 2021. Advancing Environmental Justice for Marginalized Communities in India: Progress, Challenges and Opportunities. Routledge.

Dong, K., Shahbaz, M., Zhao, J., 2022. How do pollution fees affect environmental quality in China? Energy Policy 160, 112695. https://doi.org/10.1016/j.enpol.2021.112695.

Eckstein, D., Künzel, V., Schäfer, L., 2021. Global climate risk index 2021, Who Suffers Most from Extreme Weather Events. https://www.germanwatch.org/en/19777.

Enciso-Santocildes, M., Echaniz-Barrondo, A., Gómez-Urquijo, L., 2021. Social innovation and employment in the digital age: the case of the connect employment shuttles in Spain. Inter. J. Inno. Stud. 5, 175–189. https://doi.org/10.1016/j.ijis.2021.11.001.

Evans, G., Phelan, L., 2016. Transition to a post-carbon society: linking environmental justice and just transition discourses. Energy Policy 99, 329–339. https://doi.org/10.1016/j.enpol.2016.05.003.

Feenstra, R.C., Inklaar, R., Timmer, M.P., 2015. The next generation of the Penn world table. Am. Econ. Rev. 105, 3150–3182. https://doi.org/10.1257/aer.20130954.

Fisher, S., 2015. The emerging geographies of climate justice. Geogr. J. 181, 73–82. https://doi.org/10.1111/geoj.12078.

Fu, Z., Dong, P., Li, S., Ju, Y., Liu, H., 2021. How blockchain renovate the electric vehicle charging services in the urban area? A case study of Shanghai, China. J. Clean. Prod. 315, 128172 https://doi.org/10.1016/j.jclepro.2021.128172.

Gašparović, I., Gašparović, M., 2019. Determining optimal solar power plant locations based on remote sensing and GIS methods: a case study from Croatia. Remote Sens. 11 https://doi.org/10.3390/rs11121481.

Gonzalez, A., 2019. Making "a racket" but does anybody care? A study of environmental justice access and recognition through the political ecology of voice. Geoforum 102, 142–156. https://doi.org/10.1016/j.geoforum.2019.03.024.

Green, F., Gambhir, A., 2020. Transitional assistance policies for just, equitable and smooth low-carbon transitions: who, what and how? Clim. Pol. 20, 902–921. https://doi.org/10.1080/14693062.2019.1657379.

Grigorescu, A., Pelinescu, E., Ion, A.E., Dutcas, M.F., 2021. Human Capital in Digital Economy: an empirical analysis of Central and Eastern European Countries from the European Union. Sustainability 13. https://doi.org/10.3390/su13042020.

Hao, Y., Ye, B., Gao, M., Wang, Z., Chen, W., Xiao, Z., Wu, H., 2020. How does ecology of finance affect financial constraints? Empirical evidence from Chinese listed energy- and pollution-intensive companies. J. Clean. Prod. 246, 119061 https://doi.org/10.1016/j.jclepro.2019.119061.

Heffron, R.J., McCauley, D., 2017. The concept of energy justice across the disciplines. Energy Policy 105, 658–667. https://doi.org/10.1016/j.enpol.2017.03.018.

Hess, D.J., 2016. The politics of niche-regime conflicts: distributed solar energy in the United States. Environ. Innov. Soc. Transit. 19, 42–50. https://doi.org/10.1016/j.enpol.2018.04.014.

House of Commons, 2021. Green Jobs: Government Response to the Committee's Third Repot. In: Fourth Speical Report of Session 2021–22 (Ed.). https://committees.parliament.uk/publications/8559/documents/86458/default/.

Huang, Y., Haseeb, M., Usman, M., Ozturk, I., 2022. Dynamic association between ICT, renewable energy, economic complexity and ecological footprint: is there any difference between E-7 (developing) and G-7 (developed) countries? Technol. Soc. 68, 101853 https://doi.org/10.1016/j.techsoc.2021.101853.

IEA, 2017. Digitalization and Energy. International Energy Agency. https://www.iea.org/reports/digitalisation-and-energy.

IEA, 2022. Explore Energy Data by Catagory, Indicator, Country or Region. Agency, I.E. (Ed.). https://www.iea.org/data-and-statistics/data-tables?country=WORLD.

ILOSTAT, 2022. Labour Share of GDP, Comprising Wages and Social Protection. International Labour Organization. https://ilostat.ilo.org/data/data-catalogue/.

Ishida, H., 2015. The effect of ICT development on economic growth and energy consumption in Japan. Telematics Inform. 32, 79–88. https://doi.org/10.1016/j.tele.2014.04.003.

ITU, 2022. ICT Indicators Database. International Telecommunication Union (Ed.). https://www.itu.int/en/ITU-D/Conferences/TDAG/Pages/default.aspx.

Jenkins, K., McCauley, D., Heffron, R., Stephan, H., Rehner, R., 2016. Energy justice: a conceptual review. Energy Res. Soc. Sci. 11, 174–182. https://doi.org/10.1016/j.erss.2015.10.004.

Kalt, T., 2021. Jobs vs. climate justice? Contentious narratives of labor and climate movements in the coal transition in Germany. Environ. Polit. 30, 1135–1154. https://doi.org/10.1080/09644016.2021.1892979.

Khan, Z., Ali, S., Dong, K., Li, R.Y.M., 2021a. How does fiscal decentralization affect CO_2 emissions? The roles of institutions and human capital. Energy Econ. 94, 105060 https://doi.org/10.1016/j.eneco.2020.105060.

Khan, Z., Murshed, M., Dong, K., Yang, S., 2021b. The roles of export diversification and composite country risks in carbon emissions abatement: evidence from the signatories of the regional comprehensive economic partnership agreement. Appl. Econ. 53, 4769–4787. https://doi.org/10.1080/00036846.2021.1907289.

King, A.C., Odunitan-Wayas, F.A., Chaudhury, M., et al., 2021. Community-based approaches to reducing health inequities and fostering environmental justice through global youth-engaged citizen science. Int. J. Env. Res. Pub. He. 18 (3), 892. https://doi.org/10.3390/ijerph18030892.

Lacey-Barnacle, M., 2020. Proximities of energy justice: contesting community energy and austerity in England. Energy Res. Soc. Sci. 69, 101713 https://doi.org/10.1016/j.erss.2020.101713.

Lange, S., Pohl, J., Santarius, T., 2020. Digitalization and energy consumption. Does ICT reduce energy demand? Ecol. Econ. 176, 106760 https://doi.org/10.1016/j.ecolecon.2020.106760.

Laurent, É., 2011. Issues in environmental justice within the European Union. Ecol. Econ. 70, 1846–1853. https://doi.org/10.1016/j.ecolecon.2011.06.025.

Lee, C.C., Yuan, Z., Wang, Q., 2022. How does information and communication technology affect energy security? International evidence. Energy Econ. 109, 105969 https://doi.org/10.1016/j.eneco.2022.105969.

Lewbel, A., 2012. Using heteroscedasticity to identify and estimate mismeasured and endogenous regressor models. J. Bus. Econ. Stat. 30, 67–80. https://doi.org/10.1080/07350015.2012.643126.

Li, Z., Liu, Y., 2021. Research on the spatial distribution pattern and influencing factors of digital economy development in China. IEEE Access 9, 63094–63106. https://doi.org/10.1109/ACCESS.2021.3075249.

Li, Y., Yang, X., Ran, Q., Wu, H., Irfan, M., Ahmad, M., 2021. Energy structure, digital economy, and carbon emissions: evidence from China. Environ. Sci. Pollut. Res. 28, 64606–64629. https://doi.org/10.1007/s11356-021-15304-4.

Lin, B., Zhou, Y., 2021. Does the internet development affect energy and carbon emission performance? Sustain. Prod. Consump. 28, 1–10. https://doi.org/10.1016/j.spc.2021.03.016.

Litvinenko, V.S., 2020. Digital economy as a factor in the technological development of the mineral sector. Nat. Resour. Res. 29, 1521–1541. https://doi.org/10.1007/s11053-019-09568-4.

Lowitt, S., Makgetla, N., 2021. Finance and the Just Transition. Trade and Industrial Policy Strategies.

Ma, Q., Tariq, M., Mahmood, H., Khan, Z., 2022. The nexus between digital economy and carbon dioxide emissions in China: the moderating role of investments in research and development. Technol. Soc. 68, 101910 https://doi.org/10.1016/j.techsoc.2022.101910.

Mahmudov Baxriddin, J., Mullabayev Baxtiyarjon, B., 2020. The impact of the digital economy on economic growth. Int. J. Integrated Educ. 3, 16–18. https://doi.org/10.31149/ijie.v3i6.394.

Markard, J., 2018. The next phase of the energy transition and its implications for research and policy. Nat. Energy 3, 628–633.

McCauley, D., Heffron, R., 2018. Just transition: integrating climate, energy and environmental justice. Energy Policy 119, 1–7. https://doi.org/10.1016/j.enpol.2018.04.014.

McCauley, D., Ramasar, V., Heffron, R.J., Sovacool, B.K., Mebratu, D., Mundaca, L., 2019. Energy justice in the transition to low carbon energy systems: exploring key themes in interdisciplinary research. Appl. Energy 233-234, 916–921. https://doi.org/10.1016/j.apenergy.2018.10.005.

McCauley, D., Pettigrew, K.A., Bennett, M.M., Todd, I., Wood-Donnelly, C., 2022. Which states will lead a just transition for the Arctic? A DeePeR analysis of global data on Arctic states and formal observer states. Global Envion. Chang. 73, 102480 https://doi.org/10.1016/j.gloenvcha.2022.102480.

McLaren, D.P., 2012. Procedural justice in carbon capture and storage. Energ. Environ. 23, 345–365. https://doi.org/10.1260/0958-305X.23.2-3.345.

Merhi, M.I., Ahluwalia, P., 2018. Digital economy and corruption perceptions: a cross-country analysis. Int. J. Digit. Account. Res. 18 https://doi.org/10.4192/1577-8517-v18_2.

Mesenbourg, T.L., 2001. Measuring the Digital Economy, 1. US Bureau of the Census, pp. 1–19. https://www.census.gov/content/dam/Census/library/working-papers/2001/econ/umdigital.pdf.

Mirza, U.K., Ahmad, N., Harijan, K., Majeed, T., 2009. Identifying and addressing barriers to renewable energy development in Pakistan. Renew. Sust. Energ. Rev. 13, 927–931. https://doi.org/10.1016/j.rser.2007.11.006.

Murshed, M., 2020. An empirical analysis of the non-linear impacts of ICT-trade openness on renewable energy transition, energy efficiency, clean cooking fuel access and environmental sustainability in South Asia. Environ. Sci. Pollut. R. 27, 36254–36281. https://doi.org/10.1007/s11356-020-09497-3.

ND-GAIN, 2022. ND-GAIN Country Index. Notre Dame Global Adaptation Initiative (Ed.). University of Notre Dame, South Bend, USA. https://gain.nd.edu/our-work/country-index/.

Newell, P., Mulvaney, D., 2013. The political economy of the 'just transition'. Geogr. J. 179, 132–140. https://doi.org/10.1111/geoj.12008.

Nijhuis, M., Gibescu, M., Cobben, J.F.G., 2015. Assessment of the impacts of the renewable energy and ICT driven energy transition on distribution networks. Renew. Sust. Energ. Rev. 52, 1003–1014. https://doi.org/10.1016/j.rser.2015.07.124.

Okereke, C., Coventry, P., 2016. Climate justice and the international regime: before, during, and after Paris. Wires. Clim. Change 7, 834–851. https://doi.org/10.1002/wcc.419.

Pan, W., Xie, T., Wang, Z., Ma, L., 2022. Digital economy: an innovation driver for total factor productivity. J. Bus. Res. 139, 303–311. https://doi.org/10.1016/j.jbusres.2021.09.061.

Park, Y., Meng, F., Baloch, M.A., 2018. The effect of ICT, financial development, growth, and trade openness on CO_2 emissions: an empirical analysis. Environ. Sci. Pollut. R. 25, 30708–30719. https://doi.org/10.1007/s11356-018-3108-6.

Pînzaru, F., Dima, A.M., Zbuchea, A., Vereș, Z., 2022. Adopting sustainability and digital transformation in business in Romania: a multifaceted approach in the context of the just transition. Amfiteatru Econ. 24, 28–45. https://doi.org/10.24818/EA/2022/59/5.

PWT 10.0, 2022. Penn World Table version 10.0. University of groningen (Ed.). https://www.rug.nl/ggdc/productivity/pwt/.

Quiggin, J., 2014. National accounting and the digital economy. Econ. Anal. Policy 44, 136–142. https://doi.org/10.1016/j.eap.2014.05.008.

Qureshi, S., 2019. Climate change adaptation for sustainable development: the information and communication technology (ICT) paradox. Inf. Technol. Dev. 25, 625–629. https://doi.org/10.1080/02681102.2019.1680164.

Ramzan, M., Raza, S.A., Usman, M., Sharma, G.D., Iqbal, H.A., 2022. Environmental cost of non-renewable energy and economic progress: do ICT and financial development mitigate some burden? J. Clean. Prod. 333, 130066 https://doi.org/10.1016/j.jclepro.2021.130066.

Ren, X., Cheng, C., Wang, Z., Yan, C., 2020. Spillover and dynamic effects of energy transition and economic growth on carbon dioxide emissions for the European Union: a dynamic spatial panel model. Sustain. Dev. 29, 228–242.

Ren, X., Li, Y., Shahbaz, M., Dong, K., Lu, Z., 2022. Climate risk and corporate environmental performance: empirical evidence from China. Sustain. Prod. Consump. 30, 467–477. https://doi.org/10.1016/j.spc.2021.12.023.

Riddle, S., 2015. The robots are coming for your job! Why digital literacy is so important for the jobs of the future. The Conversation 1–4. https://eprints.usq.edu.au/27741/1/Riddle%20-%202015%20-%20The%20robots%20are%20coming%20for%20your%20job.pdf.

Sadorsky, P., 2010. The impact of financial development on energy consumption in emerging economies. Energy Policy 38, 2528–2535. https://doi.org/10.1016/j.enpol.2009.12.048.

Salim, R., Yao, Y., Chen, G.S., 2017. Does human capital matter for energy consumption in China? Energy Econ. 67, 49–59. https://doi.org/10.1016/j.eneco.2017.05.016.

Scheuerman, H.L., 2018. Understanding shame: examining how justice and emotions operate in the context of restorative justice. Sociol. Compass 12, e12561. https://doi.org/10.1111/soc4.12561.

Schlosberg, D., 2004. Reconceiving environmental justice: global movements and political theories. Environ. Polit. 13, 517–540. https://doi.org/10.1080/0964401042000229025.

Schlosberg, D., 2013. Theorising environmental justice: the expanding sphere of a discourse. Environ. Polit. 22, 37–55. https://doi.org/10.1080/09644016.2013.755387.

Schmidhuber, J., Tubiello, F.N., 2007. Global food security under climate change. Proc. Natl. Acad. Sci. U. S. A. 104, 19703–19708. https://doi.org/10.1073/pnas.0701976104.

Shahzad, F., Rehman, I.U., Nawaz, F., Nawab, N., 2018. Does family control explain why corporate social responsibility affects investment efficiency? Corp. Soc. Resp. Env. Ma. 25, 880–888. https://doi.org/10.1002/csr.1504.

Shahzad, M., Wang, J., Dong, K., Zhao, J., 2022. The impact of digital economy on energy transition across the globe: the mediating role of government governance. Renew. Sust. Energ. Rev. 166 (3), 112620 https://doi.org/10.1016/j.rser.2022.112620.

Sindhu, D., Sangwan, A., 2017. Optimization of business intelligence using data digitalization and various data mining techniques. Int. J. Comput. In. 13, 1991–1997.

Sobel, M.E., 1982. Asymptotic confidence intervals for indirect effects in structural equation models. Sociol. Methodol. 13, 290–312. https://doi.org/10.2307/270723.

Sovacool, B.K., Heffron, R.J., McCauley, D., Goldthau, A., 2016. Energy decisions reframed as justice and ethical concerns. Nat. Energy 1, 16024. https://doi.org/10.1038/nenergy.2016.24.

Spencer, N., Strobl, E., 2020. Hurricanes, climate change, and social welfare: evidence from the Caribbean. Clim. Chang. 163, 337–357. https://doi.org/10.1007/s10584-020-02810-6.

Stevis, D., Felli, R., 2015. Global labour unions and just transition to a green economy. Int. Environ. Agreem-P. 15, 29–43. https://doi.org/10.1007/s10784-014-9266-1.

Thorsdottir, T.K., 2013. Iceland in Crisis: Gender Equality and Social Equity, Women and Austerity. Routledge, pp. 124–144.

Tomain, J.P., 2017. Clean Power Politics: The Democratization of Energy. Cambridge University Press.

Tranos, E., Reggiani, A., Nijkamp, P., 2013. Accessibility of cities in the digital economy. Cities 30, 59–67. https://doi.org/10.1016/j.cities.2012.03.001.

Tsani, S., 2021. Public policies for just transition: local content, employment, and human capital. Decent Work Econ. Growth 804–813.

UN, 2022a. In: Nations, U. (Ed.), SDG Indocators Database. https://unstats.un.org/sdgs/dataportal/database.

UN, 2022b. UN E-Government Survey in Media. United Nations.

UNDP, 2022. Human Development Reports. The United Nations Development Programme, New York, USA.

UNFCCC, 2015. Paris Agreement. The United Nations Framework Convention on Climate Change, Paris, France, 30 November–11 December 2015.

Unruh, G.C., 2000. Understanding carbon lock-in. Energy Policy 28, 817–830.

Vatalis, K.I., Avlogiaris, G., Tsalis, T.A., 2022. Just transition pathways of energy decarbonization under the global environmental changes. J. Environ. Manag. 309, 114713 https://doi.org/10.1016/j.jenvman.2022.114713.

Walker, G., 2009. Beyond distribution and proximity: exploring the multiple spatialities of environmental justice. Antipode 41, 614–636. https://doi.org/10.1111/j.1467-8330.2009.00691.x.

Wang, J., Dong, K., Dong, X., Taghizadeh-Hesary, F., 2022a. Assessing the digital economy and its carbon-mitigation effects: the case of China. Energy Econ. https://doi.org/10.1016/j.eneco.2022.106198.

Wang, J., Dong, X., Dong, K., 2022b. How digital industries affect China's carbon emissions? Analysis of the direct and indirect structural effects. Technol. Soc. 68, 101911 https://doi.org/10.1016/j.techsoc.2022.101911.

Wang, J., Zhao, J., Dong, K., Dong, X., 2022c. Is Financial Risk a Stumbling Block to the Development of Digital Economy? A Global Case. Emerg. Mark. Financ. Tr. https://doi.org/10.1080/1540496X.2022.2066995.

Watanabe, C., Moriya, K., Tou, Y., Neittaanmäki, P., 2018a. Consequences of the digital economy: transformation of the growth concept. Int. J. Manag. Inf. Technol. 10, 21–39. https://doi.org/10.5121/ijmit.2018.10202.

Watanabe, C., Naveed, K., Tou, Y., Neittaanmäki, P., 2018b. Measuring GDP in the digital economy: increasing dependence on uncaptured GDP. Technol. Forecast. Soc. 137, 226–240. https://doi.org/10.1016/j.techfore.2018.07.053.

WGI, 2022. The worldwide governance indicators. In: World Bank (Ed.), The Worldwide Governance Indicators: A Summary of Methodology, Data.

World Bank (Ed.), 2022. World Development Indicators. World Bank (Ed.), Washington, USA.

Wu, H., Xue, Y., Hao, Y., Ren, S., 2021. How does internet development affect energy-saving and emission reduction? Evidence from China. Energy Econ. 103, 105577 https://doi.org/10.1016/j.eneco.2021.105577.

Yao, Y., Ivanovski, K., Inekwe, J., Smyth, R., 2019. Human capital and energy consumption: evidence from OECD countries. Energy Econ. 84, 104534 https://doi.org/10.1016/j.eneco.2019.104534.

Zhao, C., Dong, X., Dong, K., 2022. Quantifying the energy trilemma in China and assessing its nexus with smart transportation. Smart and Resilient Transportation. https://doi.org/10.1108/SRT-05-2022-0008.

Zhu, L., Lo, K., 2021. Non-timber forest products as livelihood restoration in forest conservation: a restorative justice approach. Trees Forest. People 6, 100130. https://doi.org/10.1016/j.tfp.2021.100130.

Zhukovskiy, Y.L., Batueva, D.E., Buldysko, A.D., Gil, B., Starshaia, V.V., 2021. Fossil energy in the framework of sustainable development: analysis of prospects and development of forecast scenarios. Energies 14, 5268. https://doi.org/10.3390/en14175268.