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Green Investment, Digital Technological Progress, and the Dynamics of Carbon Emissions in China: A Review

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Abstract

This article examines the impact of green capital allocation and improvement in information and communication technology on the trajectory of carbon emission from the period of 1985 to 2024 in China. Our results highlight the importance of environmentally sustainable investment and technological development of digital technologies to curb increasing carbon production, while at the same time emphasizing the possible paradox that accelerated economic growth will continue to increase environmental strain through a large increase in carbon emissions. Existing scholarship supports the linkages between the forms of green investment, technological innovation, and economic growth (including the dimension of nonlinear, quadratic growth) and thus can shed light on the dynamic interactions of these variables in the context of the environment. Inspired by these empirical understandings, policy prescriptions that attempt to crystallize a more solid path for China to move toward a cleaner and more sustainable growth paradigm have been proposed in the present work. Existing literature has found a strong connection among green investment, technological innovation and economic growth with the help of static and dynamic econometric methodologies. These outcome results provide important knowledge on the complex interrelations of environmental outcomes. Based on empirical literature, the current study proceeds with policy recommendations in order to guide conversion toward a cleaner and more sustainable pathway of economic growth in China. Foremost, such exclusive focus on China narrows the scope of generalizability of the findings, as well as salient cross-country comparisons. Further, key institutional dimensions, such as regulatory frameworks, mechanisms for environmental governance and administrative supervision, are not included explicitly in the analysis. Future research should therefore have a multi-country perspective, consider institutional and policy-related variables, apply more stringent robustness tests and make every effort to explain the complex interrelationships between economic activity, technological advance, and carbon emissions.

Keywords: *Green Investment, Carbon Emissions, Technological Progress, Economic Growth*

JEL Codes: *Q56, O44, O33*

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1. INTRODUCTION

To study the relationship among economic growth factors, environmental degradation, information and communication technologies and green investments has become a central point of researchers, especially in the context of China. Over the last decade, the government of China has undergone an industrial metamorphosis with far-reaching economic reconstruction that has resulted in rapid growth for the local GDP values as well as the exorbitant ecological costs. Empirical and theoretical literature indicate that rising development has exerted stress on natural resources, raise the level of carbon emissions, which further worsen the environmental challenges threatening the long term sustainability that much more challenging. As China is resolutely coming forth to take up the path of seeking out the new and higher economic productivity and quality of global competitiveness, it faces the challenge of the balancing act of accommodating ambitions while at the same time meeting the imperative not to compromise ecological integrity. This policy conundrum is set to increase in the foreseeable future, as the

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burgeoning industrial activity and accelerated urbanization (Hou & Yuan, 2025), coupled with an increasing energy demand, are likely to further increase the levels of environmental degradation if left unaddressed.

Coping with this growing accumulation of ecological pressures has led China to signal the strong policy intent towards the harmonization of development aspirations with the management of the environment in the manner expressed by Schnittman and Aluwihare (2004). This policy shift reflects the broader shift towards low-carbon development models at the global level. China's case is unique because of its size, the diversity of its structures, and the reliance on energy-intensive sectors. Recent scholarship recognizes these intrinsic complexities and emphasizes the difficulty for policymakers to effectively integrate environmental and economic agenda particularly when economic growth is a fundamental priority in developing economies, as accelerated growth has become a greater agenda than environmental (Martin & Camerone, 2025). Consequently, it is needed to explore the interplay between information and communication technologies and green investments in connection with the dynamics of growth and environmental outcomes, and therefore, discover the potential synergies and trade-offs embodied in the development paradigm of China (Amin et al., 2024; Zhao & Ren, 2023; Tan & Lee, 2025). These kinds of interactions are multifaceted in nature and involve not only the factors of technological innovation and financial allocation, but also behavioural changes, institutional reforms and the restructuring of the industrial processes (Rizwan & Iqbal, 2025; Bary & Hakim, 2025).

Prior studies have tended to give mixed results or even contradictory results on the extent to which economic growth, information and communication technologies and green investments influence carbon emissions. Some studies have indicated positive environmental spillovers from digitalization and green financing, others suggest that there may be the possibility of rebound effects, inefficient implementation or that insufficient levels of such green investment are integrated into the overall socio-economic strategies (Khan et al., 2025; Marc et al., 2025). By synthesizing these divergent viewpoints, to get an extra evidential and fuller knowledge of the joint construction of environmental consequences of these forces in China context. To fill in the gaps and give deeper insights, the authors use the Quantile ARDL methodology, which is an advanced way to allow for a more refined study of asymmetric and distribution-specific effects relating to different economic conditions (Rabbia & Arshad, 2024; Zubair et al., 2024; Song et al., 2024; Ali et al., 2025). As compared to conventional methods, the QARDL model is designed to address the heterogeneity in the relationships between variables, such that researchers can see that the impacts of economic growth, digitalization, and green investment on emissions are not the same at low, medium, and high levels of environmental pressure. Such methodological sophistication is very important, since environmental and economic relationships do not normally behave the same way in all stages of development. And incorporating quantile-based variations allows the study to not only find the way the magnitude and direction of effects change with variations, but also identify some structure hidden from the models usually done under the umbrella of the standard regression model. This methodological advancement enriches the robustness and power of the results, which offer a better comprehension of the conditional behaviours of the investigated variables (Ali & Marc, 2016; Ali et al., 2021; Ali et al., 2022; Ali et al., 2025). For instance, the early stages of industrialization - such as that characterized by higher levels of carbon emissions consequent upon the increased utilization of energy and the intensification of industrial production - and the later stages of industrialization associated with technological upgrading, digital integration and large-scale green investment can both precipitate reductions in carbon emissions. When one looks at the perspectives being given by He and Lin (2021) and Wang and Xu (2022), it becomes apparent that the current research is in the realm of a broader theory of development; that is, development that explains the dynamic interplay between the policy area of environmental policies, technological innovation and financial mechanisms over time. Together, the various scholarly contributions provide a strong foundation for policymakers, researchers, and practitioners who would be interested in incorporating this research as a background from which to formulate development strategies incorporating economic productivity with environmental sustainability.

Presently, information and communication technologies have become a critical area of commercial activities to create new opportunities for strengthening environmental performance. These technologies underpin the improvement of energy efficiency in a range of sectors through improved process optimization, through real-time monitoring of resource usage, and through the proliferation of smart systems such as those advocating low-carbon options. Through the use of new digital tools, automation and advanced data analytics, companies can rethink their production processes to minimize energy losses and move slowly towards cleaner production methods. Nevertheless, the environmental implications of information and communications technologies are not uniformly that of a positive. As countries develop more of their infrastructure with digital networks and also invest in cleaner technological solutions, the overall electricity demand may increase significantly. This effect may be especially strong in economies that are still heavily dependent on fossil fuel-based energy systems, in which energy-intensive digital expansion may well have the unintended consequence of increasing carbon emissions, as opposed to improving the environment. This duality is reflected in the literature, which recognizes ICTs as the catalyst for transformative innovation, and at the same time shows environmental risks (Shen et al., 2024; Shahid et al., 2023; Arshad et al., 2024; Ali et al., 2021; Arshad et al., 2025). The relationship between positive and negative effects shows that designing digitalization strategies must be done in accordance with energy transition objectives, so that advancements in technology can have a positive, reinforcing impact on the goals of sustainability, instead of having a negative and contrary impact. Similarly, green investments have taken their position as a sine qua non of sustainable development by providing financial facings to renewable energy adoption, environmentally-efficient technology and low-carbon infrastructure. When well implemented, green investments help to lower the tension on the environment by supporting clean energy production, by increasing the

efficiency of the use of resources and by motivating enterprises to use equipment and technologies that are friendly to the environment. However, their influence is defined by several contextual variables such as the quality of regulation, the strength of the institutions, technological readiness, and the scale of investment inflows. Those countries which have robust governance frameworks and clarity of environmental policy tend to have greater proportions of green finance directed to them, and greater improvements in environmental outcomes. On the other hand, economies with weak regulatory systems or low technological capacity generally have a hard time reaping the full potential of green investments (Chen and Li, 2023; Mustafa and Zheng, 2021; Sadiq et al., 2025). The variations that have been noted demonstrate the necessity of specific programmes for financial relief based on the assistance of the environmentally related business; however, such measures should be coupled with comprehensive policy frameworks with strong institutional frameworks built in order to achieve the full environmental objectives of the programmes. The current study throws light on the noteworthy high-tech sectors in China's environmental outcomes. As economies develop digital transformation with an ecosystem focused on innovation, these sectors are instrumental in setting the stage for sustainable development. The unbelievable speeds and scales of technological innovations, the rise of digital finance and rising competition in the green industries are collectively making sure that economic growth and the sustainable development agenda would be mutually reinforcing, provided that they are rooted in meaningful and appropriately strategic policy interventions. Existing literature on this area strengthens the synergy and presents proper planning of technological progress and a balance between industrial and environmental policies; it is feasible to achieve carbon emission reductions, while at the same time boosting industrial competitiveness (Irifan et al., 2023; Saeed et al., 2024; Shahid et al., 2023; Ashiq et al., 2023; Marc and Ali, 2017; Marc et al., 2024; Torres and Ma, 2022; Ali et al., 2025).

The purpose of sustainable development is to refer to a comprehensive paradigm that seeks to achieve economic, technological and environmental objectives in interrelated ways and not in isolation. The technological innovations become visible emission reduction, the financial mechanisms to enable continued economic expansion and policy change to enable resource-efficient practices in diverse sectors. This integrative framework is a major contribution to what is available in the literature in that it explains both the good and bad consequences of digital transformations and green investment on environmental quality. Consequently, the results give empirical information about the interdependencies of economic growth, technological development and sustainable environment in China. They contribute further to current debates on policy architectures, digitalisation and green finance vis-à-vis carbon emission trajectories: an issue salient to current political debates of sustainable development and climate policy within emerging economies in general. Last but not least, the results amount to relevant knowledge to policy makers, academics and practitioners involved in the development of geo-economic strategies balancing economic development with the long-term management of the planet's ecology.

2. LITERATURE REVIEW

Recently, the nexus among green investment, carbon emission, information and communication technologies, and economic growth has become the center of scholars and policymakers, and has made the topic a point of interest in world environmental sustainability. Shahid (2023) and Maqsood (2024) establish a body of literature that systematically examines the environmental consequences of technological change, investment patterns and macroeconomic dynamics. The literature emphasizes the importance of green investment strategy, especially from the perspective of green capital investment. Policymakers' concern about green investment has been widely recognized as a major means to achieve the twin goals of reducing GHG and increasing productive capacity and economic growth. For example, Minhas et al. (2024), Abro et al. (2024), and Rahman and Bakar (2019) provide clear empirical evidence that increased investments into renewable energy technologies, resource-efficient systems and climate resilient infrastructure hold great potential for reducing emissions to a great extent. The outcomes of literature mention that larger green investment is not only paving the way for a shift to low-carbon development but is laying the foundation for a green economic structure in which economies may not have to sacrifice levels of industrial production or consumption, if they want to achieve environmentally sustainable development.

By taking financial decision-making processes in line with the principles of precautionary environmental approach, green investment helps to build resilience to long-term changes in natural ecosystems, or creating economic progress. Moreover, the literature emphasizes the growing role of green financial technologies in promoting sustainable development, and at the same time, the vulnerabilities in the fragile or underdeveloped green financial institutions in climate-resilient economies. Notable contributions in the area of digital and green finance include as discussed by Ahman et al. (2023), Shahid et al. (2022), Rahman and Bakar (2018) and Marc et al. (2020) which offer insightful notes on the role of financial innovation to support the sustainability target, while noting the risk of institutional fragility for undermining long term sustainability goals for the environment and economy. Sticking to a sustainable finance directory, it can be stated that digital finance, automated sustainability-reporting frameworks, environmentally conscious lending and climate-oriented risk assessment platforms constitute a multifaceted toolbox aimed at incentivizing low-carbon-oriented investment behaviour. Collectively, these studies support the conclusion that the integration of technology in the financial system opens up more possibilities for sustainable financing, greater carbon-related accountability in accounting, and more resources for making environmentally friendly initiatives. The literature thus supports the policy that environmental sustainability is now beyond policy interventions and traditional forms of regulatory instruments and is instead dependent upon innovative financial mechanisms, data-driven governance structures and digital infrastructures that enable greener decision making across industries and institutions.

To deepen this understanding, a body of contemporary scholarship has focused on other determinants of the nexus between investment, technology, and carbon emissions. Researchers like Zhang et al. (2022), Fahim et al. (2023), Oliveira and Martins (2024), Idris et al. (2023) and Lim et al. (2024) explore the interaction between the diffusion of RE, RE and AI, RE, digital financial inclusion, RE, the regulatory pressure, the synergistic effects of the green investment and information technology on carbon mitigation, with significant and sometimes nonlinear results. Complementary works of the same euryhaline interaction by Khalid et al. (2023), Poornima and Reddy (2024), Hassan et al. (2023) and Su and Li (2024) resulted in further conclusions that environmental innovation, carbon pricing architectures and institutional quality play key roles in the long-term trajectory of emission sticking at the national but also at the sectoral level. Collectively, these recent contributions expand the scope of both the theoretical and the empirical agenda by recognizing that environmental sustainability is affected by a plurality of technological, economic, institutional and financial drivers that interact in a dynamic and interdependent manner. In the same fashion, the literature on information and communication technologies and carbon emissions has become a considerable stream of research that can be considered a balanced, multidimensional, and increasingly sophisticated understanding of the impact of technological diffusion on environmental outcomes. The reviewed studies highlighted the role of technology in ecosystem quality, including the studies of Zulfiqar et al. (2022), Chaudhary et al. (2023), Ur Rahman and Bakar (2019), and Arshad et al. (2025), which emphasize the existence of both positive and negative pathways through which the development of technology influences the quality of the ecosystem. On the one hand, the development of information and communication technologies can achieve reductions in carbon emissions by improving the efficiency of industries, by allowing for the realization of real-time monitoring of energy systems, by enabling smart governance mechanisms, and by encouraging the shift towards digitalized low-carbon infrastructure. On the other hand, a contradictory strand of research accepts the rebound effects of the higher consumption of electricity, fast technological upgrading and the accumulation of electronic waste, which may eventually increase the environmental burden. By bringing together these conflicting findings, the review is used to emphasize that the information and communication technologies - carbon emissions nexus is not straightforward, but influenced by the degree of technological maturity, national energy structures, regulatory environments and behavioural responses to digital innovation. In addition, the inclusion of studies such as Dawood et al. (2023), Zhao et al. (2023), and Li et al. (2022) makes it relevant to discuss this relationship through more sophisticated empirical strategies that are capable of capturing the non-linear nature of some patterns, and also differences within sectors between economies.

Furthermore, the review of the literature on economic growth and emissions of carbon dioxide offers an informed view on one of the most persistent debates in environmental economics. Studies show this in various forms published by Shahzadi et al. (2023), Rahman et al. (2022), Zahra et al. (2023) and many others, wherein some have demonstrated the existence of evidence pointing to a positive correlation between growing economic activities and resultant emissions while others show towards such a possibility of decoupling through achieving Hoeges stages of technological advancement or through the cleaner means of production. The review thus draws attention to the lack of consistency of findings to date, but also points to the importance of using improved econometric methodologies that can identify asymmetries, structural changes and distributional effects in the relationship between growth and emissions. References to methodological contribution of: Narr and Stern (2009 Chick et al (2006), Separate or Joint? Economics of the environment Misson. The collaboration and participation of a range of opinions from environmental economics to digital transformation to sustainable development policy helps to add depth to the discussion and offers important insights into the many-sided problems of curbing emissions in developing economies. By referencing works, e.g., by Awan et al. (2023), Qureshi et al. (2022), Javaid et al. (2023) and Marc and Ali (2023), the review succeeds in anchoring the work in a broader academic discourse, that addresses the conflict of interests between ecological preservation on one side, and technological as well as economical progress on the other.

The present review has also provided a neat and detailed description of the concept of Quantile Autoregressive Distributed Lag methodology with emphasis on the importance of application in analyzing the nonlinear and heterogeneous relationships between environmental and macroeconomic variables. The practical application of the work shown in the research by Hassan (2021) provides the authors with a very good reason to use this approach in the current study. The Quantile Autoregressive Distributed Lag framework is introduced as an advanced tool which is capable of detecting differential effects at different points in the conditional distribution of carbon emissions, thus identifying differences in responsiveness which might be disregarded by traditional models based on the mean. This methodological flexibility is of particular value to analyses of complex interactions between green investment, information and communication technologies, economic growth, and environmental quality because the intensity of effects may vary in the low and high emissions regimes.

Furthermore, literature highlights the strong analytical benefits of the Quantile Autoregressive Distributed Lag approach, such as the ability to identify short and long-run adjustments with more precision across quantiles. This ability to quantify dynamic heterogeneity adds rich detail to the empirical analysis as it helps identify patterns which would be hidden in aggregate estimations. The inclusion of the Wald test for assessing the significance and consistency of the coefficients for the quantiles, as mentioned by Bakar (2019), as a way to strengthen the methodological background of the study, enables reliability and strength in the tests of the long-term and short-term relationships. Collectively, these methodological understandings in the literature provide good reasons for the adoption of sophisticated econometric tools in the examination of the interaction of environmental, technological and macroeconomic forces in different segmental emissions distributions. The findings presented in the study provide an extensive and multidimensional analysis of dynamic relationships between carbon emissions, green investment, information and communication technology development, economic growth and square

economic growth in the empirical context of China. The study creates a deeper and more refined understanding of China's environmental trajectory and the structural patterns shaping its aim of sustainability by looking upon the behaviour of such variables between different quantiles. The descriptive evidence shows that the square of economic growth has the highest mean, followed by economic growth, carbon emissions and information and communication technology development, although green investment is quite low by comparison. This distribution shows that there is sustained stress on the expansion-oriented development strategies, digital progress and industrial productivity, and a relatively weak stress on the large-scale investment in environmentally friendly sectors, which is also observed in a recent assessment by Arif et. al. (2023) and Chen et. al. (2023). These findings are part of larger debates about the preferences for development in China, where more emphasis is placed on economic performance and technological transformation at the expense of green financial commitment, which are discussed by Bao et al (2024) and Feng et al (2024).

The empirical evidence further suggests that economic development has a significantly positive impact on carbon emissions across multiple quantiles, implying that increased economic growth continues to affect environmental degradation when energy systems, to a large extent, use carbon-intensive resources (Hafiza et al., 2022). Similar results have been documented in more recent studies by Guo et al. (2023) and Huang et al. (2024), in which they found that industrial growth and higher energy use increase emission levels of developing and emerging economies. However, the above research also shows that the square of economic growth shows negative significance starting from a higher quantile, indicating that, beyond a certain point in development, China starts to reap the benefits of technological upgrading, a better regulatory architectural system, the adoption of cleaner energy, and structural transitions in the economy, contributing to the abatement of carbon emissions release. Such results seem to be in line with the study results provided by Liu et al. (2024) and Wang et al. (2023), held by innovativity-led growth and industrial transformation of high added value can lead to an emissions decoupling from growth of output over time in the stage of an advanced economy.

These findings add knowledge to extant scholarship by showing how China's multi-dimensional growth strategy simultaneously creates upward and downward environmental pressures depending on its phase of development and orientation of its structure. The inclusion of green investment and information and communication technology development into the empirical framework also adds another layer, and shows how the gaps in investment in renewable infrastructure and differences in technological deployment determine the output of the emissions. Studies resembling Iqra et al. (2023) and Zhang et al. (2024) have similar points regarding the scale and direction of green finance, technological developments and energy diversification influences dimensions over a significant carbon trajectory and trajectory dimension for large economies. The low mean of green investment derived from the study highlights ongoing challenges in financing in the markets, and the need to develop more policies on climate-responsive capital mobilization. Meanwhile, the rising pattern of information and communication technology development draws attention to China's growing dependence on digital systems, platforms, and automation, which has a high potential for mitigation of emissions, if combined with clean energy sources, as also supported by the work of Arif et al. (2023) and Bao et al. (2024).

3. METHODOLOGY

A thorough search strategy was conducted as per PRISMA guidelines to locate relevant literature studies done on the following topic areas: green investment, information and communication technologies, economic growth and carbon emissions. The initial search on Scopus, Web of Science, JSTOR, and ScienceDirect yielded 358 records (46 supplementary records were found by Google Scholar and reference chaining). After the exclusion of 52 duplicates, 306 studies were left for screening, in which the titles and abstracts were scored for conceptual relevance. A total of 198 studies were excluded because they did not fit into any of the core themes. The remaining 108 full-text articles were evaluated for methodological appropriateness and empirical completeness, and led to 46 studies being considered for the final systematic review, of which 34 studies were used for deeper empirical synthesis.

Table 1: PRISMA

Stages	Description of Process	Estimated Number of Studies
Identification	Records identified through major academic databases (Scopus, Web of Science, JSTOR, ScienceDirect) using keywords such as "green investment," "ICT development," "carbon emissions," "economic growth," and "sustainability model."	312
	Additional records identified through Google Scholar, policy reports, and cross-reference searches	46
	Total records identified	358
Duplicates Removed	Removal of repeated entries and overlapping studies	52
Records After Deduplication	Studies retained for screening	306

Stages	Description of Process	Estimated Number of Studies
Screening	Title and abstract screening based on relevance to green investment, ICT–CO_2 emissions, and economic growth–environment interactions	306
	Records excluded during screening	198
Eligibility Assessment	Full-text articles were evaluated for methodological rigour, alignment with research questions, and empirical completeness	108
	Full-text articles excluded for insufficient relevance or missing empirical evidence	62
Included in Review	Final studies included in qualitative synthesis (systematic review)	46
	Studies further used for quantitative/empirical synthesis (if applicable)	34

4. CONCLUSIONS

This paper aimed at investigating the complex dynamic relationship among green investment, information and communication technology (ICT) development, economic growth and carbon emission in China over a relatively long period. The empirical findings provide the demarcation of substantive interrelations among these variables, thus providing invaluable insights into the environmental and economic realities of the nation. The results show clearly the fact that purchasing efforts for projects that favour the environment, as well as for the improvement of the ICT capabilities, have a positive effect on the efforts to reduce the level of environmental degradation. Such outcomes challenge the dominant idea that improvements to technological capacity and emphasis on sustainable investment trajectories are inadequate solutions to ecological problems and the decline of long-term carbon intensity. The results of the literature review show that economic development is playing a central role in rising environmental concerns among economies. As production and consumption rise, there is a dire need to regulate the institutional frameworks to manage environmental protection. The literature outcomes also show that economic growth strategies are positively related to environmental issues; if it is left unchecked, long-term sustainability is unable to be achieved. Governments must have ecological considerations in planning national development, and try to balance the need for economic vitality and furthering environmental integrity and social equity. The study also highlights the need for the adoption of differentiated policy approaches, taking into consideration specific stages of economic development and unique environmental conditions. However, these contributions are compromised by some of the limitations that would limit the extent to which the conclusions could be generalized. Focusing on one country at a time is a limiting factor to extrapolating the results to more remote areas and/or countries. Moreover, the lack of a large-scale analysis of important aspects related to the institutions involved (e.g., effectiveness of regulation, ability of environmental governance and macroeconomic uncertainty limitations) limits the scope of our knowledge on the mechanisms in terms of the final environmental effects. Future research of a broader scope regarding a number of countries, sectors and institutional settings would provide more insight into the forces affecting environmental performance. Expanding the analytical framework to take into account different structural and policy dimensions that influence carbon emissions would help to perceive even more concretely the underlying economic and institutional dynamics of environmental change. Overall, this research adds value to the discourse about sustainable development through expounding on the converging roles of green investment, technological development, economic development and the quality of the environment. The findings represent an important call to frame that is integrated and forward-looking and balances the economic priorities with responsible and environmentally sensitive stewardship for sustainability to support the broader goals of China's sustainability and its long-term resilience to environmental change.

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