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Circular Economy as a Climate Shield: Labor Productivity and Regional Growth in Vietnam

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Abstract

This article examines whether circular economy (CE) practices, proxied by industrial park environmental compliance, are associated with attenuated climate-productivity relationships across Vietnamese provinces. It explores whether these associations vary systematically between key economic regions and peripheral areas. A panel dataset of 63 Vietnamese provinces was constructed for 2020–2024, yielding 312 province-year observations. We estimated two-way fixed-effects models with interaction terms between climate variables and the CE proxy, using heteroskedasticity-robust standard errors clustered at the province level. Temperature and rainfall have insignificant national average associations with labor productivity. However, the three-way interaction between temperature, CE, and key-region status is positive and statistically significant. Conditional marginal effects reveal that in key regions, the temperature association moves from negative at low CE to positive at high CE, while peripheral regions show no statistically detectable pattern. The findings are consistent with CE acting as a partial, region-specific climate shield, particularly in industrialized areas. Policies should prioritize CE capacity-building in small and medium provinces and tailor adaptation strategies regionally.

Keywords: Circular Economy, Climate Shield, Labor Productivity, Regional Heterogeneity, Vietnam

Introduction

Climate conditions shape productive efficiency by altering labor capacity, agricultural yields, and infrastructure continuity (De Lima et al., 2021; Heal & Park, 2016). Extreme temperatures reduce labor productivity and cognitive capacity through physiological heat stress (Dasgupta et al., 2021, 2024; Lai et al., 2023). Importantly, temperature-productivity relationships are often nonlinear, with productivity peaking at moderate temperatures and declining sharply beyond specific thresholds (Burke et al., 2015; Dasgupta et al., 2024). Evidence from manufacturing sectors shows that annual output falls by roughly 2% per additional °C without climate control, though adaptation measures can significantly mitigate these losses (Somanathan et al., 2021). While outdoor sectors are highly sensitive, manufacturing and services also face substantial GDP losses (Kimmich et al., 2025; Liu et al., 2021). However, the same weather shock produces unequal economic losses across regions and income levels because exposure and adaptive capacity differ fundamentally (Dasgupta et al., 2024; Lai et al., 2023).

To understand how economies buffer these shocks, we introduce the circular economy (CE) as a conditioning variable. In resilience literature, CE practices, such as circular design, reuse, and regionalization, are linked to supply system stabilization, agility, and reduced dependence on virgin materials under disruption (Cherrafi et al., 2022; Kennedy & Linnenluecke, 2022). Therefore, rather than treating CE merely as a direct productivity input, we shift the analytical focus to whether CE moderates the productivity effects of climate shocks (Chari et al., 2022; Kennedy & Linnenluecke, 2022). However, because CE-resilience links are still nascent, and highly efficient systems may lose necessary buffers or redundancy, moderation claims must be framed strictly as testable hypotheses rather than assumed causal facts (Kennedy & Linnenluecke, 2022).

Crucially, any potential "climate shield" effect is unlikely to be spatially uniform. Because climate damages and adaptive capacities vary with sectoral composition and institutional context, one-size-fits-all response functions perform poorly (Dasgupta et al., 2021; Lai et al., 2023; Shayegh et al., 2021). It is plausible that industrialized, capital-intensive regions, such as Vietnam's Southeast and Red River Delta, could realize greater protection from CE-linked infrastructure than agriculture-oriented or spatially dispersed regions. While the study tests these heterogeneous associations, it cannot directly identify latent mechanisms such as absorptive capacity or adaptive capability.

Based on this framework, this study addresses three linked questions:

1) Are temperature and rainfall significantly associated with labor productivity across Vietnamese provinces?
2) Does CE adoption moderate this climate-productivity relationship nationally?
3) Does this moderating effect differ between key economic regions and peripheral regions?

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature and develops the hypotheses (H1–H3). Section 3 details the data, variable operationalization, and econometric strategy. Section 4 presents empirical results. Section 5 discusses the findings and policy implications, and Section 6 concludes.

Literature Review and Hypothesis Development

Climate conditions and labor productivity

Heat reduces labor productivity through physiological and labor-supply pathways. Global evidence demonstrates that warming lowers both labor productivity and supply, with disproportionately high risks in tropical and Southeast Asian settings, making Vietnam a critical case for this literature (Dasgupta et al., 2021). These heat-related losses are highly dependent on exposure contexts: while outdoor and high-intensity occupations are most affected, indoor sectors can be partially buffered where adaptation measures, such as air conditioning, are widespread (Liu et al., 2021; Szewczyk et al., 2021). At the macroeconomic level, these labor-productivity shocks propagate into broader GDP losses, affecting manufacturing and services, not merely agriculture.

The temperature-productivity relationship is fundamentally nonlinear. Labor supply follows a concave response, initially improving at low temperatures but declining sharply after a specific threshold (Kim et al., 2026). Subnational studies confirm that while mild climates raise

productivity, extreme temperature variability produces sizable losses that differ by industrial structure (Kim et al., 2026). Consequently, a linear annual-mean specification in empirical models serves as a practical simplification rather than a full representation of threshold effects across Vietnam's diverse climatic zones. This motivates our first hypothesis:
Hypothesis 1a (H1a). *Temperature is significantly associated with labor productivity across Vietnamese provinces.*

Rainfall lacks a stable directional effect on productivity because it yields offsetting outcomes: it supports water availability and crop yields, but abnormal or excessive precipitation damages production through flooding, inundation, and logistical disruption. In Vietnam, agricultural studies consistently show that precipitation effects vary by season, region, and irrigation status rather than following a single national pattern (Hao & An, 2026; Ho et al., 2023; Nguyen & Scrimgeour, 2022).

Rainfall can mitigate heat damage in certain settings; for instance, higher summer precipitation reduces temperature-related losses in Vietnamese agriculture (Nguyen & Scrimgeour, 2022). Conversely, rainfall can be highly destructive. More wet-season rainfall benefits the North but severely damages irrigated farms in Central and Southern regions (Trinh, 2018). Furthermore, rainfall variability is negatively associated with long-run provincial food-crop productivity, and extreme precipitation significantly raises rice damage and inundation losses (Giang & Vy, 2021). Thus, we hypothesized:
Hypothesis 1b (H1b). *Rainfall is significantly associated with labor productivity across Vietnamese provinces.*

Circular economy as a Moderator
The circular economy (CE) literature increasingly supports framing CE as a resilience mechanism rather than merely a direct productivity driver. Across conceptual and empirical studies, CE practices are linked to flexibility, adaptability, regionalization, diversification, and reduced dependence on virgin inputs—all of which plausibly buffer disruption-sensitive production systems (Cherrafi et al., 2022; Haque, 2026; Pellegrino et al., 2026). Empirically, CE practices are positively associated with supply-chain resilience, and remanufacturing capabilities further strengthen this resilience, particularly under flexible organizational orientations (Bag et al., 2019). Recent firm-level evidence is consistent with this resilience logic (Le et al., 2023). Therefore, we hypothesized:
Hypothesis 2 (H2). *Circular-economy adoption moderates the relationship between climate conditions and labor productivity.*

Regional context and heterogeneous moderation
The expected "climate shield" effect is unlikely to be spatially uniform because climate damage depends heavily on occupational structure, sectoral mix, income levels, and interregional linkages. Research on climate economics emphasizes that local impacts vary with economic structure and baseline climate, rather than being constant across places (Dell et al., 2014). Subnational economic modeling reveals that lower-income or structurally exposed regions can suffer much larger losses, and that regions with smaller direct labor shocks can still incur substantial total losses through cross-sector and cross-region transmission (Zhao et al., 2024). It is critical to note that the mechanism behind heterogeneous CE moderation remains inferred rather than directly identified, because

available evidence supports region-specific adaptation but does not directly observe latent absorptive capacity or institutional quality (Ahmad et al., 2026). Thus, we hypothesized:
Hypothesis 3 (H3). *The moderating effect of circular-economy adoption on the climate-labor productivity relationship differs between Vietnam's key economic regions and peripheral regions.*

Data and Methodology

Data

The unit of analysis is the province-year. The initial panel is constructed as a 63-province by 5-year grid for 2020–2024, yielding 315 observations. After excluding observations with missing values in the core regression variables, the analytical sample contains 312 province-year observations across all 63 provinces and the full five-year period.

The empirical dataset combines provincial economic and socio-demographic indicators with weather-station observations and the study's CE proxy. Labor productivity is obtained from the General Statistics Office of Vietnam (GSO). Temperature and rainfall are derived from weather-station records and mapped to provinces. HDI is sourced at the provincial level, and population density is taken from provincial statistical sources. The CE proxy is constructed from counts related to industrial parks and wastewater-treatment compliance.

The study uses the historical 63-province structure. Regional classification follows Vietnam's six socio-economic regions: Northern Midlands and Mountains; Red River Delta; North Central and Central Coast; Central Highlands; Southeast; and Mekong Delta. The key-region indicator equals one for the Southeast and Red River Delta and zero otherwise.

Table **1** presents the definitions and data sources of the variables.

Table 1
Variable definitions and operationalization

Variable	Role	Operationalization	Unit
Labor productivity (LP)	Dependent variable	GRDP divided by total employment	million VND/worker
Log labor productivity (ln_LP)	Dependent variable	Natural log of LP	log points
Temperature (TEMP)	Climate regressor	Annual mean temperature aggregated to province-year	degrees C
Rainfall (RAIN)	Climate regressor	Annual total rainfall aggregated to province-year	mm
CE proxy	Moderator	100 × compliant industrial-park count / total industrial-park count; zero when no operational park is recorded	%
HDI	Control	Provincial Human Development Index	index, 0–1
Population density	Control	Population divided by area; entered as log and standardized	persons/km²
Key region	Regional moderator	1 = Southeast or Red River Delta; 0 = remaining four regions	dummy

Province FE	Fixed effect	Province-specific intercept	indicator set
Year FE	Fixed effect	Year-specific common shock	indicator set

Measurement note: The CE proxy is defined as a wastewater-treatment compliance/infrastructure share within industrial parks. It should not be interpreted as a comprehensive index of circularity.

Empirical Methodology

All reported models use two-way fixed effects. Let i index provinces and t index years. Temperature, rainfall, and CE are centered on their own province means to focus the regressions on within-province variation and reduce non-essential multicollinearity. HDI and logged population density are standardized in the analytical sample.

The baseline model estimates the direct association of within-province temperature and rainfall deviations with labor productivity, controlling for CE, HDI, and population density (Model 1):

$$\ln(LP)_{it} = \beta_0 + \beta_1 \text{TEMP_c}_{it} + \beta_2 \text{RAIN_c_100}_{it} + \beta_3 \text{CE_c}_{it} + \beta_4 \text{HDI_c}_{it} + \beta_5 \ln D_c_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where RAIN_c_100 is rainfall centered within province and divided by 100 for numerical scaling; μ_i denotes province fixed effects; and λ_t denotes year fixed effects.

To test H2, Model 2 adds temperature ×CE and rainfall ×CE interactions:

$$\begin{aligned}\ln(LP)_{it} = {} & \beta_0 + \beta_1 \text{TEMP_c}_{it} + \beta_2 \text{RAIN_c_100}_{it} + \beta_3 \text{CE_c}_{it} \\ & + \beta_4 (\text{TEMP_c} \times \text{CE_c})_{it} + \beta_5 (\text{RAIN_c_100} \times \text{CE_c})_{it} \\ & + \gamma \text{Controls}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)\end{aligned}$$

To test H3, Model 3 introduces key-region interactions:

$$\begin{aligned}\ln(LP)_{it} = {} & \beta_0 + \beta_1 \text{TEMP_c}_{it} + \beta_2 \text{RAIN_c_100}_{it} + \beta_3 \text{CE_c}_{it} \\ & + \beta_4 (\text{TEMP_c} \times \text{CE_c})_{it} + \beta_5 (\text{TEMP_c} \times \text{Key}_i) \\ & + \beta_6 (\text{CE_c} \times \text{Key}_i) + \beta_7 (\text{TEMP_c} \times \text{CE_c} \times \text{Key}_i) \\ & + \gamma \text{Controls}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)\end{aligned}$$

The coefficient β_7 is the difference in the temperature ×CE moderation slope between key and peripheral regions. A positive value indicates that the temperature association becomes more favorable with higher CE at a faster rate in key regions than in peripheral regions.

The reported standard errors are heteroskedasticity-robust HC1 standard errors clustered at the province level. Statistical analysis was performed using R version 4.3.1. The significance level was set at $\alpha = 0.10$. The empirical design identifies within-province associations conditional on fixed effects and does not establish causality. The paper therefore uses terms such as "associated with," "moderates," and "consistent with," avoiding causal claims.

Results

Descriptive Statistics

The analytical sample contains 312 province-year observations representing all 63 provinces over 2020–2024. Average labor productivity is 160.45 million VND per worker (SD = 93.65). Mean annual temperature is 25.68 °C (SD = 2.41), and mean annual rainfall is 2,192.20 mm (SD = 712.00). The CE proxy averages 78.41 percent (SD = 34.97).

Table 2 presents the descriptive statistics, and Table 3 reports the regional averages, which show strong differences in economic structure and observed conditions.

Table 2
Descriptive statistics for the analytical sample.

Variable	Mean	SD	Min	P25	Median	P75	Max	N
LP (million VND/worker)	160.45	93.65	49.40	108.00	131.00	183.00	704.00	312
ln(LP)	4.96	0.45	3.90	4.68	4.87	5.21	6.56	312
TEMP (°C)	25.68	2.41	18.30	24.50	25.70	27.80	28.70	312
RAIN (mm)	2,192.20	712.00	956.00	1,650.00	2,130.00	2,468.00	4,951.00	312
CE proxy (%)	78.41	34.97	0.00	66.70	100.00	100.00	100.00	312
HDI	0.71	0.05	0.58	0.68	0.71	0.74	0.83	312
Density (persons/km^2)	534.60	689.00	52.00	144.00	277.00	674.00	4,555.00	312

Table 3
Regional descriptive characteristics, 2020–2024

Region	Provinces	Obs.	LP	TEMP	RAIN	CE	HDI	Density
North Central and Central Coast	14	70	141	26.6	2,627	69.7	0.717	256
Northern Midlands and Mountains	14	67	122	23.6	1,900	60.9	0.675	179
Central Highlands	5	25	106	21.2	2,155	82.0	0.679	110
Southeast	6	30	293	28.1	1,502	99.8	0.756	1,179
Mekong Delta	13	65	124	28.1	2,498	82.2	0.690	483
Red River Delta	11	55	227	24.9	2,026	93.0	0.764	1,225

Baseline and National Moderation Results

Regional averages show big differences in economic structure and observed conditions. The Southeast has the highest average labor productivity at approximately 293 million VND per worker and a CE proxy of 99.8 percent. The Red River Delta follows with an average productivity of approximately 227 million VND per worker and a CE proxy of 93.0 percent. The Central Highlands has the lowest average labor productivity at approximately 106 million VND per worker, alongside the lowest mean temperature at 21.2 °C. The Mekong Delta and Southeast both record mean temperatures of 28.1 °C.

Table 4 reports the main regression estimates. Model 1 provides direct empirical tests for H1a and H1b. For H1a (temperature), the coefficient is -0.0135 (SE = 0.0196, p = 0.492). For H1b (rainfall), the coefficient per 100 mm is 0.00108 (SE = 0.00091, p = 0.238). Neither coefficient

is statistically significant at the 10 percent level. The null results suggest that annual province-level climate averages may conceal nonlinear responses, extreme events, or localized adaptation. Therefore, H1a and H1b are not supported.

Model 2 adds interactions between the CE proxy and both climate variables to test H2. The temperature ×CE coefficient is -0.00085 (SE = 0.00144, $p = 0.555$), while the rainfall ×CE coefficient is 0.0000099 (SE = 0.000150, $p = 0.947$). Neither interaction is statistically significant, providing no evidence that the CE proxy uniformly moderates climate-productivity relationships nationally. H2 is not supported.Table 4: Two-way fixed-effects estimates.

Variable	M1: Baseline	M2: National moderation	M3: Key-region moderation
TEMP_c	-0.0135 (0.0196)	-0.0133 (0.0197)	-0.0107 (0.0204)
RAIN_c / 100	0.00108 (0.00091)	0.00102 (0.00089)	0.00108 (0.00092)
CE_c	-0.00046 (0.00037)	-0.00033 (0.00045)	-0.00011 (0.00049)
TEMP × CE	—	-0.00085 (0.00144)	-0.00125 (0.00114)
RAIN × CE / 100	—	-0.0000099 (0.000150)	—
TEMP × Key	—	—	-0.0503* (0.0270)
CE × Key	—	—	-0.00342* (0.00192)
TEMP × CE × Key	—	—	0.0113** (0.0049)
HDI_c	-0.0074 (0.0131)	-0.0073 (0.0131)	-0.0078 (0.0133)
ln Density_c	-1.2517* (0.7432)	-1.2618* (0.7482)	-0.9688 (0.7802)
Within R^2	0.0368	0.0374	0.0534
Province FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	312	312	312
*Notes: Province-clustered HC1 standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. In Model 1, the TEMP and RAIN coefficients correspond to the tests for H1a and H1b, respectively.*			

Regional Conditionality

Model 3 introduces key-region interactions. The temperature ×key-region coefficient is -0.0503 ($p = 0.064$), and the CE ×key-region coefficient is -0.00342 ($p = 0.076$). Most importantly for H3, the temperature ×CE ×key-region coefficient is positive and statistically significant: $\beta = 0.0113$, SE = 0.0049, $p = 0.022$. The positive three-way interaction means that the temperature-productivity slope changes with CE differently in key regions than in peripheral regions.

To interpret this interaction-of-interactions, we calculate the conditional marginal effect of temperature on $\ln(LP)$ at three illustrative CE levels: 50 percent, 80 percent, and 100 percent (

In peripheral regions, the marginal effect of temperature is statistically indistinguishable from zero at all three evaluated CE levels. In key regions, the estimated association is negative at CE = 50 percent, becomes statistically indistinguishable from zero at CE = 80 percent, and becomes positive at CE = 100 percent with marginal significance at the 10 percent level. This

pattern is exactly what a positive three-way interaction implies: higher CE is associated with a progressively less adverse temperature-productivity relationship in key regions. Therefore, H3 is supported for the temperature channel.Table 5 and Figure 1).

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Region type	CE (%)	Marginal effect	SE	p-value	95% CI
Peripheral	50	0.0248	0.0397	0.532	[-0.0530, 0.1030]
Peripheral	80	-0.0127	0.0203	0.531	[-0.0526, 0.0271]
Peripheral	100	-0.0378	0.0308	0.220	[-0.0980, 0.0225]
Key	50	-0.3460	0.1540	0.024	[-0.6480, -0.0448]
Key	80	-0.0451	0.0287	0.116	[-0.1010, 0.0111]
Key	100	0.1560	0.0918	0.090	[-0.0243, 0.3360]

Table 6
Hypothesis assessment based on the currently estimated models

Hypothesis	Empirical test	Evidence	Assessment
H1a	Temperature associated with ln(LP)	M1: TEMP p = 0.492	Not supported
H1b	Rainfall associated with ln(LP)	M1: RAIN p = 0.238	Not supported
H2	CE moderates nationally	M2: TEMP×CE p = 0.555; RAIN×CE p = 0.947	Not supported
H3	CE moderation differs by region	M3: TEMP×CE×Key β = 0.0113, p = 0.022	Supported (temperature channel)

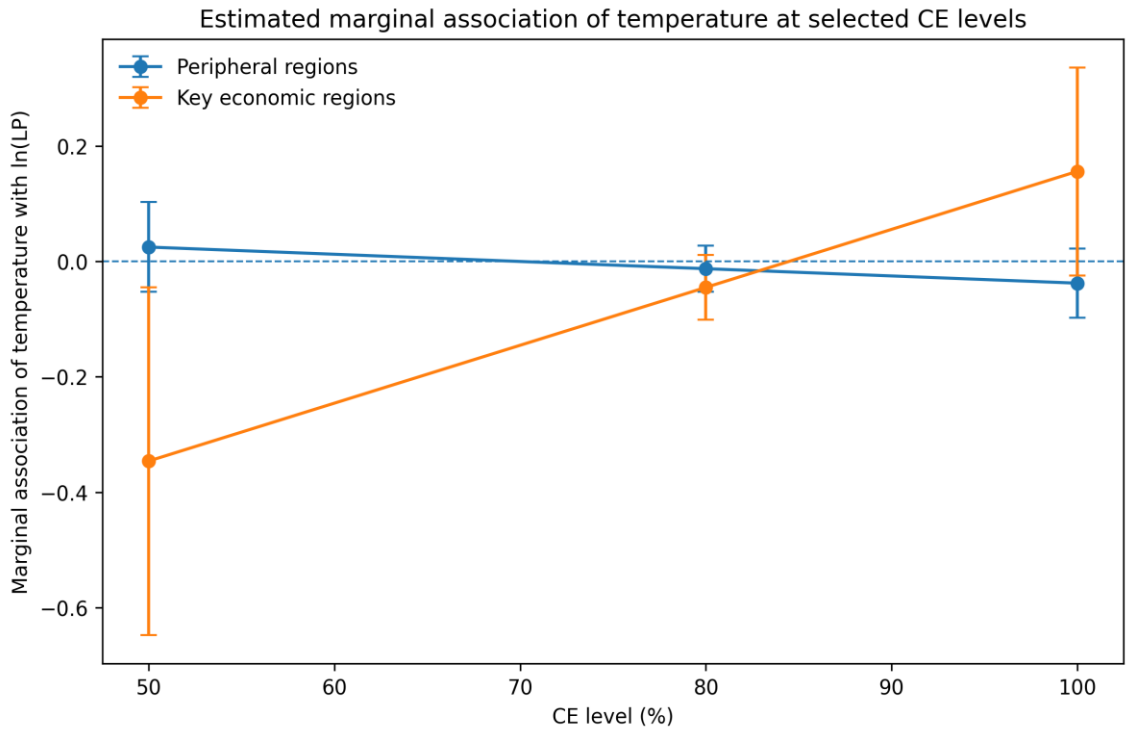


Figure 1: Conditional marginal effect of temperature on ln(LP) by CE level and region type.

Discussion

The null average association between annual province-level climate measures and labor productivity does not imply that climate is economically irrelevant. Several features of the research design can attenuate a pooled annual coefficient. First, temperature-productivity relationships can be nonlinear, so a single linear slope may compress positive and negative local responses into an average near zero (Burke et al., 2015). Second, annual averages can hide short heat waves, intense rainfall, droughts, and other events that matter for labor and infrastructure. Third, sector composition differs sharply across provinces: a temperature movement that affects outdoor agricultural work may have a smaller direct effect in climate-controlled manufacturing. Fourth, the province fixed-effects specification removes persistent cross-sectional climate differences, leaving only within-province deviations over a short five-year period.

Similarly, the absence of a nationwide protective effect from the circular economy (CE) does not render CE ineffective. If CE practices benefit industrialized regions but fail to take root in agricultural ones, aggregating the data nationally causes these distinct regional benefits and limitations to blend and become obscured. This very heterogeneity motivates the necessity of a disaggregated regional analysis. Previous literature suggests that CE can support production continuity, but this does not imply it automatically generates productivity benefits universally (Le et al., 2023).

The most significant finding of this study is that the protective role of CE is highly localized, functioning effectively only within key economic regions (the Southeast and the Red River Delta). In these areas, when CE practices are limited, heat significantly diminishes labor productivity. However, as circular and environmental management measures are scaled up, the negative impact of temperature is neutralized, and productivity even tends toward positive growth. Conversely, in peripheral regions, regardless of the level of CE adoption, weather conditions do not exhibit a clear influence on productivity.

This pattern suggests that key economic regions possess greater resilience, likely due to superior infrastructure, the ability to control work environments (e.g., air conditioning), technological capacity, and the organizational flexibility to reallocate production flows. Evidence from the Indian manufacturing sector—where climate control significantly mitigates heat-related productivity losses—provides a plausible mechanism explaining why industrialized environments respond differently (Somanathan et al., 2021). Nevertheless, the current dataset does not directly measure adaptive capacity or investments in cooling infrastructure. Consequently, these mechanisms remain plausible hypotheses that warrant further investigation in future research.

Conclusion

This study investigated whether weather conditions influence labor productivity in Vietnam, whether CE practices moderate this relationship, and whether such moderation varies between key economic regions and peripheral areas. The province-level data from 2020–2024 provides a clear, albeit conditional, answer. First, at the national level, there is insufficient evidence to conclude that temperature or rainfall significantly affects average labor productivity. Second, CE practices do not demonstrate a nationwide protective effect. However, the pivotal finding emerges at the regional level: in key economic regions, high levels of CE adoption significantly reverse the negative impact of temperature on productivity. This provides robust evidence that CE can act as a "climate shield," but only in areas with sufficient industrial and infrastructural foundations to leverage its benefits.

Conceptually, this study moves beyond treating CE merely as a direct input for productivity, placing it instead within a dynamic interaction with environmental factors. The evidence demonstrates that the protective role of CE is spatially uneven. Furthermore, we emphasize the importance of cautious interpretation: the CE measure represents only a specific dimension of environmental infrastructure, the study period is relatively short, and the observational design cannot definitively establish absolute causality.

For future research, the most valuable next step is to integrate more comprehensive CE measures with higher-frequency climate data (e.g., monthly or daily) to assess sector-specific labor productivity. More granular weather data could reveal vulnerability thresholds and

extreme events that annual averages inherently miss. Disaggregating productivity across agriculture, manufacturing, and services would clarify which sectors drive the observed regional differences. Finally, more direct measures of workplace climate control and infrastructural resilience are needed to verify whether this "climate shield" truly reflects actual adaptation mechanisms.

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