

# Solid waste treatment, FDI and economic growth: insights from Vietnam's provinces

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Journal of Asian  
Business and  
Economic Studies

81

Received 6 January 2026

Revised 24 March 2026

6 April 2026

Accepted 7 April 2026

## Abstract

**Purpose** – This study assesses whether solid waste treatment (SWT) attracts foreign direct investment (FDI) and, via that channel, raises provincial economic growth in Vietnam.

**Design/methodology/approach** – Using panel data for 63 provinces (2006–2021), the author estimates a two-equation framework: (1) the effect of SWT on FDI inflows and (2) the joint effects of SWT and FDI on provincial economic growth. The analysis employs province fixed effects, feasible generalized least squares and system generalized method of moments (system-GMM) estimators, complemented by heterogeneity analyses across provinces.

**Findings** – (1) SWT significantly and positively predicts FDI, (2) both SWT and FDI are positive and statistically significant predictors of provincial economic growth and (3) joint results from the two equations provide evidence consistent with FDI mediating the SWT-growth pathway. Importantly, the heterogeneity analysis reveals that the growth effects of SWT are not uniform, but are substantially stronger in provinces with higher FDI exposure and greater absorptive capacity.

**Practical implications** – Strengthening SWT capacity and performance can serve as an effective lever for attracting higher-quality FDI and accelerating provincial income growth, particularly in provinces with adequate economic capacity and investment readiness.

**Social implications** – Viewing SWT as a growth-enabling infrastructure can strengthen investment readiness and resilience, but basic treatment alone is insufficient for sustainability transitions, as its economic returns depend critically on local conditions.

**Originality/value** – The study reframes SWT as a productive environmental infrastructure, offering the first province-level evidence from Vietnam on an environment-investment-growth nexus with an explicit mediating mechanism and heterogeneous provincial effects.

**Keywords** Economic growth, FDI, Solid waste treatment, Environmental infrastructure, Sustainable development, Vietnam

**Paper type** Research article

## 1. Introduction

Environmental sustainability has become a central concern in developing economies undergoing rapid industrialization. As economic expansion intensifies environmental pressures, a key challenge is whether growth can be sustained without compromising environmental quality. In this context, solid waste treatment (SWT) has emerged as an important issue. Traditionally viewed as a basic public service, SWT is increasingly recognized as a form of environmental infrastructure that can generate economic returns by improving public health, reducing externalities and supporting productive activities (Mngomezulu *et al.*, 2024).

A growing body of literature highlights the role of environmental conditions in shaping investment patterns. Drawing on the Pollution Halo Hypothesis, stronger environmental

**JEL Classification** — F21, O44, Q53, R11

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**Funding:** None. This research is the output of the project number EIU.BBS.T.2025/026-B, done at Eastern International University, Vietnam.

**Declaration of interest:** The authors declare that they have no conflict of interest.



Journal of Asian Business and Economic  
Studies

Vol. 33 No. 2, 2026

pp. 81-93

Emerald Publishing Limited

2515-964X  
DOI 10.1108/JABES-01-2026-0008

practices - such as effective waste treatment – can attract foreign direct investment (FDI) by signaling regulatory quality and institutional credibility (OECD, 1999; Shah *et al.*, 2023). Empirical evidence further suggests that environmentally responsible locations are more likely to attract high-quality and sustainability-oriented FDI (Famanta *et al.*, 2024). However, most studies rely on cross-country evidence, offering limited insight into how specific environmental infrastructure affects investment decisions within countries, particularly in developing economies with strong regional disparities.

FDI is widely recognized as a key driver of economic growth through capital accumulation, technology transfer and productivity spillovers (Borensztein *et al.*, 1998; Emako *et al.*, 2022; Le *et al.*, 2024). However, environmental factors are typically treated as background conditions rather than as determinants shaping investment inflows and, indirectly, growth outcomes. As a result, little is known about whether environmental infrastructure – specifically SWT - can influence growth through FDI at the subnational level.

This gap is particularly relevant in Vietnam, where economic governance is decentralized and provinces actively compete for investment while exhibiting substantial variation in environmental management capacity. Despite growing research on FDI and environmental outcomes, integrated provincial-level evidence linking waste treatment, FDI and economic growth remains scarce.

This study addresses this gap by examining the relationships among SWTs, FDI inflows and provincial economic growth using panel data for 63 Vietnamese provinces over 2006–2021. The authors test three hypotheses (H1) SWT attracts FDI, (H2) SWT positively affects economic growth and (H3) FDI mediates the SWT-growth relationship. The analysis employs a two-equation empirical framework grounded in environmental, investment and growth theories.

This study contributes to the literature by providing the first province-level evidence from Vietnam that conceptualizes SWT as a productive environmental infrastructure influencing both investment and growth. The results show that SWT enhances FDI inflows and, through this channel, promotes economic growth. Importantly, these effects are heterogeneous and stronger in provinces with higher FDI exposure and greater absorptive capacity, indicating that environmental infrastructure is necessary but not sufficient for development. These findings offer policy-relevant insights for Vietnam and other developing economies facing similar trade-offs between growth, investment competition and environmental sustainability.

## 2. Literature review

In this study, SWT refers to the processing of collected waste in accordance with environmental standards, distinct from broader waste management activities such as collection and disposal.

### 2.1 Solid waste treatment and FDI

A first strand of literature examines how environmental conditions and infrastructure influence FDI location decisions. Beyond traditional determinants such as market size and labor costs, multinational firms increasingly consider institutional quality, infrastructure, knowledge capital and environmental conditions when selecting host locations (Bevan *et al.*, 2004; Asiedu, 2006; Raeskyesa, 2024). Within this framework, environmental factors serve as signals of governance quality and regulatory credibility.

This relationship is often framed through two competing hypotheses. The Pollution Haven Hypothesis suggests that firms relocate to regions with weaker environmental standards to reduce costs, whereas the Pollution Halo Hypothesis posits that stronger environmental practices attract higher-quality investment by reducing operational and reputational risks (Birdsall and Wheeler, 1993; Kim and Adilov, 2012; Huynh and Hoang, 2019). Increasingly, these mechanisms are viewed as context-dependent, varying with sectoral composition and institutional conditions.

Empirical evidence is mixed but increasingly nuanced. Firms tend to prefer locations with credible environmental management systems, particularly in sectors linked to global value chains (OECD, 1999), while greenfield FDI appears especially sensitive to environmental infrastructure and policy signals (Famanta *et al.*, 2024). At the subnational level, environmental infrastructure complements governance quality in shaping investment attractiveness, with regional disparities playing a key role in explaining within-country variation in FDI inflows.

Recent evidence from Association of Southeast Asian Nations (ASEAN) countries further supports this view. Stronger environmental regulations tend to attract FDI by signaling institutional credibility, whereas poor environmental quality – particularly high emissions – discourages investment by increasing environmental and reputational risks (Phung *et al.*, 2023; Yuwono *et al.*, 2025).

Within this literature, SWT represents a concrete form of environmental infrastructure that shapes investor perceptions of regulatory quality and operational risk. However, most studies rely on cross-country evidence or aggregate indicators, leaving limited insight into the subnational effects of specific infrastructure such as SWT in developing economies.

*H1.* Higher levels of solid waste treatment are associated with increased FDI inflows.

## *2.2 Solid waste treatment and economic growth*

A second strand of literature examines the role of environmental infrastructure in economic development. While traditionally viewed as a cost, environmental management is increasingly recognized as a productive input that enhances efficiency and long-term growth. Both early and recent studies show that effective waste treatment improves resource allocation, reduces environmental externalities and creates economic value through recycling and material recovery (Dinan, 1993; Tallentire and Steubing, 2020; Azwardi *et al.*, 2023; Mngomezulu *et al.*, 2024).

However, existing studies largely rely on national or sectoral data and often treat environmental factors as outcomes rather than drivers of growth. Examining SWT as a productive environmental infrastructure at the provincial level, therefore, offers a new perspective on the environment-growth nexus.

*H2.* Solid waste treatment positively contributes to provincial economic growth.

## *2.3 FDI as a mediating channel between solid waste treatment and economic growth*

A third strand of literature focuses on the relationship between FDI and economic growth. Within the endogenous growth framework, FDI promotes development through capital accumulation, technology transfer and productivity spillovers, although its effects depend on host-country characteristics such as human capital and institutional quality (Romer, 1990; Borensztein *et al.*, 1998).

Empirical evidence generally supports a positive but heterogeneous FDI-growth relationship, with stronger effects observed in contexts with favorable institutional and structural conditions (Pegkas, 2015; Ayenew, 2022; Yimer, 2022; Le *et al.*, 2024). Despite this, environmental conditions are typically treated as background factors rather than determinants of FDI.

Integrating this literature with the environmental infrastructure perspective suggests a transmission mechanism whereby environmental infrastructure indirectly influences growth through FDI inflows. In this context, SWT can enhance investment attractiveness by improving environmental quality and signaling institutional credibility, while FDI reinforces both environmental and economic performance through technology transfer. However, direct empirical evidence on this environment-FDI-growth linkage, particularly at the subnational level, remains limited.

H3. FDI serves as a mediating channel through which solid waste treatment increases economic growth.

2.4 Conceptual framework

To clarify the hypothesized relationships, Figure A1 [1] presents the conceptual framework of the study. SWT – as a form of environmental infrastructure – is expected to directly influence economic growth and indirectly affect growth through FDI. This study contributes to the literature in three ways: by conceptualizing SWT as a productive input, by integrating the environmental-FDI and FDI-growth literature through a mediation framework and by providing novel subnational evidence from a decentralized developing economy.

3. Empirical models and data

3.1 The impact of solid waste treatment on FDI

Environmental infrastructure, including waste treatment, can influence FDI by signaling institutional quality, sustainability and market readiness. Under the Pollution Halo Hypothesis, multinational firms prefer locations with strong environmental practices, viewing them as indicators of governance quality and policy stability (Birdsall and Wheeler, 1993; OECD, 1999; Shah et al., 2023). Well-developed waste treatment systems can reduce operational risks and transaction costs, thereby enhancing investment attractiveness (Pegkas, 2015; Emako et al., 2022).

In this study, SWT is measured in terms of treatment capacity and performance, capturing environmental infrastructure quality at the provincial level. It reflects regulatory capacity and investment readiness rather than waste generation itself. Accordingly, the first empirical model is specified as follows:

$$FDI_{it} = \alpha_0 + \alpha_1 SWT_{it} + X'_{it} \delta_j + \mu 1_i + \lambda 1_t + u_{it} \tag{1}$$

Where:

The dependent variable FDI measures registered FDI inflows at the provincial level (VND billion). While registered FDI does not fully reflect immediate capital disbursement, it appropriately captures investment attraction and location decisions, which are directly influenced by provincial environmental infrastructure such as SWT. As improvements in waste treatment primarily affect investor expectations and regulatory confidence, registered FDI provides a relevant proxy for investment dynamics and is strongly correlated with realized investment over the medium term. The main explanatory variable SWT measures solid waste treatment capacity, defined as the percentage of collected solid waste treated in accordance with national standards.

X is a vector of control variables, selected based on previous studies, including:

- (1) LGQ (local governance quality) is measured by six dimensions, including participation at local level (PART), vertical accountability (ACCT), transparency (TRANS), public administrative procedures (ADMIN), control of corruption (CORR) and public service delivery (DELIV). Data for LGQ were extracted from the Viet Nam Provincial Governance and Public Administration Performance Index (PAPI). Strong local governance improves the business environment by reducing uncertainty and transaction costs, thereby attracting FDI (Huynh et al., 2020; Hoang et al., 2023). It also enhances investor confidence and supports long-term investments, especially where institutions protect property rights, enforce contracts and foster entrepreneurship (Bevan et al., 2004; Tran and Le, 2019).
- (2) GDPP (gross domestic product per capita) captures economic development. Higher income levels indicate better market conditions and are associated with increased FDI inflows (Borensztein et al., 1998; Asiedu, 2006).

- (3) LABOR (trained labor force) measures human capital quality. A higher share of skilled workers attracts FDI by improving productivity and technological capacity (Javorcik, 2004; Li, 2024).
- (4) TEL (telephone) is the number of fixed and mobile telephone subscribers, representing the digital-communication intensity. A higher number of telephone subscribers indicates better connectivity, facilitating trade and growth (Abu Bakar *et al.*, 2012; Kurniawati, 2022).
- (5) FIRM (private enterprises per 1,000 people) proxies for local business dynamism and infrastructure, capturing entrepreneurial activity and market development relevant for foreign investors (Nielsen *et al.*, 2017; Yang *et al.*, 2017).

$\alpha_1$  and  $\delta_j$  are the respective coefficients of the independent variable and control variables;  $\mu_{1i}$  and  $\lambda_{1t}$  denote country-specific and time fixed effects (FE), respectively;  $i$  and  $t$  denote province and year, respectively; and  $u$  is the error term.

Data for FDI and control variables, including GDPP, LABOR, TEL and FIRM were collected from Vietnam's General Statistics Office (VGSO).

### 3.2 The impact of solid waste treatment and FDI on economic growth

Within the endogenous growth framework, FDI promotes economic growth through capital accumulation, technology transfer and productivity spillovers (Romer, 1990; Borensztein *et al.*, 1998; Le *et al.*, 2024). At the same time, effective waste treatment enhances productivity by improving environmental quality and public health. Accordingly, FDI is expected to mediate the relationship between environmental infrastructure and growth. Thus, the author formulates the second empirical model as follows:

$$GDPP_{it} = \beta_0 + \beta_1 SWT_{it} + \beta_2 FDI_{it} + Z'_{it} \theta_j + \mu_{2i} + \lambda_{2t} + v_{it} \quad (2)$$

Where:

The dependent variable GDPP is gross domestic product per capita, representing economic growth. The independent variables are the SWT and FDI.

$Z$  is a vector of control variables, selected based on previous studies, including determinants of economic growth such as non-state investment capital (CAP), trained labor force (LABOR), LGQ and education (EDU).

- (1) CAP (Non-state investment capital) proxies domestic capital accumulation. Growth theory identifies physical capital as a key driver of growth (Solow, 1956; Mankiw *et al.*, 1992), and investment flows are commonly used as practical proxies in subnational analyses (Barro, 1991).
- (2) LABOR (Trained labor force) reflects human capital quality. A more skilled workforce enhances productivity and innovation, thereby supporting economic growth (Barro, 2001).
- (3) LGQ captures institutional effectiveness, transparency and accountability. Better governance promotes growth by improving institutional performance and reducing corruption (Lopes *et al.*, 2023).
- (4) EDU (education), measured by the share of high school graduates, strengthens human capital and supports innovation and technological adaptation, which are crucial for long-run growth (Hanushek and Woessmann, 2021).

$\beta_1$ ,  $\beta_2$  and  $\theta_j$  are the respective coefficients of the independent variables and control variables;  $\mu_{2i}$  and  $\lambda_{2t}$  denote country-specific and time FE, respectively;  $i$  and  $t$  denote province and year, respectively; and  $v$  is the residual.

Data for GDPP, SWT, FDI and control variables, including CAP, LABOR and EDU were collected from VGSO, while data for LGQ were extracted from the Viet Nam Provincial Governance and PAPI. All monetary variables are expressed in constant prices to ensure comparability over time. Specifically, nominal values are deflated using the official gross domestic product (GDP) deflators published by VGSO, with 2010 as the base year. The deflation procedure and data sources are applied consistently across provinces and years, and the resulting real variables are used in all empirical estimations. All variables with their measurements and sources are provided in [Table A1 \[1\]](#).

To ensure comparability and reduce scale effects, all scale-sensitive variables are expressed in logarithmic form. All models include province and year FE to control for unobserved heterogeneity and common shocks. Robustness is assessed using system generalized method of moments (System-GMM) estimations. LABOR and EDU capture complementary dimensions of human capital – short-term workforce skills and long-term accumulation – and are therefore retained jointly.

The panel covers 63 provinces over 2006–2021 and is unbalanced due to data availability, particularly for governance indicators that are only available from 2009. Missing observations are handled using standard panel-data methods: the fixed-effects estimator remains consistent under an unbalanced panel by exploiting within-province variation, while the System-GMM estimator accommodates data gaps by relying on available lagged values as internal instruments, ensuring efficient use of all valid observations. Summary statistics are displayed in [Table A2 \[1\]](#).

#### 4. Econometric methodology

In this study, the author applies two main estimation methods for panel data, including the pooled ordinary least squares (OLS) and the random effects (RE). To determine the more suitable method between OLS and RE, the author conducted the Breusch-Pagan Lagrange Multiplier (LM) test. This test sets the null hypothesis that there is no difference between the entities in the sample. If the null hypothesis is rejected, the author continues to estimate the model using the FE method. Then, to choose between RE and FE, the author performs the Hausman test. This test sets the null hypothesis that there is no systematic difference between the entities in the sample. The result of the Hausman test determines the final estimation method. Specifically, if the null hypothesis is rejected, the FE method is considered more suitable. Conversely, if the null hypothesis cannot be rejected, the RE method will be selected ([Greene, 2012](#)). While fixed-effects estimation with robust standard errors corrects for unobserved heterogeneity and heteroskedasticity, it does not explicitly model the error variance–covariance structure. In contrast, feasible generalized least squares (FGLS) accounts for heteroskedasticity, serial correlation and cross-sectional dependence (CD) by estimating the full error structure, thereby improving estimation efficiency ([Bai et al., 2021](#)). Accordingly, FGLS was employed to enhance the efficiency of the estimates.

An important econometric concern in this study relates to the potential endogeneity and simultaneity among SWTs, FDIs and economic growth. Improvements in waste treatment may attract FDI and support growth, but higher income levels and stronger investment performance can, in turn, enable greater fiscal capacity and institutional demand for improved waste treatment. Similarly, the relationship between FDI and economic growth has long been recognized as potentially simultaneous. While province FE help control for time-invariant unobserved heterogeneity and FGLS addresses heteroskedasticity and CD, these estimators do not fully resolve reverse causality or dynamic feedback effects. To mitigate these concerns, the author complements the baseline FE and FGLS estimates with dynamic System-GMM estimations, which explicitly account for endogeneity by using internal instruments derived from lagged levels and differences of the endogenous variables. This approach allows us to assess the robustness of the main results under a dynamic specification while acknowledging the remaining limitations imposed by data availability.

To complement the two-equation framework, the author conducts a formal mediation test following the [Sobel \(1982\)](#) approach. Specifically, the author computes the indirect effect of SWT on economic growth through FDI as the product of the estimated coefficients from [Eq. \(1\)](#) and [Eq. \(2\)](#) and assess its statistical significance using standard errors derived from the delta method. This approach allows us to formally quantify the extent to which FDI transmits the effect of environmental infrastructure on economic growth.

## 5. Empirical results and discussions

The author begins by testing CD using Pesaran's CD test ([Pesaran, 2004](#)), followed by the covariate-augmented Dickey-Fuller (CADF) unit root test ([Pesaran, 2007](#)). As shown in [Table A3 \[1\]](#), CD is present, and most variables are stationary at level, except EDU, which is first-differenced in subsequent estimations.

[Eqs. \(1\)](#) and [\(2\)](#) are estimated using baseline and extended specifications. Diagnostic tests (LM, Hausman, Wooldridge and Modified Wald) support the use of FE, while FGLS is employed to correct for heteroskedasticity. Results are reported in [Table A4 \[1\]](#) and [Table 1](#).

### 5.1 Baseline results

[Table A4 \[1\]](#) shows that SWT has a positive and statistically significant effect on FDI across all specifications. A one-percentage-point increase in SWT raises FDI inflows by approximately 0.3–0.6%, confirming the first hypothesis and supporting the Pollution Halo Hypothesis, where sound environmental practices signal institutional quality and reduce reputational and operational risks for foreign investors ([OECD, 1999](#); [Shah et al., 2023](#)). The control variables - including GDPP, LGQ, LABOR, TEL and FIRM - behave as expected, being consistent with prior studies ([Borensztein et al., 1998](#); [Bevan et al., 2004](#); [Javorcik, 2004](#); [Yang et al., 2017](#); [Tran and Le, 2019](#); [Huynh et al., 2020](#); [Hoang et al., 2023](#); [Li, 2024](#)).

[Table 1](#) presents the results for [Eq. \(2\)](#), examining the effects of SWT and FDI on provincial economic growth (GDPP). In specification 2.1, both SWT and FDI exert positive and statistically significant effects on GDPP, under both FE and FGLS methods. The coefficients

**Table 1.** Estimation results for [Eq. \(2\)](#)

| Dependent variable: LnGDPP |                 |                 |                 |                 |
|----------------------------|-----------------|-----------------|-----------------|-----------------|
| Regressors                 | (2.1)<br>FE     | FGLS            | (2.2)<br>FE     | FGLS            |
| SWT                        | 0.002*** (3.06) | 0.003*** (7.17) | 0.001** (3.78)  | 0.002*** (8.61) |
| LnFDI                      | 0.297*** (3.81) | 0.409*** (6.17) | 0.109*** (2.26) | 0.235*** (8.64) |
| LnCAP                      |                 |                 | 0.438*** (7.92) | 0.351*** (8.12) |
| LABOR                      |                 |                 | 0.035*** (2.38) | 0.056*** (4.51) |
| LnLGQ                      |                 |                 | 1.856*** (4.14) | 0.499*** (2.34) |
| LnEDU                      |                 |                 | 0.204** (2.36)  | 0.318*** (7.24) |
| Year FE                    | Yes             | Yes             | Yes             | Yes             |
| Province FE                | Yes             | Yes             | Yes             | Yes             |
| Constant                   | 3.033***        | 2.785***        | 2.486***        | 2.663***        |
| Obs                        | 553             | 553             | 421             | 421             |
| Hausman                    | 175.24***       |                 | 156.72***       |                 |
| Wooldridge                 | 191             |                 | 178             |                 |
| MW-P                       | 0.000           | 0.573           | 0.000           | 0.284           |
| LM-P                       | 0.475           |                 | 0.338           |                 |

**Note(s):** *T*-statistics for FE and *Z*-statistics for FGLS are presented in brackets. The symbols \*\*\*, \*\* and \* represent statistically significant levels at 1%, 5% and 10%, respectively. *p* represents the *P*-value of the respective tests

**Source(s):** Author's own work



for SWT range from 0.002 to 0.003, while those for FDI range from 0.297 to 0.409, indicating that improvements in waste treatment and higher levels of foreign investment contribute to higher GDP per capita.

In specification 2.2, with the inclusion of control variables, the results remain consistent. SWT and FDI continue to exhibit significant positive effects on economic growth, reaffirming the second and third hypotheses. Notably, the magnitude of FDI's effect decreases slightly (to 0.109–0.235), suggesting partial mediation and potential interaction with the included controls. These are the novel findings of this study, strongly contributing to the literature of this field. Control variables behave as expected: CAP, LABOR, LGQ and EDU all contribute positively to growth, consistent with the literature (Barro, 2001; Hanushek and Woessmann, 2021; Pham *et al.*, 2022; Lopes *et al.*, 2023).

The empirical evidence supports a comprehensive, sustainability-centered development strategy and extends the existing literature by providing new subnational evidence from a developing economy. *First*, the strong positive effect of SWT on both FDI and GDPP validates environmental infrastructure as a dual economic-environmental lever at the provincial level, a dimension that has received limited empirical attention in previous studies. In the context of Vietnam's decentralized growth model, provinces that improve waste treatment not only address environmental challenges but also actively shape their investment attractiveness, unlocking economic potential by attracting FDI and improving public health, which in turn translates into higher productivity. *Second*, our results show that FDI serves not merely as a direct source of capital, but as a mediating channel through which environmental infrastructure translates into economic growth, highlighting a mechanism that has been largely overlooked in earlier empirical work. While this finding is consistent with the broader growth-enhancing role of FDI documented by Le *et al.* (2024) and Borensztein *et al.* (1998), the novelty of the present study lies in identifying environmental infrastructure as a precursor that conditions and amplifies FDI's growth effects at the subnational level. *Lastly*, the significance of control variables - especially LGQ, LABOR and EDU - highlights that the economic returns to SWT and foreign investment depend on complementary institutional quality and human capital, offering new insights into why similar environmental investments may yield heterogeneous growth outcomes across provinces. Together, these findings move beyond confirming established relationships and clarify how environmental infrastructure, FDI and local development interact in developing-country settings, thereby contributing fresh empirical evidence to the sustainability and development literature. These findings are broadly consistent with emerging evidence from ASEAN economies, where environmental quality, infrastructure and governance increasingly shape investment patterns. For example, evidence from Indonesia shows that stronger local governance and regulatory quality significantly enhance provincial FDI performance (Yuwono *et al.*, 2025), while broader studies on Southeast Asia indicate that FDI contributes more effectively to growth in regions with stronger institutional and policy frameworks (Phung *et al.*, 2023). Similar to these contexts, our results suggest that Vietnam's provincial disparities in environmental infrastructure and absorptive capacity play a decisive role in translating investment into economic performance.

### 5.2 Mediation analysis

To formally evaluate the mediating role of FDI, the author conducts a Sobel mediation test using the estimated coefficients from Eq. (1) and Eq. (2). The results, reported in Table A5 [1], show that the indirect effect of SWT on economic growth through FDI is positive and statistically significant across specifications. The magnitude of the indirect effect ranges from 0.0009 to 0.0025, depending on the estimator. The Sobel test statistics are statistically significant at the 1–5% level, confirming that FDI serves as an important transmission channel linking environmental infrastructure to economic performance. These findings provide formal statistical support for the interpretation that the relationship between SWT and economic



growth operates, in part, through FDI inflows, while also remaining consistent with the direct effect identified in the baseline models.

### 5.3 Provincial heterogeneity analysis

Vietnam's provinces differ markedly in environmental conditions, investment capacity and economic scale. The heterogeneous distributions of SWT, FDI and income level across 63 provinces of Vietnam over the period 2006–2021 on average are displayed in [Figures A2, A3 and A4 \[1\]](#), respectively. To examine whether the effects of SWT and FDI vary across these heterogeneous contexts, the author conducts a provincial heterogeneity analysis along three dimensions: SWT capacity, FDI intensity and income level. Provinces are divided into groups based on sample-period means. All models include province and year FE, with FGLS estimates reported for efficiency. Results for provincial heterogeneity by SWT capacity, FDI intensity and income level are presented in [Tables A6, A7 and A8 \[1\]](#), respectively. Results reveal strong variation across contexts.

First, SWT has a stronger impact on FDI in provinces with higher treatment capacity, suggesting threshold effects in environmental infrastructure. Second, the growth impact of SWT is significantly larger in high-FDI provinces, indicating that FDI amplifies the productivity returns of environmental investment. Third, SWT contributes to growth primarily in higher-income provinces, where absorptive capacity and institutional quality are stronger.

In addition, to further examine heterogeneity beyond group-based comparisons, the author estimates models including interaction terms between SWT and a key provincial characteristic: FDI intensity. The results are reported in [Table A9 \[1\]](#). The interaction between SWT and FDI intensity is positive and statistically significant, indicating that the growth effect of SWT is amplified in provinces with higher levels of foreign investment. Importantly, the baseline effect of SWT remains positive, while the interaction terms capture the additional marginal effects associated with local conditions. These findings confirm that the growth impact of environmental infrastructure is not uniform but increases with investment intensity, thereby reinforcing the results obtained from the group-based heterogeneity analysis.

### 5.4 Robustness checks

To further address potential reverse causality, the author re-estimates the baseline models using a one-period lag of SWT. The results are reported in [Appendix Tables A10 and A11 \[1\]](#). [Table A10 \[1\]](#) shows that lagged SWT continues to exert a positive and statistically significant effect on FDI inflows across both FE and FGLS estimations. The magnitude of the coefficients is slightly smaller than in the baseline models, which is expected given the dynamic adjustment, but the overall conclusion remains unchanged. [Table A11 \[1\]](#) presents the corresponding results for economic growth. Lagged SWT and FDI both remain positive and statistically significant determinants of GDP per capita. The persistence of these effects confirms that the relationship between environmental infrastructure, investment and growth is not driven by short-run simultaneity or reverse causality.

To further address potential endogeneity and simultaneity among SWT, FDI and economic growth, the author re-estimates both [Eqs. \(1\) and \(2\)](#) using a dynamic System-GMM estimator ([Arellano and Bover, 1995; Blundell and Bond, 1998](#)). Both models include lagged dependent variables to capture persistence. SWT is treated as endogenous in both equations, while FDI is additionally treated as endogenous in the growth equation; all are instrumented using their lagged levels and differences. Year dummies are included to control for common shocks.

The System-GMM estimates for both equations, reported in [Appendix Table A12 \[1\]](#), are broadly consistent with the baseline fixed-effects and FGLS results while explicitly accounting for dynamic persistence and potential endogeneity. SWT remains positive and significant in both equations, confirming its role in attracting FDI and promoting growth. FDI also continues to positively affect growth, supporting its mediating role, while lagged

dependent variables indicate strong persistence. Taken together, these results reinforce the robustness of the proposed environment-investment-growth mechanism and support the mediating role of FDI when endogeneity concerns are addressed. Diagnostic tests validate the model specification: the Arellano-Bond tests confirm first-order but not second-order serial correlation and the Hansen test supports instrument validity. The number of instruments remains below the number of cross-sectional units, mitigating concerns about instrument proliferation. Overall, these results reinforce the robustness of the proposed environment-investment-growth mechanism.

## 6. Conclusion and policy implications

This study empirically investigates the relationships among SWT, FDI and economic growth across 63 provinces in Vietnam from 2006 to 2021. Using a two-equation panel-data framework grounded in the literature on environmental infrastructure, investment behavior and endogenous growth, the analysis provides four main findings. First, improvements in SWT significantly increase FDI inflows, indicating that environmental management enhances provincial investment attractiveness. Second, both SWT and FDI contribute positively to provincial economic growth. Third, FDI operates as a mediating channel through which environmental infrastructure indirectly promotes growth. Fourth, and critically, the provincial heterogeneity analysis shows that the growth effects of SWT are not uniform, but are substantially stronger in provinces with higher FDI exposure and greater absorptive capacity. This finding confirms that environmental infrastructure is necessary but not sufficient for growth and that its economic returns depend on local conditions.

These findings provide new evidence on the “environment-investment-growth” nexus in a developing-country context, highlighting the critical role of subnational heterogeneity. From a policy perspective, the results show that the effectiveness of SWT depends strongly on FDI exposure and local absorptive capacity. In provinces with higher FDI intensity and stronger economic capacity, improvements in SWT significantly enhance investment attractiveness and translate into higher growth. In contrast, in less-developed provinces, similar investments yield weaker returns unless complemented by improvements in governance quality, human capital and the domestic business environment. These results also underscore the need for place-based policy approaches, rather than uniform national strategies. Environmental infrastructure investments should be aligned with local development conditions, ensuring that provinces possess the institutional and economic capacity to convert environmental improvements into productive outcomes.

Beyond Vietnam, these implications are relevant for other developing and emerging economies with pronounced regional disparities, such as Indonesia, India and the Philippines. In such contexts, SWT can function as a productive environmental infrastructure that supports investment and growth, particularly where local institutions are sufficiently developed.

Although doing its best, this study cannot avoid limitations that suggest avenues for future research. First, our measure of SWT captures the extent of treatment rather than its technological quality or environmental effectiveness, which future studies could address by distinguishing between advanced, circular-economy-oriented practices and basic compliance. Second, data constraints prevent us from differentiating between green and pollution-intensive FDI, an important distinction for understanding the environmental-growth nexus more precisely. Finally, future research could explore sectoral heterogeneity in greater depth, as well as examine whether similar mechanisms operate in other developing economies with comparable institutional and fiscal structures.

## Compliance with ethical standards

Disclosure of potential conflicts of interest.

**Data availability statement**

The data that supports the findings of this study are available from the corresponding author upon reasonable request.

**Notes**

1. Please see it in the Online Appendix.

**Supplementary material**

The supplementary material for this article can be found online.

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