GREEN GROWTH IN THE ERA OF INDUSTRIAL REVOLUTION 4.0 - PROVINCIAL EVIDENCE IN VIETNAM

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Abstract: ***This study analyzes the success of an economy in reducing its emission intensity per unit of economic growth. The Pooled Ordinary Least Squares (POLS) model is used on panel data from nine cities in Northern Vietnam over the period 2015-2021. The empirical results show a statistically significant negative impact between the air quality index and growth, that is, when the economy relies heavily on energy-intensive industries, increased output leads to increased pollution, and a growth slowdown occurs because environmental costs exceed economic benefits. In addition, the results also indicate a positive impact of provincial budget revenue, but no empirical evidence is found on the impact of foreign direct investment as well as digital transformation on provincial economic growth. From here, policy recommendations are proposed towards promoting a green economy, towards sustainable growth by taking advantage of the achievements of the 4th industrial revolution.***

• Keywords: *green economy development, sustainable growth, gross regional domestic product, digital transformation, Vietnam.*

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1. Introduction

The concept of green economy development has emerged as a pivotal paradigm in contemporary economic discourse, aiming to reconcile the imperatives of economic growth with the preservation of environmental integrity and social inclusiveness. It is generally defined as a development model that fosters economic expansion while minimizing ecological degradation, reducing carbon intensity, and promoting resource efficiency. Within this framework, production and consumption patterns are restructured to ensure that growth is not achieved at the expense of environmental sustainability. In other words, green economy development reflects a transformative process in which innovation, technological advancement, and institutional reforms are leveraged to enhance both competitiveness and ecological resilience.

Closely related to this paradigm is the notion of sustainable growth, which extends beyond the traditional objective of maximizing output to encompass long-term stability, intergenerational equity, and balanced progress across economic, environmental, and social dimensions. Sustainable growth is characterized not only by the ability of an economy to expand consistently over time, but also by its capacity to do so without exhausting natural resources, exacerbating inequality, or undermining resilience to shocks. In this sense, sustainable growth constitutes the ultimate policy goal toward which green economy strategies are oriented, as it ensures that the benefits of development are durable, widely shared, and environmentally viable.

The mechanism through which green economy development contributes to sustainable growth can be elucidated through several transmission channels. First, the adoption of cleaner technologies and renewable energy sources reduces pollution and enhances the health and productivity of the labor force, thereby generating long-term economic gains. Second, the promotion of circular economy practices fosters resource efficiency, lowers production costs, and creates new market opportunities in green industries. Third, by incentivizing sustainable investment and innovation, green economy development enhances structural transformation and diversification, which are essential for stable and resilient growth trajectories. These dynamics illustrate that green economy policies do not merely represent environmental constraints but can act as catalysts for new growth drivers, technological upgrading, and competitiveness at both national and sub-national levels.

In the context of the Fourth Industrial Revolution, digital transformation has become an indispensable enabler in strengthening the nexus between green economy development and sustainable growth. Digital technologies such as artificial intelligence, blockchain, and the Internet of Things enhance the capacity to monitor environmental performance, optimize resource allocation, and improve the transparency of

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green supply chains. They also facilitate the design of innovative business models, including smart energy grids, digital platforms for circular consumption, and precision agriculture, which simultaneously reduce environmental footprints and stimulate economic dynamism. Moreover, digital transformation empowers local governments to design evidence-based policies and integrate environmental considerations into development planning, thereby magnifying the effectiveness of green economy strategies.

This study is particularly significant for Vietnam, where provincial economies face the dual challenge of sustaining high growth rates while mitigating the adverse consequences of environmental degradation. By providing empirical evidence at the provincial level, the research offers nuanced insights into the heterogeneity of green economy outcomes and the moderating role of digital transformation in enhancing sustainability. The findings are expected to inform policymakers on how to balance short-term economic imperatives with long-term ecological and social objectives. In doing so, the research contributes not only to the academic debate on the intersection of green growth, digitalization, and sustainable development but also to the practical formulation of policies that promote green competitiveness, enhance local economic resilience, and align Vietnam's development trajectory with global sustainability agendas.

Analysis is organised in a coherent arc. After an opening overview, a synoptic synthesis of antecedent scholarship is furnished to anchor the investigation. Thereafter, procedures for data construction and study architecture are specified with exactitude, emphasising replicability. The subsequent section delineates and explicates econometric evidence, indicating how insights map onto stated aims. In the closing movement, actionable regulatory instruments are articulated, with the claim that judicious implementation would catalyse the country's medium-term expansion under uncertain technological and market conditions ahead.

2. Literature review

The nexus between state budget revenues and local economic growth has been widely examined and continues to draw considerable scholarly interest. Yu & Fang (2021) applied generalized decomposition methodology (GDIM) to examine determinants of energy-related fine particulate (PM2.5) emissions across China. Building upon GDIM outputs, a novel separation metric was developed to evaluate the dissociation between particulate discharges and economic expansion, and the roles of technological and non-technological drivers in shaping that metric were estimated. Additionally, the magnitudes of individual components were numerically ascertained, which permitted cross-period comparison and informed policy interpretation. The principal findings were reported as follows. Among three salient outcomes, one demonstrated that technological influence substantially facilitated the dissociation of emissions from output, although its contribution diminished progressively over time. Conversely, non-technological drivers obstructed the dissociation process, yet their adverse contribution declined during 2000-2014. These patterns retained robustness across provinces.

At city levels, in Hao et al. (2018), city-level panel information from 2013 to 2015 was employed to evaluate the effect of particulate concentrations on income per capita through a simultaneous-equations framework, marking its first application in this context. Temporal and regional dummies were incorporated to address unobserved heterogeneity. Estimates revealed that air pollution exerted a significantly adverse effect on economic performance. Specifically, holding other factors constant, a five-unit increase in PM2.5 was associated with a decline of roughly 2,500 yuan in per capita output by 2015. Moreover, the findings suggested that sustained growth contributed to mitigating pollution, thereby generating reinforcing benefits for development.

Continuing the idea of (2018), Zhang et al. (2020) assessed China's decoupling trajectory between particulate emissions and economic expansion through an investment-oriented perspective. Drawing upon panel information for 30 provinces from 1998 to 2016, decomposition and decoupling approaches were jointly applied to disentangle the influence of conventional drivers and three innovative investment-related variables across the nation and four sub-regions. Results indicated that emissions remained only weakly separated from growth nationally and regionally. At the aggregate level, investment magnitude exerted the strongest effect, while compositional change contributed minimally, and emission intensity emerged as the most significant mitigating factor. Sub-nationally, efficiency improvements supported decoupling, though the expansive investment scale in the western provinces offset these gains. At the provincial level, structural and scale effects in Inner Mongolia and Xinjiang exerted disproportionate influence. Policy implications were advanced to curtail particulate emissions effectively.

Another recent considerable study, Fu et al. (2020) employed the most recent monitoring data from 2015-2017 together with an exposure-response modeling framework to quantify health damages attributable to PM2.5 pollution. Economic losses were evaluated through disease cost, adjusted human capital, and willingness-to-pay approaches. Vulnerable groups, particularly the elderly and infants, were found disproportionately affected. Influenced by growth dynamics, demographic density, and industrial structure, cities such as Heze, Zhengzhou, Handan, and Liaocheng experienced the most severe impacts. Although health-related damages and associated economic losses displayed a declining trajectory, reflecting the effectiveness of pollution-control measures, the overall burden remained substantial and continued to pose serious challenges.

Recently, Bildirici & Kayıkçı (2024) explored dynamic interactions and causal linkages among energy intensity, output growth, urbanization, energy utilization, foreign direct investment, and PM2.5 concentrations during 1995-2019 for China, India, Germany, Canada, the United States, and the United Kingdom by employing the Panel Fourier Bootstrapping ARDL framework and associated causality procedures. Evidence of long-run equilibrium among variables was identified, with the error-correction parameter estimated at -0.169. Empirical findings revealed bidirectional feedback between economic expansion and particulate emissions, between inward investment and pollution, and between energy intensity and PM2.5. Furthermore, increased economic activity, evolving energy consumption patterns, and accelerating urbanization were observed to exacerbate particulate concentrations, thereby intensifying environmental pressures in these economies.

Srisaringkarn & Aruga (2025) analyzed spatial interdependencies of PM2.5 concentrations among Thai provinces and assessed their association with socio-economic determinants over the period 2012-2022. Empirical outcomes demonstrated that particulate pollution exhibited significant spatial clustering, implying that emissions were not geographically isolated but tended to diffuse across administrative boundaries. In other words, elevated PM2.5 levels in one province generated spillover effects into adjacent areas, underscoring the necessity of coordinated regional strategies rather than fragmented, locality-specific interventions to effectively mitigate the pervasive challenge of air quality deterioration.

A comprehensive review of existing literature revealed that investigating the economic consequences of PM2.5 on local growth dynamics was both theoretically justified and empirically warranted. It was further recognized that prior research had often overlooked the integration of specific contextual determinants. To address this limitation, the present study deliberately incorporated additional independent variables - namely foreign direct investment, the digital transformation environment, and state budget revenues - ensuring analytical novelty while filling substantive empirical gaps and thereby extending the frontier of knowledge on localized growth-environment interactions. The article will use the idea of Hao et al. (2018) with improvements suitable for the reality of Vietnam.

3. Methodology and research data

This study uses annual time series data of nine cities in the North of Vietnam, including Hanoi, Bac Ninh, Quang Ninh, Hung Yên, Cao Bang, Lao Cai, Lang Son, Son La and Phu Tho from 2015 to 2021, including Gross regional domestic product as local economic growth, State budet revenue as fiscal capacity, Foreign direct investment, Turnover of postal service and telecommunication service as proxy of digital transformation and PM25 - measuring the concentration of ultrafine dust particles in the air with a diameter of 2.5 micrometers or less - as an indirect measure of sustainable development or an indicator of the environmental costs of economic growth.

Because the dataset exhibits a panel structure, estimation strategies revolve around pooled ordinary least squares, fixed effects, and random effects specifications. This analytical framework, extensively employed across economics, epidemiology, and broader social inquiry, is designed to interrogate observations containing both temporal and cross-sectional variation. Information is typically accumulated longitudinally for identical entities, permitting regressions that exploit dual dimensions of variability. By contrast, multivariate econometric designs extend coverage across additional axes - commonly individuals, periods, and a supplementary dimension - thereby enabling richer inferential capacity.

Table 1 below reports the description of the variables used in the study.

Table 1. Variables, Measurement and Source

Variables name	Symbols	Variables measurement	Source
Loal economic growth	GRDP	Gross regional domestic product (at current prices, bill. Dongs)	General State Office
Foreign direct investment	FDI	Foreign direct investment (implementation capital (Mill. USD)	
State budet revenue	SBR	State budet revenue (Bill. Dongs)	
Digital Transformation	DIGITAL	Turnover of postal service and telecommunication service (Bill. dongs)	
Air Quality Index	MP25	Average of the concentration of ultrafine dust particles in the air with a diameter of 2.5 micrometers or less (μg/m³)	Center of Environmental Monitoring

Source: Authors' summary.

The empirical model is specified as:

$$\mathrm{GRDP}_{\mathrm{it}} = \beta_0 + \beta_1 * FDI_{it} + \beta_2 * SBR_{it} + \beta_3 * \mathrm{DIGITAL}_{it} + \beta_4 * IMP25_{it} + \alpha_i + \mu_t + u_{it},$$

where β_i are the regression coefficients, α_i is a fixed effect in error, μ_t is error over time and u_{it} is the residuals over time and cities.

4. Empirical results

Table 2 below presents the descriptive statistics on mean of all variables used in this study.

Table 2. Descriptive on GRDP of cites

City	Mean	Min	Max	Standard deviation	Number
Bac Ninh	180738.2	128673.4	227614.6	37231.06	7
Cao Bang	15790	10369	19843	3358.511	7
Hanoi	865662.9	599178	1067540	175651.8	7
Hung Yen	83580.69	59006.2	112305.7	19246.54	7
Lang Son	29834.93	23382	37292.6	5391.697	7
Lao Cai	46347.07	31812.5	62703.3	11674.87	7

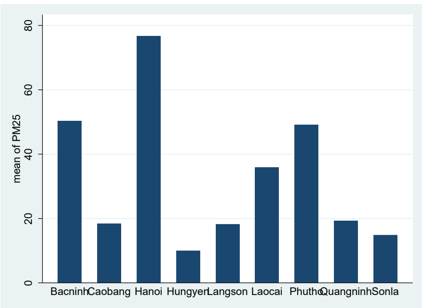
City	Mean	Min	Max	Standard deviation	Number
Phu Tho	62125.67	44550.7	80764	13545.16	7
Quang Ninh	168496.4	104498	238186.3	50472.88	7
Son La	47659.17	36360.6	56685.1	7668.276	7

Source: Summarized by the authors

The descriptive statistics of GRDP across provinces reveal substantial heterogeneity. Hanoi records the highest mean value at 865,662.9, with a wide range from 599,178 to 1,067,540 and a large standard deviation (175,651.8), indicating both economic concentration and significant variation over time. Bac Ninh and Quang Ninh also demonstrate relatively high averages, 180,738.2 and 168,496.4 respectively, accompanied by considerable dispersion. In contrast, Cao Bang shows the lowest mean (15,790) with limited fluctuation. Provinces such as Lang Son, Lao Cai, Phu Tho, and Son La exhibit moderate levels of GRDP with relatively smaller variability, reflecting more stable but less dynamic economic performance.

The visualization of mean of PM25 for all nine cites during the period 2015-2021 serves as an essential analytical tool to provide both descriptive insights and preliminary interpretations of environmental factors in the analysis model affecting green growth as in Figure 1.

Figure 1. Bar graph of PM25 of nine cities during the period of 2015-2021



Source: Executed by the authors

The descriptive statistics of average PM2.5 concentrations demonstrate notable spatial disparities across provinces. Hanoi records the highest mean level at 76.74, pointing to severe air pollution pressures in the capital. Bac Ninh (50.31) and Phu Tho (49.17) also report elevated averages, underscoring the environmental challenges associated with industrial and urban expansion. Lao Cai shows a moderate concentration of 35.90, while Quang Ninh (19.28), Cao Bang (18.45), Lang Son (18.26), and Son La (14.89) register relatively lower levels. Hung Yen reports the lowest mean (9.99), reflecting comparatively cleaner air quality. Overall, the distribution illustrates considerable heterogeneity in PM2.5 exposure across provinces, with urban and industrialized regions facing more acute pollution burdens.

Initially, the stochastic-effects specification was estimated and subjected to a diagnostic procedure to determine the appropriate estimator between pooled ordinary least squares and entity-specific alternatives. The Lagrange-multiplier examination returned a p-value above 0.05, indicating absence of significant between-unit variance; thus pooled ordinary least squares was adopted. The corresponding estimates appear in Table 3 for the provincial dataset under investigation overall.

Table 3. POLS estimation result

GRDP	Coefficient	Standard error	Z	P > |z|	95% confident interval	
FDI	72.88532	73.00347	1.00	0.318	-70.19885	215.9695
SBR	3.35128	.5750756	5.83	0.000	2.224152	4.478407
DIGITAL	1.806627	1.59742	1.13	0.258	-1.324259	4.937513
PM25	-1196.767	709.1473	-1.69	0.091	-2586.67	193.1366
CONSTANT	-6042.394	41848.98	-0.14	0.885	-88064.89	75980.1

Source: Summarized by the authors

After performing the POLS model regression, necessary tests include testing for autocorrelation of the residuals (see Table 4) and testing whether the residuals have heteroscedasticity (see Table 5).

Table 4. Results of autocorrelation test

Test	Statistics	Probability
Random Effects, Two Sided	ALM (Var(u) = 0) = 0.03	Pr > chi2(1) = 0.8610
Random Effects, One Sided	ALM (Var(u) = 0) = - 0.18	Pr > N(0,1) = 0.5695
Serial Correlation	ALM (lambda = 0) = 1.29	Pr > chi2(1) = 0.2560
Joint Test	LM (Var(u) = 0, lambda = 0) = 2.33	Pr > chi2(2) = 0.3125

Source: Summarized by the authors

Probabiity values of tests in Table 4 are all greater than 0.05 indicating that the residual of the model has no autocorrelation.

Table 5. Results of heteroscedasticity test

Statistics	Degree of Freedom	Probability > F
W0 = 0.68285716	df(1, 8)	0.43255722
W50 = 0.18441021	df(1, 8)	0.6789416
W10 = 0.68285716	df(1, 8)	0.43255722

Source: Summarized by the authors

Probabiity values of tests in Table 5 are all greater than 0.05 indicating that the residual of the model has no heteroscedasticity. Therefore, the estimation results in Table 3 can be used in analysis as follows:

$$GRDP_{it} = -6042.39 + 72.88 * FDI_{it} + 3.35 * SBR_{it} + 1.80 * DIGITAL_{TS_{it}} - 1196.76 * PM25_{it} + u_{it}$$

In which, the results show a positive impact of local state budget revenue on local economic growth, as shown by the positive regression coefficient of SBR and statistical significance at the 1% level. The results also show a negative impact of PM25 on local economic growth at the 10% significance level. This result is consistent with the results in Hao et al. (2018) and Fu et al. (2020). However, there is no evidence of the impact of local FDI and digital transformation process on local economic growth at the 5% level.

Public revenue generation exerts a positive influence on local economic growth through several reinforcing mechanisms. Adequate fiscal capacity enables governments to allocate resources toward infrastructure development, human capital formation, and essential public services, thereby enhancing productivity and regional competitiveness. Stable budgetary inflows also provide room for countercyclical policies and targeted subsidies that stimulate private sector dynamism. Moreover, efficient utilization of tax revenues strengthens institutional credibility, reduces market uncertainty, and fosters an enabling business environment. Collectively, these channels illustrate how sustainable revenue collection underpins long-term local growth trajectories and contributes to balanced and inclusive economic development.

Elevated PM2.5 concentrations exert an adverse impact on local economic growth through multiple detrimental channels. Deteriorating air quality undermines labor productivity by increasing morbidity and reducing workforce efficiency, while simultaneously escalating public health expenditures. High pollution levels also discourage investment, diminish tourism appeal, and erode overall quality of life, thereby constraining regional competitiveness. Furthermore, environmental degradation imposes hidden costs on ecosystems and infrastructure, weakening long-term development prospects. Collectively, these negative externalities demonstrate how persistent exposure to PM2.5 concentrations undermines sustainable growth trajectories and creates structural barriers to achieving resilient and inclusive local economic expansion.

The absence of empirical evidence linking digital transformation to local economic growth may be attributed to several underlying factors. In many regions, digital initiatives remain fragmented, with inadequate infrastructure and limited human capital constraining their effective utilization. Moreover, the productivity gains from digital adoption often materialize only in the long term, creating a temporal lag between investment and measurable outcomes. Institutional weaknesses, uneven policy implementation, and disparities in technological readiness across provinces further dilute potential impacts. Consequently, the expected positive association may not emerge clearly in the data, reflecting structural and contextual limitations rather than theoretical invalidity.

5. Conclusion

The model reveals that air quality index has a significant negative influence on local economic growth during the research period of 2015-2021. Building upon the empirical findings, it becomes imperative to propose targeted policy measures that can promote a green economy, towards sustainable growth by taking advantage of the achievements of the 4th industrial revolution.

Firstly, given the empirical finding that air quality deterioration negatively influences local growth, strengthening environmental governance emerges as a fundamental solution. Leveraging Fourth Industrial Revolution technologies, such as artificial intelligence and the Internet of Things, local authorities can deploy advanced air-quality monitoring systems that provide real-time data for regulatory enforcement. These digital platforms enhance transparency, allow precise identification of pollution hotspots, and enable timely policy interventions. By integrating environmental surveillance with fiscal incentives for green production, such initiatives not only reduce emissions but also create an enabling environment for sustainable industrial development at the provincial level.

Secondly, although digital transformation has not yet demonstrated measurable effects on economic growth, it holds significant latent potential when integrated with green innovation strategies. Local governments should incentivize enterprises to adopt clean technologies and circular production methods, supported by digital solutions such as blockchain-enabled traceability and smart energy management systems. These tools reduce environmental externalities while enhancing operational efficiency, competitiveness, and consumer trust in sustainable goods. By combining technological adoption with research collaboration between universities and firms, provinces can foster an ecosystem where digitalization reinforces green economy development, thus laying the groundwork for sustained and inclusive growth trajectories.

Thirdly, the limited growth impact of digital transformation may stem from insufficient absorptive capacity at the local level. Therefore, a strategic emphasis on human capital development is essential. Training programs should focus on equipping workers, entrepreneurs, and policymakers with the digital and environmental competencies necessary to manage emerging technologies effectively. By aligning vocational education, e-learning platforms, and industry partnerships, provinces can cultivate a workforce capable of utilizing digital tools to implement eco-efficient practices. Such capacity-building not only magnifies the long-term benefits of digital transformation but also ensures that local economies can pursue green growth without compromising sustainability objectives.

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