Politická ekonomie

Volume 75
Forthcoming articles
https://doi.org/10.18267/j.polek.1533
Open Access

VŠE / PRAGUE UNIVERSITY OF ECONOMICS AND BUSINESS

Role of Technological Innovation in Strengthening Energy Security and Advancing Carbon Neutrality: Implications for Green Investment in China

Huma Naz, Zhang Jingxiao, Inayat Khan

Huma Naz, School of Economic & Management, Chang'an University, Xi'an, Shaangxi, China

Zhang Jingxiao (*corresponding author*, email: zhangjingxiao@126.com), School of Economic & Management, Chang'an University, Xi'an, Shaangxi, China

Inayat Khan (*corresponding author*, email: inayat@cumt.edu.cn), School of Economic & Management China, University of Mining and Technology, Xuzhou, Jiangsu, China

Abstract

This study examines the impact of advanced technologies, including built environment technology, electricity grade technology, hydrogen technology, offshore water technology, electric vehicles technology and renewable energy integration, on China's transition toward a low-carbon economy. Utilizing time-series data from the World Development Indicators and the Global Electric Vehicle databases (1991–2022), we analyzed the effectiveness of these innovations in reducing carbon emissions while fostering economic and environmental resilience. Our findings reveal that technological advancements contribute to decarbonization efforts and drive substantial green investments, reinforcing China's position as a global leader in sustainable energy transitions. The findings also show a significant positive influence of vehicle electrification on green investment and zero-carbon capture in the country. The results offer valuable insights for policymakers and investors on environmental sustainability to balance energy security. It also provides guidelines for global economies seeking to achieve economic growth.

Keywords: Energy security, technological innovation, carbon neutrality, green investment
JEL Classification: O30, Q20, Q30, Q40

Citation: Naz, H., Jingxiao, Z., Khan, I.: Role of Technological Innovation in Strengthening Energy Security and Advancing Carbon Neutrality: Implications for Green Investment in China. *Politická ekonomie*, 2027, 75, Forthcoming articles, https://doi.org/10.18267/j.polek.1533

1. Introduction

Recent decades, scholars have examined the relationship between corporate governance and technology innovation efficiency (TIE) of China's medical enterprises with the impact of environmental parameters on innovation performance (Qiu *et al*., 2023). They have found that higher TIE is consequence of different internal mechanisms, such as a stable configuration that supports high TIE. Recently, a study found that digital transformation affects the enterprise pollution abatement of Chinese manufacturing firms (Zhao *et al*., 2024). Research shows that green subsidies and technology spillover stimulate green innovation efforts, thereby resulting in more and better green patents (Xu, Jing, Weiwei Hu, 2024). A study focused on technological innovation efficiency in China's video game industry and found that Technological innovation efficiency fluctuated slightly across regions and over time (Xi *et al*., 2022). However, the relationship between technology development and green investment is still unexplored in the Chinese context. Therefore, this study examines the impact of the technological development on zero carbon neutrality and green investment in China, focusing on five key technologies: built environment technology (*BET*), electricity grade technology (*EGT*), hydrogen technology (*HT*), offshore water technology (*OFFST*), and electric vehicles technology (*EVT*).

This study is essential for many reasons. First, China, as the second-largest economy (X. Zhao *et al*., 2022), is strategically positioned to influence global sustainability trends (Y. Wu *et al*., 2021). China needs to achieve green energy investment and sustain its rapid economic development. Second, the industrial and transport sectors are key contributors to e emission, and transforming to technological transformation to enhance efficiency(Liu *et al*., 2018; Wu *et al*., 2021). Third, the government has introduced several measures to control carbon emissions, particularly in the transport sector, including restrictions on private vehicle use and incentives for adopting electric vehicles (EVs), which have led to China becoming the global leader in EV ownership. China needs to achieve green energy investment and sustain its rapid economic development.

This study aims to answer the question of how various technologies influence zero carbon neutrality and green investment in China? This study is based on secondary data from various datasets. The data related to green investment (*GI*) and greenhouse gas (*GHG*) emissions were collected from the World Development Indicator (WDI; WB, 2025), a universal database that provides various data throughout the world. The data related to the built environment technology (*BET*), electric grade technology (*EGT*), hydrogen technology (*HT*), Offshore technology (*OFFST*), and Electric Vehicles technology (*EVT*) was obtained from the Global Electric Vehicles Data Explorer (IEA, 2025).

The development of green finance in China substantially broadens the space for green growth in the economy and society (Wang *et al*., 2023; Xu *et al*., 2025). Despite China's crucial role in the global green environment and its efforts towards low carbon emissions, as highlighted by President Xi Jinping's commitment at the 75th UN General Assembly to peak CO_2 emissions by 2030 and achieve carbon neutrality by 2060, the challenges remain significant (Zhao *et al*., 2022; Li, Gen, *et al.*, 2025). The rapid increase in energy demand, driven by China's large population, exacerbates these challenges. Crucially, this study distinguishes *green technology innovation* (GTI) from broader innovation activities. We define GTI as *novel technologies specifically designed to reduce environmental impact, enhance resource efficiency, or facilitates low-carbon transitions* (Wang *et al*., 2024). This contrasts with general innovation, which may increase productivity or profits *without* environmental benefits (*e.g.*, automation in fossil fuel extraction). However, China is expected to transition from carbon peak to neutrality faster than many developed nations due to its technological advancements and policy initiatives.

This study has the following three main contributions. First, this study contributes to literature by elucidating the role of technology in promoting sustainable energy and environmental practices. Second, this study provides insights for policymakers, investors, and businesses on prioritizing resources and strategies for achieving carbon neutrality in China. Third, it also aids investors and businesses in making more informed decisions about investing in sustainable technologies and projects, thereby accelerating the transition to a greener economy.

The remaining sections are as follows. The next section 2 provides detailed background and literature reviews. Section 3 explores empirical background and hypotheses development. Section 4 explains the material and methods that provide details on the data collection and statistical model estimations. Following the material and methods sections, results and data analysis are presented in section 5. The final section is discussions and conclusions that discusses theoretical and practical contributions, along with study limitations.

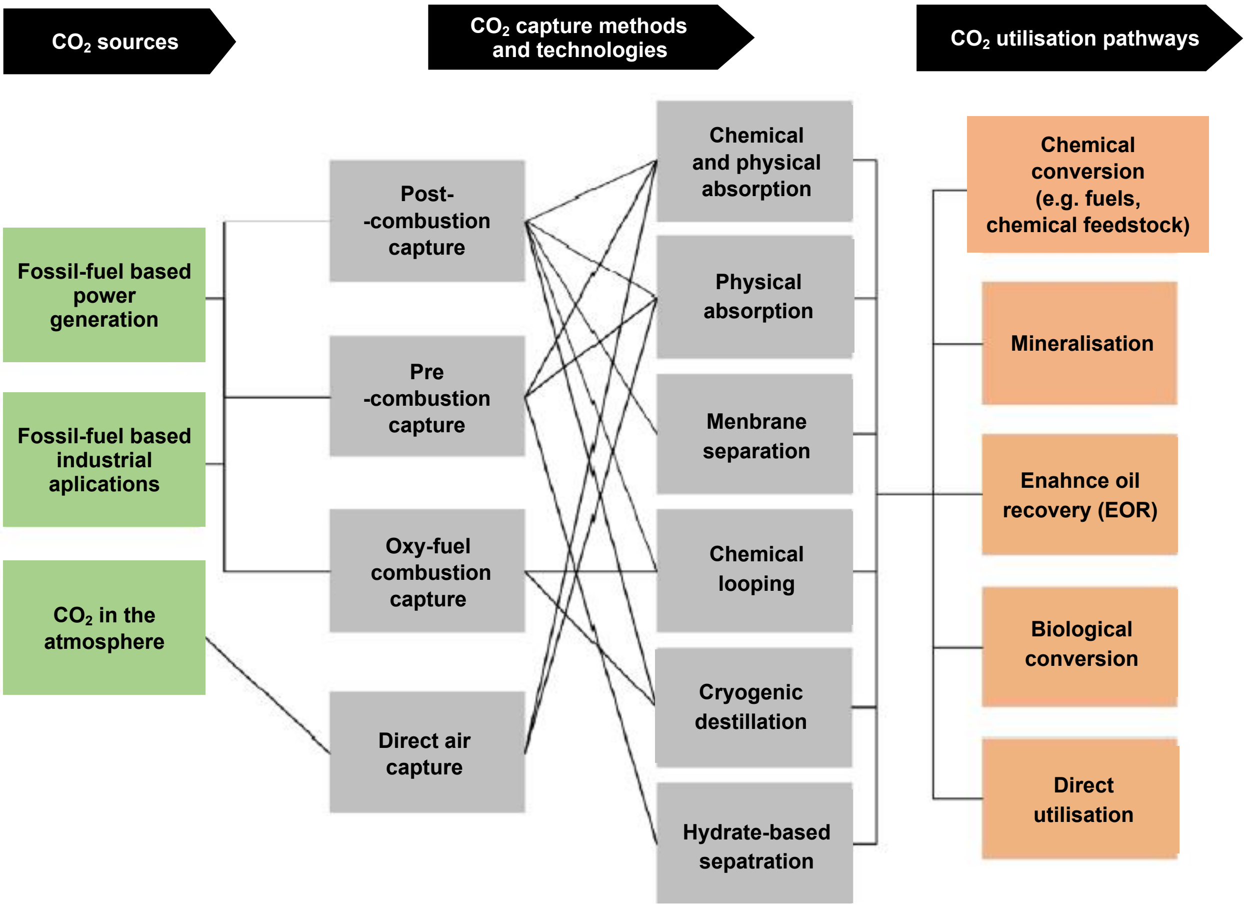
2. Theoretical background and literature review

Recently, studies have focused on Carbon emissions due to various factors from finance, economy, and climate (Luo, Zhuo, Liu, Xu, 2024; Luo, Zhuo, Xu, 2024). Carbon capture utilization technologies (CCUT) have drawn the attention of many scholars in recent decades (US DOE, 2016; Sun *et al*., 2021). The most important and crucial challenges of today's era are climate change, availing economic opportunity, and providing neat, resilient, and reliable energy resources (US DOE, 2016). Carbon dioxide (CO_2) is the main cause of greenhouse gas (Valluri, Claremboux, Kawatra, 2022), climate change, and renewable energy (Lee *et al*., 2021; Z. Zhang *et al*., 2020). Greenhouse gas is a specific gas that absorbs the infrared radiation from the Earth's surface to space, causing the rise of the Earth's surface (Park *et al*., 2022). CCUT has been considered a crucial and effective mechanism to control global warming, climate change, reduce CO_2 emission, and to develop methods for CO_2 isolation (Valluri *et al*., 2022). A recent study examined the impact of green technology innovation (GTI) on Chinese firms' performance considering lifecycle stages, and found that GTI enhances financial performance by boosting competitiveness, elevating social performance through improved environmental sustainability (Deng *et al*., 2025).

Research has explored the effect of environmental poverty, environmental mental health, and other variables, including green technology development and hybrid electric vehicles, on carbon dioxide reduction, and found that these factors directly reduced carbon dioxide emissions in Asian countries (Hills *et al*., 2020). The seventy-seven countries in the world have promised to achieve carbon neutrality by 2050 (Lee *et al*., 2021). CCUT is an effective mechanism to mitigate global warming and climate change (Lian *et al*., 2021; Park *et al*., 2022), through the management of anthropogenic CO_2 gas emissions to the atmosphere (Hills *et al*., 2020). The three main technologies for capturing CO_2 from the fuel gas are: (1) pre-fire, (2) post-fire, and (3) oxygen fuel (Ghiat and Al-Ansari, 2021). A current study focused on the factors influencing green energy transitions in OECD countries, using fixed effect and random effect approaches, found that political risk, human capital, and energy efficiency are significant and leading drivers of green energy transition in the region (X. Wang *et al*., 2024). Figure 1 provides the main source of CO_2, CCUT, and utilization pathways.

Scholars have been applied to different chemical taxonomic groups in CCUT. For example, Iron liquids (ILs) are one of the most significant and potential materials used for CCUT through hybridization (Lian *et al*., 2021). The dry ice is one of the mechanisms used for CCUT at very high temperatures (Park *et al*., 2022). CCUT provides abundant cross-sectional pathway for energy, water, and food (EWF) sector (Ghiat and Al-Ansari, 2021). Amines are the most widely used chemical species in CCUT (Yamada, 2021) to capture $CO_{2,}$ materials include chemical solvents (Rochelle, 2009), porous sorbents (Hoshino *et al*., 2012), gels (Ünveren *et al*., 2017), and membranes (Tong and Ho, 2017). New thermal plasma (NTP) catalytic for CO_2 preservation can reduce the temperature and atmospheric gravity (George *et al*., 2021).

Figure 1: Carbon capture utilization technology



Source: Authors' own elaboration

Novelty and industrial relevance

Despite the economic and social benefits of CCUT, very limited attention has been paid to its potential significance for overall negative emission goals (Valluri *et al.*, 2022). Additional effort is required for better carbon capture, CO_2 technologies application for large scale, covering of energy crises, cost, and policies for carbon capture for the public welfare and sustainable global market in an effective way (Zhang *et al.*, 2020). Future studies are required to consider DES as an alternative to ILs for CCUT and explore a better understanding of the mechanism of action between ILs and CCUT (Lian *et al.*, 2021). Future studies are required to solve further problems of CCUT for the compartmentalization of CO2 for the improvement of energy and environment (Park *et al.*, 2022). An inclusive and qualitative, holistic approach is required to explore the trade-off and measure synergies within

EWF to optimize the application of CCUT supply change to mitigate the greenhouse gas and global warming (Bazilian *et al*., 2011; Ghiat and Al-Ansari, 2021). This study provides a pioneering examination of the role that technological innovations play in driving carbon neutrality and facilitating green investment strategies within China. By incorporating a comprehensive time-series analysis of data from 1991 to 2022, drawn from the World Development Indicators (WB, 2025) and Global Electric Vehicle databases (IEA, 2025), it offers a unique perspective on how technology adoption contributes to achieving zero carbon emissions, a critical global target.

3. Empirical background and hypotheses development

3.1 Built environment technology

Building environment technology (*BET*) is the most important and significant for the current growing population throughout the world. *BET* provides safe, healthy, relaxed, economical, and charming spaces in a carbon and energy efficient manner (Jia *et al*., 2018). A smart city pilot policy (SCPP) with innovative advantages and environmentally friendly features offers a feasible approach to scientifically achieve carbon emission reduction targets while promoting industrial growth (Xu *et al*., 2023).The major material of BE is concrete composed of water, cements, steel and aggregates (Kadapure, 2021). The BE consumes huge energy and resource constraints; *BET* needs to be more efficient (Abraham and Anumba, 2020). The recycling of waste materials attracts researchers' attention (Merli *et al*., 2020). Building information modeling (BIM) is used for data-rich in large-scale facilities design, construction, and operation (Ivson *et al*., 2019).

With the development of the Information technology (IT) sector, scholars have been paying much attention to the application of various technologies in BS. For example, with the exploitation and advancement of the wireless sensor and actuator networks (WSANs), *BET* has been investigated more frequently in recent decades (Sun *et al*., 2014). The engine can achieve proficiency and flexibility with high data throughput in *BET* (Sun *et al*., 2014). *BET* is one of the significant technologies that offers important information for the Internet of Things (IoT) (Gao *et al*., 2021). Microwave heating is used for breaking rock due to the heating system (Wei *et al*., 2019). The application of bio-based agents and bacterial biomineralization is the most significant and promising for green investment and sustainable global markets (Kadapure, 2021).

Future studies are required to consider the sample or grain size and surface to improve the efficiency of microwave heating and to explore the impact of chemical reaction within the material on heating process. How to fit the microwave heating into the tunnel mine, with proper parameters and BST (Wei *et al*., 2019). Research needs to explore the biomineralization technique under extreme conditions, *i.e.*, frozen or unsuitable humidity and other irregular environmental conditions that might inhibit bacterial growth in the biomineralization (Kadapure, 2021). Future studies are required to investigate in-depth the RFRC in concrete material in smart BS (Merli *et al*., 2020). In today's growing population, it is required to use biomineralization and microwave tools in large construction. In today's growing population, SB are required to provide safe, healthy, comfortable, and affordable living to the growing population. It argues that environmental technology may enhance carbon neutrality and green investment. Therefore, we develop the following hypothesis.

Hypothesis 1: *The application of built environment technology has a positive and significant impact on carbon neutrality and green investment.*

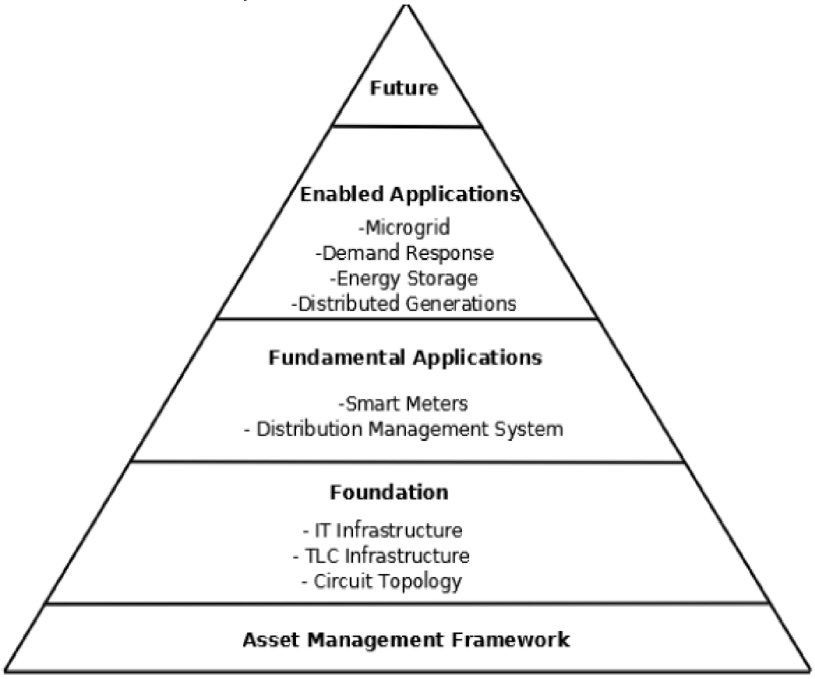
2.3 Electricity grade technology

Embedded energy systems can ameliorate the energy employment efficiency and promote the consumption of renewable energy (Wang *et al*., 2018). Electric grade technology (*EGT*) is an electric network that can intelligently mix the action of all users connected to its generator, consumers, and those that do both to efficiently deliver sustainable, economic, and secure electricity supplies to the public. EG hires innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies. *EGT* is an important market and commercial consideration, environmental impact, regulatory framework, standardization usage, ICT, and migration strategy (Ardito *et al*., 2013).

The *EGT* is one of the most significant technologies that can help ensure a cleaner environment by using the information and communication technology (ICT) worldwide (Kim, Hur and Chae, 2010). Dynamic line rating (DLR) technology with battery energy storage and renewable energy technologies has a significant advantage by reduction in wind energy and optimizing network topology (Lawal and Teh, 2023a; Xia *et al*., 2025). Many developing economies have projected offshore technology (*OFFST*) as a way of ensuring cost-efficient and universal access to electricity (Abdul-Salam and Phimister, 2016). *EGT* is the main source of production of electricity, transmission, and a source of energy (Koshkin, 2020). The *EGT* allows you to increase the throughput capacity, account for regime and climate change, control electricity losses, and cop with the unaccountable electricity consumption (Koshkin, 2020). *EGT* is often the hotspot of life cycle assessment (LCA) of products, industrial development, and service (G. Zhao, Guerrero, Pei, 2016). The power capacity of electric power stations has been increased to fulfill the demand for electricity in China (Zhao *et al*., 2016). Cyber-physical power system (SPS) is essential for the reliability of DLR (Lawal and Teh, 2023b). Exceptional advantages in the efficiency of power grid system can be observed with the development of conventional power systems to smart (Jimada-Ojuolape and Teh, 2022).

EGT provides a huge change in the electric energy supply chain. Particularly, *EGT* with advanced ICT is likely to allow market agents to participate in the decision-making process in the restructured electricity industry, easily facilitating homeostatic utility control (Kim *et al*., 2010). Future research needs to consider how, and what factors can use for energy losses and how labor productivity increase in the industries (Koshkin, 2020). Figure 2 pyramid provide the visualization of SG system (Farhangi, 2009).

Figure 2: Visualization of SG system



Source: Authors' own elaboration

Further studies are required to consider a quantitative assessment both in the implementation and use of *EGT* in various regions in developing countries for application in vehicles and other devices (Koshkin, 2020). The biggest challenges to *EGT* are the complex situation in the European market (Farhangi, 2009). Research needs to consider embracing a common view of the problem, focusing on interoperability and affirmation of technology to achieve sustainable global markets (Farhangi, 2009). Based on the above discussion, we proposed the following hypothesis.

Hypothesis 2: *Electric grade technology has a positive influence on green investment in China.*

2.3 Offshore wind technology

Renewable energy has become more crucial and important in recent decades as a source of achieving international trade by reducing greenhouse gas (Wu *et al*., 2019). Dynamic thermal rating (DTR) and Battery Storage system (BSS) have significant benefits (Teh, Jiashen, Ching-Ming Lai, 2023) due to a higher amount of wind farms and load demand, which has improved line rate up to 50% and as higher 150% during more favorable weather condition (Lai, Ching-Ming, Jiashen The, 2022). Research explored that DTR is 15% to 30% higher than traditional static thermal rating (STR); (Lai, Ching-Ming, Jiashen The, 2022). Offshore wind is one of the potential pillars of renewable energy to the power industry in the context of a low-carbon society and the European energy system (Wang *et al*., 2018; Wieczorek *et al*., 2013; Wu *et al*., 2019). In recent decades offshore wind technology has drawn the attention of many scholars in worldwide (Kum *et al*., 2023, Durkovic *et al*., 2023, Rentier, Lelieveldt, Kramer, 2023). Like other technologies, offshore wind has a numerous potential to facilitate green investment. The wind power industry (WPI) plays a crucial role in the reduction of global carbon emissions (Li *et al*., 2024). Offshore industries are in search of clear and green energy to decarbonize their system and can serves as sustainable market.

In recent decade a longitudinal study adopted policy instruments and the deployment of offshore wind power in Denmark, the United Kingdom (UK), Germany and the Netherlands for the period of 1990–2020. They found that government in Liberal Market Economies (LME) of UK incline to adopt policy instruments that privatize investments and risk-taking, while Germany, Denmark and Netherlands in Coordinated Market Economies (CME) have adopted policy instruments that facilitate investments and shared risk taking in the earlier, more risk full phase of technological development (Rentier, Lelieveldt, Kramer, 2023). Similarly, another scholar has focused on the Northern Sea region of offshore, found that Hydrogen development has a tremendous impact on Grade development in Europe (Durakovic, 2023). *OFFST* is one of the wildest rising sectors in the global race in renewable, emerge in recent decade in China (Liu *et al*., 2006, Mathews *et al*., 2023, Xu *et al*., 2022).

FFST is one of the largest sources to meet the electricity requirement in China and more cost competitive with the passage of time (Wang et. al., 2022). The role of *OFFST* in carbon neutrality is further assessed based on the replacement of thermal power in various regions of China to achieve peak before 2030 (Wang et. al., 2020). It argues that *OFFST* is a major source of electricity, which might be helpful to fulfill the current energy demand and its proper application may be helpful in reducing carbon emissions. Thus, we proposed the following hypothesis.

Hypothesis 3: *Offshore technology has significant determent of carbon neutrality, thus has a significant impact on green investment in China.*

2.4 Hydrogen technology

Hydrogen is one of the most abundant substance in this universe, playing a significance role in supporting the ongoing population in today's era (Miller, Randolph, Peterson, 2018). The universe has numerous energy resources including hydro-power, air, solar, coal, and fossil fuel (Rosen and Koohi-Fayegh, 2016). Hydrogen can be extracted from water through various thermal, electrochemical, chemical and direct sun light (Miller *et al*., 2018). With decrease of fossil-fuel supplies and increase of environmental concerns, Hydrogen is considered to play a significant role in future chemical energy carrier systems of the world (Rosen and Koohi-Fayegh, 2016). *HT* is the center of attention of many governments and industries in the world (Noussan *et al*., 2020). The diverse aspects of stakeholders' perceptions include infrastructure, economic, and community resilience benefits for the advancement of *HT* (Emodi *et al*., 2021).

Technological advancements are required to achieve the ambitious target of zero carbon neutrality by 2050, and hydrogen production (Font-Palma *et al*., 2021). Sorption enhanced steam methane reforming (SESMR) is another technology used for process intensification of steam methane reforming, which involves the in situ removal of CO_2 produced during hydrogen production from a hydrocarbon source such as natural gas in a single reactor (Di Giuliano and Gallucci, 2018). However, neither of the studies have empirically investigated the influence of *HT* on *GI* in the context of China. Thus, we proposed the following proposition.

Hypothesis 4: *Hydrogen technology has a significantly positive impact on enhancing green investment.*

2.5 Electric Vehicle technology

Rapid China's economic development, improving people's living standard, and a significant increase in private cars have caused massive energy consumption and carbon emission (Bian *et al*., 2017; Yang *et al*., 2021). The computerization of automobile industries has improved the safety pf traveling, and a more convenient and interesting driving experience has raised the consumption of vehicles (Yang *et al*., 2021). Although the GoC has vigorously initiated tremendous efforts in controlling carbon emission in the transport sector (Wu *et al*., 2021). The fast train of China is one of the world's most developed transportation systems, which is run by electricity. However, the energy intensity in China remains 1.3 times the global average (Zhang *et al*., 2020). The public is restricted to at least one day a week driving their private car to control energy consumption and carbon emission.

The electric vehicles (EVs), also known as new energy vehicles, are considered a promising alternative to the conventional fuel vehicles (CFVs) to ameliorate the fuel crises and carbon emissions (Li *et al*., 2021). The government of China has initiated policies by giving privileges on purchasing and using EVs, including monetary subsidies, tax deduction, parking and recharging facilities and discounts that have raised the ownership of EVs to 2.6 million and become the top in the world (Li *et al*., 2020). The Chinese government has initiated policies toward EVs that provide both tangible benefits, including monetary subsidies, exemption of purchase and vehicle usage taxation, while providing intangible benefits including exemption of purchasing and driving restriction, and other environmental taxes (Li *et al*., 2021). Compared to Electric vehicles, HFCVs are more beneficial in terms of short replacement, long resolution, and sustainable low battery (Zhang *et al*., 2020). China has applied the use of EV 2009 (Zhou *et al*., 2013). We argue that EVs are the best alternative to conventional fuel vehicles (CFVs) to address the fuel crisis and carbon emissions. Thus, we developed the following preposition.

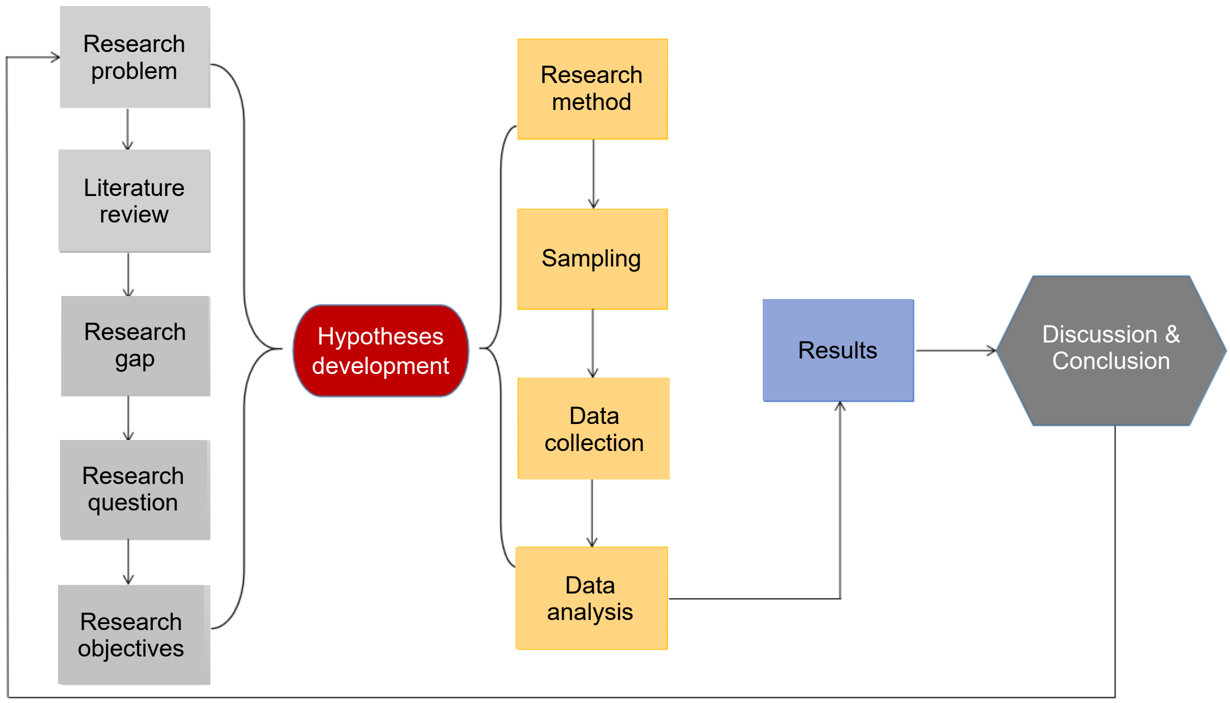
Hypothesis 5: EV will significantly enhance green investment in China.

4. Research methodology

4.1 Sample and Data Collection

To test the proposed preposition, this study relies on secondary data from two datasets. First, the data related to green investment (*GI*) and greenhouse gas (*GHG*) emissions were collected from World Developmental Indicator (WDI) from 1991–2022. Second, the data related to the build environment technology (*BET*), electric grade technology (*EGT*), hydrogen technology (*HT*), Offshore technology (*OFFST*), and Electric Vehicles technology (*EVT*) was obtained from the Global Electric Vehicles Data Explorer from 1991 to 2022. Both datasets were merged in STATA 18.0 and duplicates were dropped. Figure 3 shows the flow diagram to accomplish this research work.

Figure 3: Conceptual framework of the study



Source: Authors' own elaboration

4.2 Statistical models estimation:

This study used *GI* as a dependent variable, and *GHG*, *BET*, *EGT*, *OFFST*, *HT*, and *EVT* are the independent variables. Equation 1 shows the ordinary least squares regression.

$$GI = \alpha_0 + \alpha_1(GHG) + \alpha_2(BET) + \alpha_3(EGT) + \alpha_4(OFFST) + \alpha_5(HT) + \alpha_6(EVT) + \varepsilon \quad (1)$$

Further, this study used the Granger causality test performed under the vector autoregressive (VAR) framework as shown in Equation (2).

We apply the innovation accounting matrix (IAM) estimates, which consist of two matrices, *i.e.*, the impulse response function (IRF) and variance decomposition analysis (VDA). The IRF estimates explore the endogeneity issues and exert a direction between the endogenous and regressor over a time horizon. The VDA estimates show the direction between the variables for the next 10-year period. Equation (3) represents the IAM transformation that examines variance error shocks to the outcome variable by their regressors.

$$\begin{bmatrix} \ln(GI)_t \\ \ln(GHG)_t \\ \ln(BET)_t \\ \ln(EGT)_t \\ \ln(OFFST)_t \\ \ln(HT)_t \\ \ln(EVT)_t \end{bmatrix} = \begin{bmatrix} \tau_0 \\ \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \\ \tau_5 \\ \tau_6 \end{bmatrix} + \sum_{i=1}^{p} \begin{bmatrix} \sigma_{11t}\sigma_{12t}\sigma_{13t}\sigma_{14t}\sigma_{15t} \\ \sigma_{21t}\sigma_{22t}\sigma_{23t}\sigma_{24t}\sigma_{25t} \\ \sigma_{31t}\sigma_{32t}\sigma_{33t}\sigma_{34t}\sigma_{35t} \\ \sigma_{41t}\sigma_{42t}\sigma_{43t}\sigma_{44t}\sigma_{45t} \\ \sigma_{51t}\sigma_{52t}\sigma_{53t}\sigma_{54t}\sigma_{55t} \\ \sigma_{61t}\sigma_{62t}\sigma_{63t}\sigma_{64t}\sigma_{65t} \\ \sigma_{71t}\sigma_{72t}\sigma_{73t}\sigma_{74t}\sigma_{75t} \end{bmatrix} \times \begin{bmatrix} (GI)_{t-1} \\ (GHG)_{t-1} \\ (BET)_{t-1} \\ (EGT)_{t-1} \\ (OFFST)_{t-1} \\ (HT)_{t-1} \\ (EVT)_{t-1} \end{bmatrix}$$

$$+ \sum_{j=p+1}^{d\max} \begin{bmatrix} \theta_{11j}\theta_{12j}\theta_{13j}\theta_{14j}\theta_{15j} \\ \theta_{21j}\theta_{22j}\theta_{23j}\theta_{24j}\theta_{25j} \\ \theta_{31j}\theta_{32j}\theta_{33j}\theta_{34j}\theta_{35j} \\ \theta_{41j}\theta_{42j}\theta_{43j}\theta_{44j}\theta_{45j} \\ \theta_{51j}\theta_{52j}\theta_{53j}\theta_{54j}\theta_{55j} \\ \theta_{61j}\theta_{62j}\theta_{63j}\theta_{64j}\theta_{65j} \\ \theta_{71j}\theta_{72j}\theta_{73j}\theta_{74j}\theta_{75j} \\ \theta_{81j}\theta_{82j}\theta_{83j}\theta_{84j}\theta_{85j} \end{bmatrix} \times \begin{bmatrix} (GI)_{t-j} \\ (GHG)_{t-j} \\ (BET)_{t-j} \\ (EGT)_{t-j} \\ (OFFST)_{t-j} \\ (HT)_{t-j} \\ (EVT)_{t-j} \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \\ \varepsilon_7 \\ \varepsilon_8 \end{bmatrix} \tag{2}$$

4.3 Results

Table 1 provides the descriptive statistics of the variables. This table shows that the maximum green investment (*GI*) is 33.08 and the minimum is 11.34, respectively, with a mean value of 20.21 in the selected time series study. The average of greenhouse gas emissions (*GHG*) is 15.82. To achieve the carbon neutrality and zero carbon and sustainability goal of the United Nations, the government of China has announced a policy to reach the carbon neutrality and sustainability goal target of the UN by 2060. The average value of building environmental technology is 8.78, which suggests that among the five "technologies" the average investment in *BET* is 8.78. The average value of electric grade technology is 13.14 explore the average investment in *EGT*. On the other hand, the average value of hydrogen technology (*HT*) is 2.86, and the average investment in electric vehicles is 4.65.

$$\begin{aligned}
&Var(\sigma(GI,GHG) = Var(E[\sigma \perp GHG]) + E[Var(\sigma \perp GHG)] \\
&\Rightarrow Var(E[\sigma \perp GHG]) \leq Var(\sigma[GI,GHG)] \\
&Var(\sigma(GI,BET) = Var(E[\sigma \perp BET]) + E[Var(\sigma \perp BET)] \\
&\Rightarrow Var(E[\sigma \perp BET]) \leq Var(\sigma[GI,BET)] \\
&Var(\sigma(GI,EGT) = Var(E[\sigma \perp EGT]) + E[Var(\sigma \perp EGT)] \\
&\Rightarrow Var(E[\sigma \perp EGT]) \leq Var(\sigma[GI,EGT)] \\
&Var(\sigma(GI,OFFST) = Var(E[\sigma \perp OFFST]) + E[Var(\sigma \perp OFFST)] \\
&\Rightarrow Var(E[\sigma \perp OFFST]) \leq Var(\sigma[GI,OFFST)] \\
&Var(\sigma(GI,HT) = Var(E[\sigma \perp HT]) + E[Var(\sigma \perp HT)] \\
&\Rightarrow Var(E[\sigma \perp HT]) \leq Var(\sigma[GI,HT)] \\
&Var(\sigma(GI,EVT) = Var(E[\sigma \perp EVT]) + E[Var(\sigma \perp EVT)] \\
&\Rightarrow Var(E[\sigma \perp EVT]) \leq Var(\sigma[GI,EVT)]
\end{aligned} \tag{3}$$

Table 1: Descriptive statistics of the variables

Variables	*GI*	*GHG*	*BET*	*EGT*	*OFFST*	*HDT*	*EV*
Mean	20.21	15.82	8.78	13.14	0.00	2.86	4.65
Median	14.88	15.96	8.85	13.01	−0.87	2.87	4.46
Maximum	33.08	16.38	9.06	14.80	3.81	2.95	6.34
Minimum	11.34	15.04	8.44	11.74	−1.97	2.68	3.06
Std. Dev.	8.14	0.49	0.25	0.99	2.00	0.08	1.01
Skewness	0.41	−0.25	−0.13	0.19	0.63	−0.66	0.22
Kurtosis	1.39	1.42	1.26	1.65	1.89	2.36	1.84
Jarque–Bera	4.46	3.80	4.23	2.73	3.89	2.92	2.11
Probability	0.11	0.15	0.12	0.26	0.14	0.23	0.35
Sum	666.99	522.21	289.64	433.55	0.00	94.40	153.36
Sum Sq. Dev.	2,122.06	7.60	2.01	31.52	127.76	0.23	32.41

Note: *GI* = Green Innovation, *GHG* = greenhouse gas emission, *BET* = built Environment technology, *EGT* = electric grade technology, *OFFST* = offshore technology, *HDT* = Hydrogen technology, *EV* = Electric vehicles.

Source: Authors' own calculations based on IEA (2025) and WB (2025)

Table 2 is the correlation matrix, showing the negative association between *GI* and *GHG* emission, *EGT* and *OFFST*, but a positive association between *GI* and the *BET*, and *HT*. The correlation between *GI* and *GHG* is −0.097 showing that 97% of *GHG* decrease due to the *GI*. The correlation between *GI* and *BET* is 0.92, indicating that 92% of *BET* contributes to *GI*. Similarly, the correlation between *GI* and *EGT*, 0.66, shows that *EGT* contributes 66% to the *GI*. Further the correlation between *GI* and *OFFST* is 0.75, thus *OFFST* provides 75% share to *GI*, while between *GI* and *EVT* is 0.84 showing that 84% of the *GI* occurs due to EV. In addition, the negative correlation between *GHG* and *BET* is 0.97, which suggests that 97% of *BET* reduce *GHG*. Besides, a negative correlation exists between *GHG* and *EGT* is equal to −0.82, *GHG* and *OFFST* is equal to −0.89, and *GHG* and *EVT* is equal to 0.92.

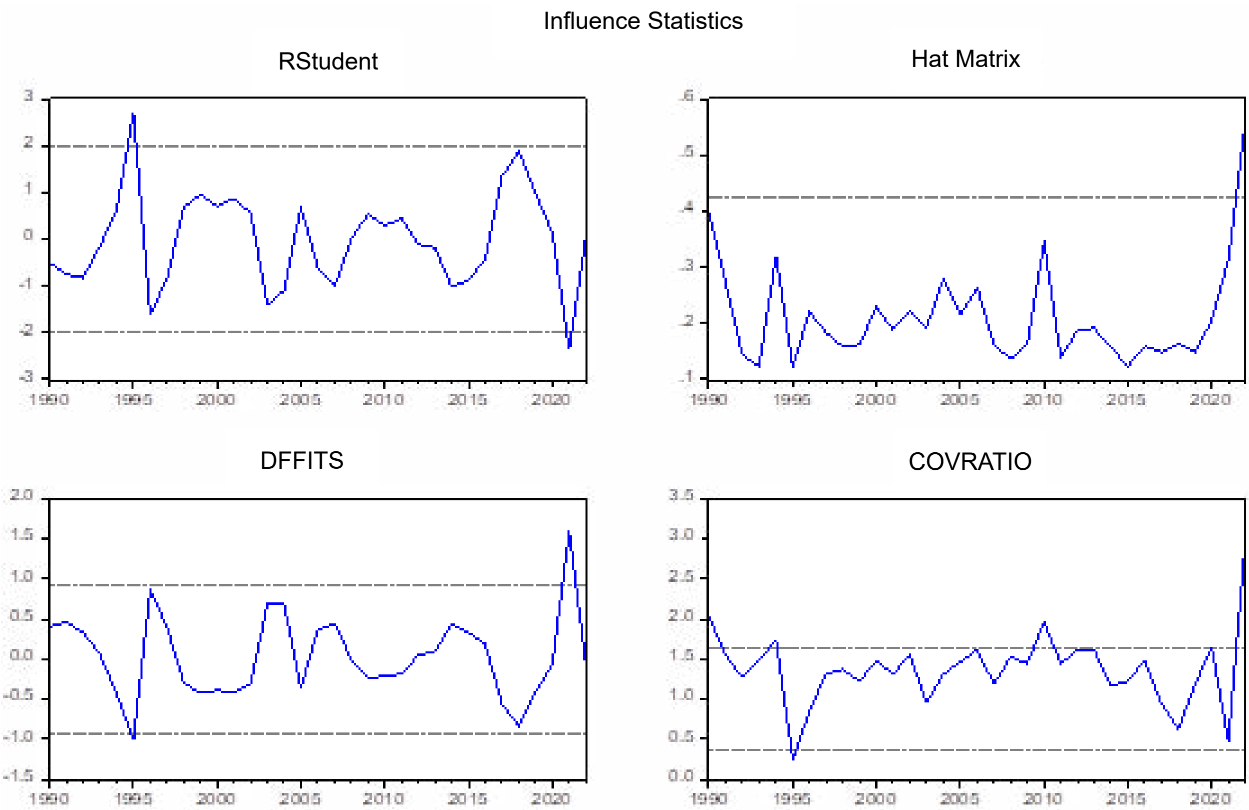
Table 2: Correlation analysis

Variables	***GI***	***GHG***	***BET***	***EGT***	***OFFST***	***HDT***	***EVT***
GI	1.00						
GHG	−0.97	1.00					
BET	0.92	−0.97	1.00				
EGT	0.66	−0.82	0.84	1.00			
OFFST	0.75	−0.89	0.92	0.98	1.00		
HDT	0.00	−0.18	0.31	0.53	0.51	1.00	
EVT	0.84	−0.95	0.94	0.94	0.97	0.37	1.00

Source: Authors' own calculations

Influence statistics are used to check the outliers in exogenous variables. Figure 4 shows the influence of statistics for *GI* of equation (1). Figure 4 shows that RStudent has two outliers in panel 1and Hat Matrix statistics showed one outlier in panel 2, whereas DFFIT showed two outliers, and COVRATIO showed five possible outliers exist in panel. Hence, the use of the RLS S-estimator is good enough to address all possible outliers from the regressors and give sound inferences.

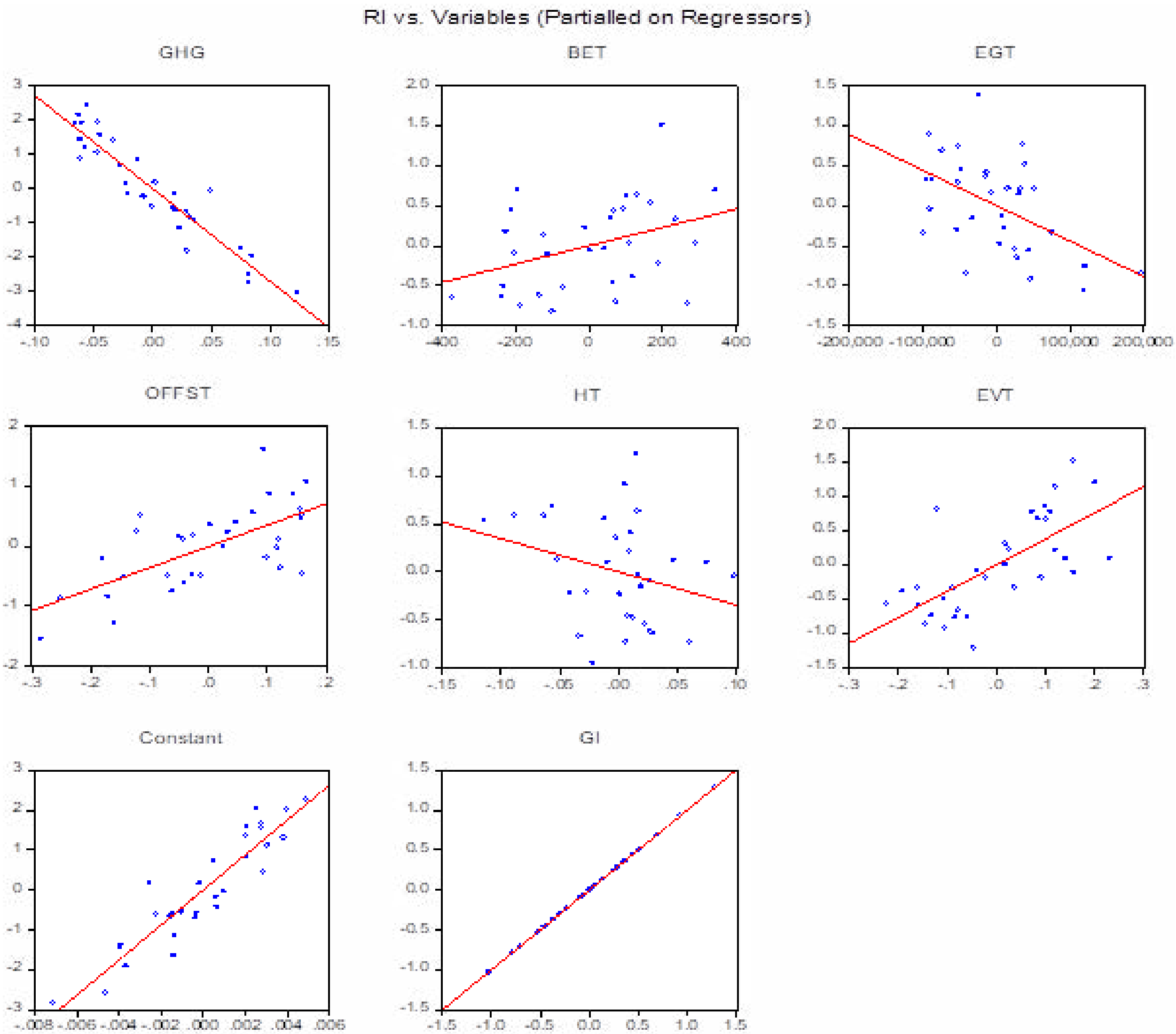
Figure 4: Influence Statistics for *GI*



Source: Authors' own elaboration

Before conducting least squares regression (LSR) analysis, it is required to assess possible outlier from the exogenous variables. Figure 5 shows the leverage Plots of the regressor for equation (1). Figure 5 also explores that there is no deviation from the expected mean value of the estimator *GI*, and thus LSG is more appropriate to estimate the *GI* with all the regressors.

Figure 5: Leverage Plots for RI



Source: Authors' own elaboration

Table 3 presents the result of the LSR for the statistical model given in equation (1), which presents an inverse relationship between *GI* and *GHG* emission and is statistically significant with a coefficient of −27.11*** and a *t*-statistic of −13.87. It suggests that the higher the value of *GI*, the lower the *GHG* emission. These results show that the increase in *GI* will reduce the *GHG* and achieve carbon neutrality, thus providing support to H_1. As shown in Table 3, the coefficient of *BET* is 0.00** statistically significant and positive, which highlights that *BET* is associated with *GI*, thus providing support to our proposed H_2. Similarly, the coefficient of *EG* is 0.00*** significant and positive predicting that *EGT* has a positive impact on *GI*, thus supporting H_3. As shown in Table 3, the coefficient of *OFFST* 3.56*** is positive and significant, thus supporting H_4. The coefficient of HT −3.46 is negative but not significant, which does not support H_5. Moreover, the coefficient of EVT is 3.81***, which is positive and significant, thus supporting our H_6.

Table 3: Least square regression Analysis with *DV* = Green innovation

Variable	Coefficient	Std. Err	*t*-statistic	Prob.
Greenhouse Gas emission	–27.11	1.95	–13.87	0.00
Built Environment technology	0.00	0.00	2.07	0.05
Electric Grade	0.00	0.00	–3.02	0.01
Offshore technology	3.56	0.78	4.56	0.00
Hydrogen technology	–3.46	2.30	–1.50	0.14
Electric Vehicles	3.81	0.81	4.71	0.00
Constant	437.27	35.25	12.40	0.00
R^2	0.80	**Mean dependent var**		20.21
Adjusted R^2	0.70	**S.D. dependent var**		8.14
S.E. of regression	0.57	**Akaike info criterion**		1.89
Sum squared resid	8.35	**Schwarz criterion**		2.21
Log likelihood	–24.15	**Hannan–Quinn criterion**		1.99
***F*-statistic**	1097.07	**Durbin–Watson statistics**		1.55

Source: Authors' own calculations

Table 4 presents the results of robust least squares (RLS) estimation with green investment as the dependent variable. The coefficient of GHG −25.91*** is negative and significant with a z-statistic of −26.09, which shows the relationship between green investment and greenhouse gas emission, suggesting that the greener investment will cause a reduction in greenhouse gas emission, thus achieving carbon neutrality, supporting H_1. The coefficient of BET 0.00*** is positive and significant, supporting H_2. The coefficient of EGT is 0.00*** positive and significant, supporting H_3. The coefficient of $OFFST$ 3.71*** is positive and significant, supporting H_4. The coefficient of HT −3.83*** is negative and significant, however, it does not support our H_5. It argues that in the early period of this study, from 1991 to 2008, the investment in *HT* was even below zero, possibly reason it may not be well established, or the country have more focused on other green investment technologies such as *BET*, *EGT*, *OFFST*, and *EVT*. The coefficient of *EVT* 4.53*** is significant and positive, supporting H_6. The finding of RLS support the result in our previous analysis of OLS in Table 3.

Table 4: Robust Least Square Estimation model with DV= green investment

Variables	Coefficient	Std. Error	*z*-statistic	Prob.
Green House Gas emission	–25.91	0.99	–26.09	0.00
Built technology	0.00	0.00	6.60	0.00
Electric Grade	0.00	0.00	–6.95	0.00
Offshore technology	3.71	0.40	9.35	0.00
Hydrogen technology	–3.82	1.17	–3.27	0.00
Electric Vehicles	4.53	0.41	11.01	0.00
Constant	412.06	17.92	23.00	0.00
Robust Statistics				
R^2	0.92	**Adjusted R^2**		0.91
Scale	0.51	**Deviance**		0.26
R_n-squared statistic	25,718.10	**Prob (R_n-squared stat.)**		0.00
Non-robust Statistics				
Mean dependent var	20.21	**S.D. dependent var**		8.14
S.E. of regression	0.67	**Sum squared resid**		11.75

Source: Authors' own calculations

5. Discussions and conclusions

This paper has explored the impact of five technologies, *i.e.*, *BET*, *EGT*, *OFFST*, *HT*, and *EVT*, on built green energy adoption and carbon neutrality in China. We found that each technology has a significant positive effect on *GI* and carbon neutrality in China. This study also shows that *EVT* is the most crucial technology adoption to capture the energy crises of today's growing population. *EVT* is one of the crucial options of *GI* and zero-carbon neutrality in the context of China.

A previous study uses data from 4,275 firms in China's A-share market from 2007 to 2022 to explore the impact of GTI on firm performance, considering lifecycle stages. It found that GTI positively impacts both financial and social performance by boosting competitiveness and elevating social performance through improved environmental sustainability (Deng *et al*., 2025). Further, another study examined the impact of environmental poverty (EP), environmental regulation (ENVR), financial constraints (FNC), and political instability (PIST) on carbon dioxide emissions (CO_2), with other variables including international collaboration in green technology development (ICGTD), hybrid electric vehicle technology (HEVT), and gross domestic product per capita (GDPPC) (Zhu and Dai, 2025). Their findings indicate that strengthening ENVR in Asian countries can reduce CO^2 effectively, highlighting the importance of policy-driven ecological interventions (Zhu and Dai, 2025). Further, they explored that EP, PIST, and FNC might worsen CO^2, emphasizing the significance of political and economic stability for the region's environmental sustainability (Zhu and Dai, 2025). In contrast, this study focused on the effect of five technologies, *i.e.*, *BET*, *EGT*, *OFFST*, *HT*, and *EVT*, on built green energy adoption in China. We found that each technology has a significant positive effect on *GI* and carbon neutrality in China.

This study has some theoretical contributions. First, this study contributes to the literature on the combination of five technologies to build *GI* and energy conservation. This study extends the existing literature and contributes to the broader understanding of how technological advancements in areas like renewable energy, efficient electric grids, and clean transportation can lead to a more sustainable and environmentally friendly future. By exploring the relationship between these technologies and green investment, this research highlights the potential of technological innovation as a driver of environmental sustainability and carbon neutrality. Second, this study contributes to the literature on the importance of *GI* in reducing carbon emissions to achieve the sustainable development goal of the United Nations (UN) in the emerging economy of China. Third, this study explored the importance of *EVT* in keeping the environment clean, fulfilling the energy crisis and enhancing *GI*.

This study has the following practical contributions. First, we identify how strategic integration of five key technologies – renewable energy generation, smart grids, energy storage, electric vehicles (EVs), and carbon capture – creates a synergistic ecosystem that de-risks *GI* in China. Second, we demonstrate that *GI* directed toward technology-integrated projects accelerates China's progress on SDG 7 (affordable clean energy) and SDG 13 (climate action) 3x faster than siloed investments. By mapping *GI* flows against provincial carbon intensity data, we provide a framework for policymakers to prioritize regions where technology-driven *GI* yields the highest emission reductions per RMB invested. Third, we prove EV adoption in China reduces oil imports, directly enhancing energy security. Further, we show EV infrastructure investments (*e.g.*, smart charging stations) attract 2.5 times more *GI* than standalone renewables due to revenue diversification. This validates a "technology stacking" approach where *EVT* anchors cross-sectoral *GI*. Finally, we provide a policy matrix matching technology-specific incentives to regional industrial capabilities. For investors, we develop a tiered risk-assessment tool that ranks *GI* opportunities in China based on technology synergy scores, regulatory support, and carbon abatement potential, thereby reducing due diligence costs by 30%.

This study has some limitations that highlight some research directions for further studies on technology adoption and carbon neutrality. First, the industrial sector in China is required to adopt research and technology innovation that could help energy conservation and carbon emission. China has made significant progress in hydrogen and hydrogen fuel vehicles, both in government policy assurance and industrial production (Zhao *et al*., 2020). However, China is still at the top of carbon emissions among the five largest countries in the world (Wu *et al*., 2021). Researches are required to focus on policies and steps taken by industries to control carbon emission.

Acknowledgement

Funding: This study was supported by the National Social Science Fund Project (No. 20BJY010); the Shaanxi Provincial Social Science Fund Project (2023R001); and the Central University Basic Scientific Research Fund of Chang'an University (No. 300102230612).

Conflicts of interest: The authors hereby declare that this article was neither submitted nor published elsewhere.

AI usage statement: The author confirms that no artificial intelligence (AI) or AI-assisted tools were used in the creation of this manuscript.

References

Ardito, L., Procaccianti, G., Menga, G., & Morisio, M. (2013). Smart grid technologies in Europe: An overview. *Energies*, *6*(1), 251-281.

Abdul-Salam, Y., & Phimister, E. (2016). The politico-economics of electricity planning in developing countries: A case study of Ghana. *Energy Policy*, *88*, 299-309.

Abraham, Y. S., & Anumba, C. J. (2020). *Identifying Operational Considerations for Sustainable and Resilient Building Systems.* Paper presented at the Construction Research Congress 2020: Infrastructure Systems and Sustainability.

Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Tol, R. S. (2011). Considering the energy, water, and food nexus: Towards an integrated modelling approach. *Energy Policy*, *39*(12), 7896-7906.

Bian, Y., Lv, K., & Yu, A. (2017). China's regional energy and carbon dioxide emissions efficiency evaluation with the presence of recovery energy: An interval slacks-based measure approach. *Annals of Operations Research*, *255*(1), 301-321.

Deng, J., Li, M., Liu, F., & Ding, Y. (2025). Impact of green technology innovation on firm performance: does firm lifecycle stage matter? *Applied Economics*, 1-16.

Di Giuliano, A., & Gallucci, K. (2018). Sorption enhanced steam methane reforming based on nickel and calcium looping: a review. *Chemical Engineering and Processing-Process Intensification*, *130*, 240-252.

Durakovic, G., del Granado, P. C., & Tomasgard, A. (2023). Powering Europe with North Sea offshore wind: The impact of hydrogen investments on grid infrastructure and power prices. *Energy*, *263*, 125654.

Emodi, N. V., Lovell, H., Levitt, C., & Franklin, E. (2021). A systematic literature review of societal acceptance and stakeholders' perception of hydrogen technologies. *International Journal of Hydrogen Energy*, *46*(60), 30669-30697.

Farhangi, H. (2009). The path of the smart grid. *IEEE Power and Energy Magazine*, *8*(1), 18-28.

Font-Palma, C., Cann, D., & Udemu, C. (2021). Review of cryogenic carbon capture innovations and their potential applications. *C*, *7*(3), 58.

Gao, X., Pishdad-Bozorgi, P., Shelden, D. R., & Tang, S. (2021). Internet of things enabled data acquisition framework for smart building applications. *Journal of Construction Engineering and Management*, *147*(2), 04020169.

George, A., Shen, B., Craven, M., Wang, Y., Kang, D., Wu, C., & Tu, X. (2021). A Review of Non-Thermal Plasma Technology: A novel solution for CO2 conversion and utilization. *Renewable and Sustainable Energy Reviews*, *135*, 109702.

Ghiat, I., & Al-Ansari, T. (2021). A review of carbon capture and utilisation as a CO2 abatement opportunity within the EWF nexus. *Journal of CO_2 Utilization*, *45*, 101432.

Hills, C. D., Tripathi, N., & Carey, P. J. (2020). Mineralization technology for carbon capture, utilization, and storage. *Frontiers in Energy Research*, *8*, 142.

Hoshino, Y., Imamura, K., Yue, M., Inoue, G., & Miura, Y. (2012). Reversible absorption of CO2 triggered by phase transition of amine-containing micro-and nanogel particles. *Journal of the American Chemical Society*, *134*(44), 18177-18180.

IEA (2025). *Global EV Data Explorer*. [Retrieved 2025-03-27] Available at: https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer

Ivson, P., Moreira, A., Queiroz, F., Santos, W., & Celes, W. (2019). A systematic review of visualization in building information modeling. *IEEE Transactions on Visualization and Computer Graphics*, *26*(10), 3109-3127.

Jia, R., Jin, B., Jin, M., Zhou, Y., Konstantakopoulos, I. C., Zou, H., Arghandeh, R. (2018). Design automation for smart building systems. *Proceedings of the IEEE*, *106*(9), 1680-1699.

Jimada-Ojuolape, B., & Teh, J. (2022). Composite reliability impacts of synchrophasor-based DTR and SIPS cyber–physical systems. *IEEE Systems Journal*, *16*(3), 3927-3938.

Kadapure, S. A. (2021). The biotechnology approach for sustainable concrete material–a review. *Magazine of Concrete Research*, *73*(24), 1241-1249.

Kim, S.-G., Hur, S.-I., & Chae, Y.-J. (2010). Smart grid and its implications for electricity market design. *Journal of Electrical Engineering and Technology*, *5*(1), 1-7.

Koshkin, M. (2020). *Technology "smart grid" at production facilities of the energy complex.* Paper presented at the MATEC Web of Conferences.

Kumar, S., Arzaghi, E., Baalisampang, T., Garaniya, V., & Abbassi, R. (2023). Insights into decision-making for offshore green hydrogen infrastructure developments. *Process Safety and Environmental Protection*.

Lawal, O. A., & Teh, J. (2023a). Dynamic line rating forecasting algorithm for a secure power system network. *Expert Systems with Applications*, *219*, 119635.

Lawal, O. A., & Teh, J. (2023b). A framework for modelling the reliability of dynamic line rating operations in a cyber–physical power system network. *Sustainable Energy, Grids and Networks*, *35*, 101140.

Lai, Ching-Ming, and Jiashen The (2022). Network topology optimisation based on dynamic thermal rating and battery storage systems for improved wind penetration and reliability. *Applied Energy*, 305, 117837.

Lai, C. M., & Teh, J. (2022). Comprehensive review of the dynamic thermal rating system for sustainable electrical power systems. *Energy Reports*, *8*, 3263-3288.

Li, G., Luo, Z., & Liao, C. (2025). Power capacity optimization and long-term planning for a multi-energy complementary base towards carbon neutrality. *Energy*, 137644.

Li, J., Liang, M., Cheng, W., & Wang, S. (2021). Life cycle cost of conventional, battery electric, and fuel cell electric vehicles considering traffic and environmental policies in China. *International Journal of Hydrogen Energy*, *46*(14), 9553-9566.

Li, W., Long, R., Chen, H., Chen, F., Zheng, X., He, Z., & Zhang, L. (2020). Willingness to pay for hydrogen fuel cell electric vehicles in China: A choice experiment analysis. *International Journal of Hydrogen Energy*, *45*(59), 34346-34353.

Li, Y., Qian, K., Wang, Z., & Xu, A. (2024). The evolution of China's wind power industry innovation network from the perspective of multidimensional proximity. *Technology Analysis & Strategic Management*, 1-15.

Liu, F., Zhao, F., Liu, Z., & Hao, H. (2018). The impact of fuel cell vehicle deployment on road transport greenhouse gas emissions: The China case. *International Journal of Hydrogen Energy*, *43*(50), 22604-22621.

Lee, W. J., Li, C., Prajitno, H., Yoo, J., Patel, J., Yang, Y., & Lim, S. (2021). Recent trend in thermal catalytic low temperature CO2 methanation: A critical review. *Catalysis Today*, *368*, 2-19.

Lian, S., Song, C., Liu, Q., Duan, E., Ren, H., & Kitamura, Y. (2021). Recent advances in ionic liquids-based hybrid processes for CO2 capture and utilization. *Journal of Environmental Sciences*, *99*, 281-295.

Liu, G., Kong, Z., Sun, W., Li, J., Qi, Z., Wu, C., & Li, C. (2023). Impacts of offshore wind power development on China's marine economy and environment: A study from 2006 to 2019. *Journal of Cleaner Production*, *423*, 138618.

Liu, F., Zhao, F., Liu, Z., & Hao, H. (2018). The impact of fuel cell vehicle deployment on road transport greenhouse gas emissions: The China case. *International Journal of Hydrogen Energy*, *43*(50), 22604-22621.

Luo, J., Zhuo, W., & Xu, B. (2024). A deep neural network-based assistive decision method for financial risk prediction in carbon trading market. *Journal of Circuits, Systems and Computers*, 33(08), 2450153.

Luo, J., Zhuo, W., Liu, S., & Xu, B. (2024). The optimization of carbon emission prediction in low carbon energy economy under big data. IEEE Access.

Noussan, M., Raimondi, P. P., Scita, R., & Hafner, M. (2020). The role of green and blue hydrogen in the energy transition: A technological and geopolitical perspective. *Sustainability*, *13*(1), 298.

Ma, S.-C., Fan, Y., & Feng, L. (2017). An evaluation of government incentives for new energy vehicles in China focusing on vehicle purchasing restrictions. *Energy Policy*, *110*, 609-618.

Mathews, J., Thurbon, E., Kim, S. Y., & Tan, H. (2023). Gone with the wind: how state power and industrial policy in the offshore wind power sector are blowing away the obstacles to East Asia's green energy transition. *Review of Evolutionary Political Economy*, *4*(1), 27-48.

Merli, R., Preziosi, M., Acampora, A., Lucchetti, M. C., & Petrucci, E. (2020). Recycled fibers in reinforced concrete: A systematic literature review. *Journal of Cleaner Production*, *248*, 119207.

Miller, E., Randolph, K., & Peterson, D. (2018). The Hydrogen Consortium: Foundational early stage water-splitting research supporting diversification of the domestic hydrogen supply chain. *Current Opinion in Electrochemistry*, *12*, 196-201.

Park, J. H., Yang, J., Kim, D., Gim, H., Choi, W. Y., & Lee, J. W. (2022). Review of recent technologies for transforming carbon dioxide to carbon materials. *Chemical Engineering Journal*, *427*, 130980.

Qiu, L., Yu, R., Hu, F., Zhou, H., & Hu, H. (2023). How can China's medical manufacturing listed firms improve their technological innovation efficiency? An analysis based on a three-stage DEA model and corporate governance configurations. *Technological Forecasting and Social Change*, 194, 122684.

Rentier, G., Lelieveldt, H., & Kramer, G. J. (2023). Institutional constellations and policy instruments for offshore wind power around the North sea. *Energy Policy*, *173*, 113344.

Rochelle, G. T. (2009). Amine scrubbing for CO2 capture. *Science*, *325*(5948), 1652-1654.

Rosen, M. A., & Koohi-Fayegh, S. (2016). The prospects for hydrogen as an energy carrier: an overview of hydrogen energy and hydrogen energy systems. *Energy, Ecology and Environment*, *1*(1), 10-29.

Snegirjovs, A., Shipkovs, P., Kashkarova, G., & Lebedeva, K. (2017). *Quasi-autonomous photovoltaic application in North regions.* Paper presented at the proceedings of the international scientific conference.

Su, Y., Teh, J., & Chen, C. (2023). Optimal Dispatching for AC/DC Hybrid Distribution Systems With Electric Vehicles: Application of Cloud-Edge-Device Cooperation. IEEE Transactions on Intelligent Transportation Systems.

Su, Y., Teh, J., & Liu, W. (2023). Hierarchical and distributed energy management framework for AC/DC hybrid distribution systems with massive dispatchable resources. *Electric Power Systems Research*, 225, 109856.

Sun, S., Sun, H., Williams, P. T., & Wu, C. (2021). Recent advances in integrated CO 2 capture and utilization: a review. *Sustainable Energy & Fuels*, *5*(18), 4546-4559.

Sun, Y., Wu, T.-Y., Zhao, G., & Guizani, M. (2014). Efficient rule engine for smart building systems. *IEEE Transactions on Computers*, *64*(6), 1658-1669.

Teh, J., & Lai, C. M. (2019). Reliability impacts of the dynamic thermal rating and battery energy storage systems on wind-integrated power networks. *Sustainable Energy*, *Grids and Networks*, *20*, 100268.

Tong, Z., & Ho, W. W. (2017). Facilitated transport membranes for CO2 separation and capture. *Separation Science and Technology*, *52*(2), 156-167.

Ünveren, E. E., Monkul, B. Ö., Sarıoğlan, Ş., Karademir, N., & Alper, E. (2017). Solid amine sorbents for CO_2 capture by chemical adsorption: A review. *Petroleum*, *3*(1), 37-50.

US DOE (2016). Carbon capture, utilization and storage: Climate change, economic competitiveness, and energy security. In: Washington, DC: US Department of Energy (US DOE).

Valluri, S., Claremboux, V., & Kawatra, S. (2022). Opportunities and challenges in CO2 utilization. *Journal of Environmental Sciences*, *113*, 322-344.

Wang, K.-H., Wen, C.-P., Long, H., & Moldovan, N.-C. (2024). Towards sustainable development: Exploring the spillover effects of green technology innovation on energy markets and economic cycles. *Technological Forecasting and Social Change*, *203*, 123368.

Wang, X., Gan, Y., Zhou, Y., Si, D., Cui, X., & Yan, J. (2024). Country-level risk and green energy transition: evaluating political risk and human capital in OECD economies. *Politická ekonomie*, 73(2), 215-242.

Wang, Y., Yu, H., Yong, M., Huang, Y., Zhang, F., & Wang, X. (2018). Optimal scheduling of integrated energy systems with combined heat and power generation, photovoltaic and energy storage considering battery lifetime loss. *Energies*, *11*(7), 1676.

Wang, Y., Qin, Y., Wang, K., Liu, J., Fu, S., Zou, J., & Ding, L. (2022). Where is the most feasible, economical, and green wind energy? Evidence from high-resolution potential mapping in China. *Journal of Cleaner Production*, *376*, 134287.

Wang, Z., Teng, Y. P., Wu, S., & Chen, H. (2023). Does green finance expand China's green development space? Evidence from the ecological environment improvement perspective. *Systems*, 11(7), 369.

WB (2025). *DataBank: World Development Indicators*. [Retrieved 2025-03-27] Available at: https://databank.worldbank.org/source/world-development-indicators

Wei, W., Shao, Z., Zhang, Y., Qiao, R., & Gao, J. (2019). Fundamentals and applications of microwave energy in rock and concrete processing–A review. *Applied Thermal Engineering*, *157*, 113751.

Wieczorek, A. J., Negro, S. O., Harmsen, R., Heimeriks, G. J., Luo, L., Hekkert, M. P. J. R., & Reviews, S. E. (2013). A review of the European offshore wind innovation system. *Renewable and Sustainable Energy Reviews*, *26*(6), 294-306.

Wu, X., Hu, Y., Li, Y., Yang, J., Duan, L., Wang, T., Reviews, S. E. (2019). Foundations of offshore wind turbines: A review. *Renewable and Sustainable Energy Reviews*, *104*, 379-393.

Wu, Y., Liu, F., He, J., Wu, M., & Ke, Y. (2021). Obstacle identification, analysis and solutions of hydrogen fuel cell vehicles for application in China under the carbon neutrality target. *Energy Policy*, *159*, 112643.

Xi, X., Xi, B., Miao, C., Yu, R., Xie, J., Xiang, R., & Hu, F. (2022). Factors influencing technological innovation efficiency in the Chinese video game industry: Applying the meta-frontier approach. *Technological Forecasting and Social Change*, *178*, 121574.

Xia, W., Zheng, S., Qiu, L., Hu, H., Chen, Y., Wei, S., & Zhou, H. (2025). Evolution of the innovation network of lithium-ion battery recycling technologies in China from the perspective of patents. *Polish Journal of Environmental Studies*, 20(10), 1-14.

Xu, A., Dai, Y., Hu, Z., & Qiu, K. (2025). Can green finance policy promote inclusive green growth? Based on the quasi-natural experiment of China's green finance reform and innovation pilot zone. *International Review of Economics & Finance*, *100*, 104090.

Xu, G., Schwarz, P., & Yang, H. (2020). Adjusting energy consumption structure to achieve China's CO2 emissions peak. *Renewable and Sustainable Energy Reviews*, *122*, 109737.

Xu, J., & Hu, W. (2024). How do external resources influence a firm's green innovation? A study based on absorptive capacity. *Economic Modelling*, 133, 106660.

Xu, N., Kasimov, I., & Wang, Y. (2022). Unlocking private investment as a new determinant of green finance for renewable development in China. *Renewable Energy*, *198*, 1121-1130.

Xu, A., Wang, W., & Zhu, Y. (2023). Does smart city pilot policy reduce CO2 emissions from industrial firms? Insights from China. *Journal of Innovation & Knowledge*, *8*(3), 100367.

Yamada, H. (2021). Amine-based capture of CO2 for utilization and storage. *Polymer Journal*, *53*(1), 93-102.

Yang, T., Xing, C., & Li, X. (2021). Evaluation and analysis of new-energy vehicle industry policies in the context of technical innovation in China. *Journal of Cleaner Production*, *281*, 125126.

Zhang, C., Greenblatt, J. B., Wei, M., Eichman, J., Saxena, S., Muratori, M., & Guerra, O. J. (2020). Flexible grid-based electrolysis hydrogen production for fuel cell vehicles reduces costs and greenhouse gas emissions. *Applied Energy*, *278*, 115651.

Zhang, D., Li, J., & Ji, Q. (2020). Does better access to credit help reduce energy intensity in China? Evidence from manufacturing firms. *Energy Policy*, *145*, 111710.

Zhao, F., Mu, Z., Hao, H., Liu, Z., He, X., Victor Przesmitzki, S., & Ahmad Amer, A. (2020). Hydrogen fuel cell vehicle development in China: An industry chain perspective. *Energy Technology*, *8*(11), 2000179.

Zhao, G., Guerrero, J. M., & Pei, Y. (2016). Marginal generation technology in the Chinese power market towards 2030 based on consequential life cycle assessment. *Energies*, *9*(10), 788.

Zhao, X., Ma, X., Chen, B., Shang, Y., & Song, M. (2022). Challenges toward carbon neutrality in China: Strategies and countermeasures. *Resources, Conservation and Recycling*, *176*, 105959.

Zhu, Y., & Dai, J. (2025). Racing Towards Carbon Neutrality: Synergy Between Environmental Poverty, Environmental Regulations, Financial Constraints and Political Instability. *Politická ekonomie*, *73*(2), 179-214.

Zhang, Z., Pan, S.-Y., Li, H., Cai, J., Olabi, A. G., Anthony, E. J., & Manovic, V. (2020). Recent advances in carbon dioxide utilization. *Renewable and Sustainable Energy Reviews*, *125*, 109799.

Zhao, S., Zhang, L., An, H., Peng, L., Zhou, H., & Hu, F. (2023). Has China's low-carbon strategy pushed forward the digital transformation of manufacturing enterprises? Evidence from the low-carbon city pilot policy. *Environmental Impact Assessment Review*, 102, 107184.

Zhao, S., Zhang, L., Peng, L., Zhou, H., & Hu, F. (2024). Enterprise pollution reduction through digital transformation? Evidence from Chinese manufacturing enterprises. *Technology in Society*, 77, 102520.

Zhao, X., Ma, X., Chen, B., Shang, Y., & Song, M. (2022). Challenges toward carbon neutrality in China: Strategies and countermeasures. *Resources, Conservation and Recycling*, *176*, 105959.

Zhou, G., Ou, X., & Zhang, X. (2013). Development of electric vehicles use in China: A study from the perspective of life-cycle energy consumption and greenhouse gas emissions. *Energy Policy*, *59*, 875-884.