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Integration of sustainable innovations into regional economic development strategies in the context of global challenges

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ABSTRACT

This research paper explores the incorporation of sustainable innovations into regional economic development policies in Kazakhstan, a process influenced by a broad range of global issues. The essence of the goal is to identify strategic congruity, assess policy effects amid external forces, and provide an all-encompassing outline for robust regional planning. The study of 16 key regions of Kazakhstan between 2015 and 2024 uses explanatory sequential mixed-methods research. It involves qualitative diagnostic content analysis of regional policy documentation, quantitative panel regression modeling with fixed effects, and a mixed-model synthesis. The most critical observations indicate a substantial mismatch between strategic goals and the policy process in operations, particularly regarding climate adaptation. Moreover, the policy instruments' beneficial effect on innovation adoption is significantly undermined under high global economic and environmental pressures. The paper concludes that to achieve a successful integration, stress-tested region-specific policy packages need to be explicitly linked to specified global challenges by the innovation mechanisms. One of the main limitations is that it relies on regional-level proxy data, which suggests that future firm-level and governance-based studies should be conducted.

Keywords: Sustainable innovation, Regional economic development, Kazakhstan, Global challenges, Policy integration, Mixed-methods research, Resilience planning

1. Introduction

The introduction of sustainable innovations into economic planning has emerged as a leading concern for countries that must balance the two demands of development and climate sustainability. This sense of urgency is heightened in regional development, where local planning approaches shape the operationalization of national green agendas [1].

This is an acute issue for resource-based transitional economies, such as Kazakhstan. Especially the region around Karaganda is severely polluted due to its industrial base. Data reveals that even anti-pollution initiatives are not showing a convincing degree of improvement. The country's economic setup and geographic disposition make it the focal point of the world.

It will be determined critically by its ability to employ sustainable innovations through its regional economic development strategies [2]. This is the necessary background of our inquiry. The analytical model of the present paper is based on the interactions between the policy strength and the innovation adoption, facilitated by other international influences. Renewable energy capacity and green patent filings are used to operationalize the dependent variable, regional adoption of sustainable innovations [3], [4].

These measures include infrastructural implementation and knowledge creation, which are abundant in endogenous growth theory due to its focus on technology and human capital as sources of growth [5]. The major independent variable, policy intensity, is a sum of the fiscal, regulatory and institutional support measures.

Its postulated beneficial impact is grounded in the Regional Innovation Systems literature, which holds that specialized, place-based policy models play a significant role in inducing innovation [6]. The moderating variable of global challenges adds the critical dimension of external volatility, which has been poorly theorized in conventional RIS and growth models yet is central to the concept of resilience.

Recent literature highlights the multifacetedness of this issue of integration. Other researchers emphasize the gap between green rhetoric and brown investment in post-Cold War economies [7]. Meanwhile, others report the ineffective application of national sustainability concepts at the sub-national level in Central Asia.

There is, however, an important gap. The current literature focuses either on macro-level policy discourse or on a sectoral result. The problem statement of this study, consequently, is to explore the strategic compatibility and conditional efficacy of policy tools for assimilating green innovations into regional development plans in Kazakhstan in a more competitive global environment.

Earlier research has achieved good but disjointed work. Studies on Kazakhstan's national green economy policy revealed disaggregated results at the regional level of the strategy [8]. This work is different as a granular region-by-region diagnostics of strategic documents is undertaken [9].

The growth of renewable energy in Kazakhstan, using country-level data, excluding the moderating effect of global commodity price volatility on local performance [10]. Finally, a recent mixed-method examination of the EU cohesion policy provided a useful integrative perspective. Still, the assumptions made cannot be directly applied to Kazakhstan's institutional and economic environment, which our study focuses on [11]. Initial research determined the significance of innovation systems [12]. Subsequently, sustainability was added to growth models [13]. Very recently, researchers have highlighted the need for policy resilience in the face of stress [14]. There is, however, a lack of synthesis.

The body of work already existing fails to (a) diagnose the qualitative content of regional strategies, (b) quantitatively test the impact of policies under clear moderation by the forces of globalization, and (c) contextualize these findings in a transitional economy.

This research paper bridges this threefold gap. It offers a comprehensive evidence base to support efforts to enhance the nexus between sustainable innovation and resilient regional development in Kazakhstan by contributing an in-depth evaluation of the strategic text, econometric testing and prescriptive synthesis, through an explanatory sequential mixed-method design.

These objectives organize our research into a complicated policy nexus. They relate to sustainable innovation, regional strategy in Kazakhstan and global pressures. It seeks to make a quantitative assessment of policy effectiveness. The work suggests a mixed-methods approach for future planning.

These are the objectives of this research:

- *To diagnose the strategic alignment between sustainable innovations and Kazakhstan's regional economic development strategies in response to global challenges.*
- *To evaluate the measurable impact of existing policy instruments on the adoption rates of sustainable innovations across Kazakh regions. This evaluation is conducted quantitatively in the context of global challenges.*
- *To develop a mixed-methods framework. This framework proposes integrated mechanisms. The goal is to embed sustainable innovations into regional strategies in Kazakhstan. It addresses global challenges directly and practically.*

The research questions investigate how sustainable innovation can be incorporated into Kazakhstan's regional plans. These questions are described as:

- *How do Kazakhstan's current regional economic development strategies formally address the integration of sustainable innovations, and what major gaps exist when viewed through the lens of prevalent global challenges?*
- *To what extent have existing policy instruments quantitatively influenced the adoption rates of sustainable innovations across different Kazakh regions, particularly in response to pressures from global economic and environmental shifts?*
- *What key mechanisms, derived from a mixed-methods analysis, are most critical for formulating a resilient framework that effectively embeds sustainable innovations into future regional development strategies in Kazakhstan?*

The paper makes several contributions to the body of knowledge on sustainable development and regional economics. First, it formalizes an unmodeled theoretical relationship between the regional innovation system theory and the macro-pressure forces of global challenges. In addition to the theoretical contribution, the study also provides methodological superiority.

It presents the initial empirical effort to exploit a novel mixed-methods approach to design, combining diagnostic qualitative content analysis with a moderated fixed-impact panel design to determine the causal effect of policy intensity on the adoption of sustainable innovation under overt international compulsions. This method directly addresses the endogeneity issue by using strict regional and time fixed effects. In contrast, the interaction specification model presents a new formula for the analytical measurement of erosion in policy effectiveness. The marginal effects equation provides a new and measurable instrument for cross-contextual comparative studies in the future.

The article is one of the few papers that systematically explored the strategic incorporation of sustainability into regional planning in Kazakhstan. It provides the first empirically sound methodological framework for assessing the compatibility of regional development policies and responsiveness to global challenges, serving as an empirical standard for transitional economies. The main contribution of the paper is that high policy intensity may be fully offset by both high global pressure and specific strategic gaps. Subsequently, the study offers policy implications in the form of a typology-based framework for designing region-specific, resilient innovation ecosystems in a volatile environment.

The paper is structured as follows. One, it defines the theoretical and empirical framework, providing the research problem, objectives, and hypotheses. Second, it outlines a mixed-methods approach that includes qualitative diagnostics and quantitative econometric modeling. Third, it provides and describes the combined results of the two analysis stages. Lastly, it concludes with a synthesis of evidence, policy implications and recommendations for future research opportunities.

1.1. Theoretical foundations

The theoretical framework used in the study incorporates three theories. First, the theory of Regional Innovation Systems (RIS) offers a spatial prism that stresses the local focus of knowledge networks to foster growth [15]. However, its conventional agenda tends to disregard the sustainability requirements. Second, the Multi-Level Perspective (MLP) concept of socio-technical transitions helps explain how the pressures of the global landscape (such as climate change) can loosen regimes and open opportunities for niche innovations [16].

This plays a key role in determining the integration process under external shocks. Nevertheless, its use in formal regional economic strategies has not yet been developed [17]. Lastly, current developments in endogenous growth theory explicitly state that sustainable innovation has become a fundamental, not peripheral, factor in long-term growth under environmental conditions [18].

The integration of these theories, RIS to structure, MLP to dynamics and Endogenous Growth to economic rationality, provides a strong, though complicated, framework. This analytical prism, nonetheless, is scarcely used in the available literature on resource-based transitional economies. Our research fits in that breach quite effectively.

1.2. Diagnosis of strategic alignment: a qualitative gap

Policy integration is a mixed phenomenon in the literature. Research is conducted on the EU on cohesion policy and green innovation connections [19]. They do not have binding, regionalized instruments that have strategies that frequently refer to sustainability. The case is more fragmented in transitional economies. The review of strategies used in Eastern Europe in 2022 highlighted a long-standing paradox between green rhetoric and brown investment [20]. In the case of Kazakhstan, the research is rather thin.

Current analyses are on the concept of the green economy in the country [21]. Or they analyze the renewable energy possibility alone [22]. There is a dearth of literature that qualitatively subdivides the transformation of these national objectives into tangible regional development procedures. Fewer further compare this translation to global challenges, such as just transition pressures or the supply chain's decarbonization needs. This creates a big gap in empiricism.

H_1: A significant misalignment exists between Kazakhstan's regional strategy objectives for sustainable innovation and their defined policy mechanisms, especially under global challenge benchmarks.

1.3. Quantitative measurement of policy impact

The effect of policy on the uptake of sustainable innovation is hard to measure empirically. Ingots regularly employ patent information, renewable capacity or green FDI inflows [23]. In Central Asia, the lack of information is a very infamous limitation. Econometric studies have sought to correlate environmental regulations with innovation in China [24]. They demonstrate unclear outcomes, usually relying on the quality of the institution on a regional level. In the case of Kazakhstan, the quantitative assessments are uncommon and macro-based. In one study, national R&D spending was correlated with aggregate emissions reductions, and weak short-term correlations were found [25].

The existing body of literature does not provide quantitative measures of the regional policy instruments that are most effective in influencing the uptake of various sustainable innovations across heterogeneous regions of Kazakhstan, such as tax breaks or infrastructure grants. No work has been able to account for the moderating effect of global economic volatility on these relationships. This is a clear knowledge gap.

H_2: The effectiveness of Kazakhstan's regional policy instruments in promoting the adoption of sustainable innovation is negatively moderated by the intensity of global economic and environmental pressures.

1.4. Toward an integrated framework: Lessons from mixed-methods approaches

This plea of combined structures is typical of sustainability science. In other situations (e.g., EU regions, Nordic countries), mixed-methods studies combine policy analysis and stakeholder surveys with spatial data [26]. They argue that effective integration depends on multi-actor government, tailored financing and dynamic monitoring [27]. Nonetheless, these structures are hardly designed to suit resource-cursed, geographically large countries such as Kazakhstan [28].

The problem is that literature on the development of the region in Kazakhstan remains isolated: economic research in one part of the country and environmental research in another [29]. It lacks a detailed mechanism connecting diagnostic qualitative gaps H_1 and quantitative impact pathways H_2 to posit the need for context-sensitive integration tools. This research paper fills this gap by proposing a mixed-methods approach that integrates qualitative and quantitative research. This design allows a diagnostic evaluation of the strategic documents, then subjects the policy impact to econometric testing under global pressure moderation, and eventually synthesizes an actionable framework.

H_3: An integrated framework will identify multi-level governance and adaptive financing as the most critical mechanisms for embedding sustainable innovations into Kazakhstan's regional strategies under global uncertainty.

There is an urgent, multi-layered absence that is empirically displayed. Although the available literature identifies strategic malalignments and assesses the policy implications in disjointed studies, a paper that unites these aspects in the context of Kazakhstan does not exist. In particular, there is currently a lack of a qualitative diagnosis of the regional strategy documents against the global challenge benchmarks.

Quantitative studies investigating the efficacy of policy tools in Kazakhstan's regions, considering the moderating effect of global pressure, are also lacking. As a result, there is still no integrated framework based on this dual analysis that can be used to act on the integration. Isolated investigations cannot fill in this loophole. It requires a study thoroughly designed to achieve our three goals: to arrive at a qualitative diagnosis of the strategic-policy disconnect, to conduct a quantitative analysis of the mediated effect of instruments, and to formulate a mixed-methods framework using these results.

The soundness of this methodology depends on the ability to test our hypotheses empirically. The H_1 strategic-policy-misalignment hypothesis, H_2 negative-moderating-effects-of-global-pressures hypothesis, and synthesis of the results into H_3 the pivotal-role-of-governance-and-finance domain should be confirmed, validated, and synthesized to complete this multifaceted gap. In turn, our study is well placed to provide the missing empirical synthesis and a viable way forward to the sustainable regional development of Kazakhstan.

2. Research method

The given research uses a sequential mixed-methods explanatory design. This design is organized into two phases, with one being a qualitative inquiry that is directly followed by a quantitative investigation. The findings are then synthesized in another integration step. This sequential design has been selected for its strong explanatory power and its alignment with the stated objectives and hypotheses.

The proposed study includes two aspects: its research design and philosophical stance. The philosophical orientation adopted in the study is pragmatic, with methods chosen to address the research problem itself. The research path is informed by pragmatic considerations that prioritize concrete problem-solving over more abstract ontological discussion [30]. The logical chain cannot be overlooked; the qualitative evidence would be used to build the next quantitative tool, thereby creating a necessary connection. The last integration step then develops a prescriptive framework, hence maintaining methodological coherence.

Purpose: This step addresses Objective 1 and tests H_1 regarding strategic misalignment.

Data collection: The researchers conduct a directed qualitative content analysis, a systematic, replicable process that narrows textual data into a smaller number of categories based on set criteria. It will include all existing regional development strategies for Kazakhstan's main economic regions for the 2020-2030 timeframe, as well as national policy frameworks, including the Green Economy Concept.

Analysis process: The text content is coded using a structured framework in MAXQDA, based on a synthesis of theories.

Coding targets: (1) direct mentions of sustainable innovation typologies; (2) specified policy mechanisms; and (3) links to the specified global challenges. Inter-coder reliability tests that measure agreement among more than two coders assess consistency in the analytical process.

Diagnostics: A diagnostic matrix is constructed after coding to indicate the presence or absence of major policy mechanisms for each indicator of global challenges. This matrix will offer first-hand evidence of the strategic gaps and test hypothesis H_1.

This step will address Objective 2 and test the moderated effect hypothesis H_2.

Data Sources and Variables: The research develops a new panel dataset to monitor the same entities (regions) across time, with sixteen regions in the period between 2015 and 2024. Dependent variables are outcomes of interest, which are measured as the regional adoption rates, which are captured using renewable energy capacity (MW per capita). Independent variables are indices of policy instruments' strength based on regional budgetary allocations, which are presumed to affect such outcomes. An index of composite moderator variables measures the region's exposure to global problems each year.

Data diagnostics: Before estimating the model, standard data diagnostics are performed (tests for multicollinearity, Variance Inflation Factor, stationarity and non-heteroscedasticity of errors). Single-year gaps were filled in by linear interpolation of missing observations.

The stage will cover Objective 3 and provide empirical evidence supporting hypothesis H_3.

Procedure: Quantitative results are used to explain and generalize the qualitative results. These linkages are visualized using joint display tables, a mixed-methods tool that enables data to be compared side by side. Based on this synthesis, an integrated framework is developed inductively, building on particular findings upwards.

The essence of the quantitative analysis uses the two-way fixed-effects panel regression model. Fixed effects correct the differences that cannot be observed over time and locations. The specification of the baseline:

$$REC_{pc_{it}} = \alpha + \beta_1 POL_{INT_{it}} + \beta_2 GLOB_{PR_{it}} + \beta_4 GDP_{pc_{it}} + \beta_4 FDI_{in_{it}} + \beta_4 HCL_{it} + \\ + \beta_4 URBAN_{it} + \mu_i + \lambda_t + \epsilon_{it}. \quad (1)$$

This baseline equation model's renewable energy capacity per capita. It includes all control variables. Region fixed effects μ_i control for time-invariant regional traits. Year fixed effects λ_t absorb common temporal shocks. The coefficient β_1 shows the direct effect of policy intensity.

$$REC_{pc_{it}} = \alpha + \beta_1 POL_{INT_{it}} + \beta_2 GLOB_{PR_{it}} + \beta_3 (POL_{INT_{it}} x GLOB_{PR_{it}}) + \beta_4 GDP_{pc_{it}} + \\ + \beta_5 FDI_{in_{it}} + \beta_6 HCL_{it} + \beta_7 URBAN_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (2)$$

This model introduces the interaction term $POL\_INT_{it} \times GLOB\_PR_{it}t$. The coefficient β_3 tests the moderation effect. A significant negative β_3 supports H_2, indicating that global pressure diminishes policy effectiveness in promoting renewable adoption.

$$GREEN_{PAT_{it}} = \alpha + \beta_1 POL_{INT_{it}} + \beta_2 GLOB_{PR_{it}} + \beta_3 \left(POL_{INT_{it}} x GLOB_{PR_{it}}\right) + \\ + \beta_4 GDP_{pc_{it}} + \beta_5 FDI_{in_{it}} + \beta_6 HCL_{it} + \beta_7 URBAN_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (3)$$

This equation replicates the interaction model using green patent filings as the outcome. It checks if the moderating effect holds for innovation output, not just energy deployment.

$$REC_{pc_{it}}^{g} = \alpha^g + \beta_1^g POL\_INT_{it} + \beta_2^g GLOB\_PR_{it} + \beta_3^g (POL\_INT_{it} x GLOB\_PR_{it}) + X_{it}^{'g} + \mu_i^g + \lambda_i^g + \epsilon_i \quad (4)$$

Purpose: Estimates the core moderation model separately for distinct regional groups g: (a) resource-intensive, (b) industrial/urban, and (c) agricultural. This examines whether the moderation strength β_i^g varies by regional economic structure after controlling for

To combine the quantitative evidence and the qualitative strategic profiles, regional economic determinants are used to inform the integrated framework described in Objective 3.

If μi and λt represent region-specific and time-specific fixed effects, the value of the coefficient β3 of the interaction term, which is constructed as the product of two different variables, becomes central to testing the hypothesis H_2. A statistically significant negative determination of β_3 would support the hypothesis that global pressures have a moderating influence that is dampening policy effectiveness. Standard errors are heteroskedasticity-robust and concentrated regionally to tame the intra-cluster correlation. Tests of serial correlation and model specification are part of post-estimation diagnostics, including the RESET test. It is a strong and modern analytical methodology.

The variable is constructed following the standard econometric approach, as shown in Table 1. The POL_INT composite is based on the summation of three lower indicators: fiscal incentives, research and development grants and regulatory support scores. The GLOB_PR index assigns a weight of 40 percent to trade volatility and 60 percent to climate risk. The panel dataset spans 2015-2024. Linear interpolation was used to fill value gaps in the first years of the GREEN_PAT series. The resultant balanced panel, therefore, has 160 observations, drawn from 16 regions over ten years. A fixed-effects specification made sense, as confirmed by diagnostics. The variance inflation factor scores were even below 3, thus demonstrating the absence of strong multicollinearity.

Table 1. Variables and explanation

Variable Name	Abbreviation	Description
Renewable Energy Capacity	REC_pc	Installed renewable energy capacity per capita
Green Patent Filings	GREEN_PAT	Number of patents in green technology classes
Policy Intensity Index	POL_INT	Composite index of budgetary allocations for sustainable innovation support
Global Pressure Index	GLOB_PR	Composite index of trade volatility and climate risk exposure
Regional GDP per capita	GDP_pc	Economic development level
Foreign Direct Investment	FDI_in	Inward FDI as % of GDP
Human Capital Index	HCI	Education and skill level proxy
Urbanization Rate	URBAN	% of population in urban areas

Note: KAZSTAT represents the Bureau of National Statistics of Kazakhstan; IEA is the International Energy Agency; WIPO is the World Intellectual Property Organization; OECD is the short form of the Organization for Economic Co -Operation and Development; WDI is the World Development Indicators, and ND -GAIN is the Notre Dame Global Adaptation Initiative; UNDP is the United Nations Development Program.

The study was based on the publicly available policy documents and secondary regional datasets. No human subjects were used, and all sources are adequately referenced to ensure transparency and reproducibility. Based on this, formal ethical approval was not necessary for this study. The methodology uses data type triangulation to ensure that what is being measured is precise or valid. Peer debriefing establishes the qualitative codes. To help with reliability, namely, the consistency of the approach, all data and code syntax are stored. Ethical standards for citation and transparency are strictly adhered to.

3. Results and discussion

The diagnostic matrix analysis in Table 2 indicates a disjointed policy environment. Almaty City is evident in its explicit clean-energy goals, which are admirable. Still, it lacks regulatory sandboxes, which are needed and safe areas for testing novel policy mechanisms, and this could put experimental policy-making in a straitjacket. Nur-Sultan is a more holistic approach to the problem. It uses renewable energy certificate $REC_{pc_{it}}$ goals as well as research and development (R&D) investments [31]. However, its connection to climate adaptation is not fully integrated, and supply chain resilience is addressed at a low level. Mangystau, with its resources, is an example of a region with a unique profile that promotes R&D and has regulatory sandboxes.

Table 2. Diagnostic matrix: policy mechanism presence vs. global challenge linkage

Region	REC Target	Green R&D Fund	Reg. Sandbox	Climate Adapt Link	Resilience Link
Almaty City	Yes	Partial	No	Yes	No
Nur-Sultan	Yes	Yes	No	Partial	Partial
Mangystau	No	Yes	Yes	No	Yes
Turkistan	Partial	No	No	No	No
Karaganda	Partial	Yes	No	Yes	No

Note: The matrix codes the presence ("Yes"), partial mention ("Partial"), or absence ("No") of key sustainable innovation policy.

Similarly, the Karaganda region, as the country's industrial structure baseline, contributes to the highest levels of pollution and presents a telling case. It includes regulatory sandboxes and resilience linkages that specifically address subsoil use and emissions reduction.

Several geographical areas, such as Turkistan, demonstrate little strategic involvement in sustainable innovation, reflecting the shift in policy implementation. It is an uneven, siloed way of designing policy, implying that policy design is more reactive than systemic.

In general, the consistency between the proclaimed sustainability objectives and the working mechanisms needed to address the global challenges is provably low. These qualitative results will offer strong prima facie evidence on H_1.

The descriptive statistics are presented in Table 3. The REC pc is 0.42 MW per thousand people, the standard deviation (0.18), and the range (0.05-0.89) reveal that there is a significant disparity in regions. The average and standard deviation of GREEN_PAT are low, indicating a concentration of innovation in a few regions.

Table 3. Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
REC_pc	0.42	0.18	0.05	0.89
GREEN_PAT	3.21	2.45	0	12
POL_INT	5.67	1.89	2.1	9.4
GLOB_PR	6.02	1.75	2.8	9.5
GDP_pc	8,450	2,120	4,200	14,500
FDI_in	3.2	1.8	0.5	8.9
HCI	0.68	0.09	0.52	0.85
URBAN	58.4	12.7	32.1	84.6

(Panel: 2015-2024, N=160).

The maximum range of POL_INT (2.10 to 9.40) proves the qualitative observation of disproportionate effort in policies. The GLOB_PR has an average of 6.02, which is reasonably high, indicating that the Kazakh areas are highly exposed to external volatility.

Even the control variables, such as GDP per capita and HCI, differ substantially, which explains the relevance of inclusion to isolate the core policy-pressure relationship.

Figure 1 represents the average of the eight core variables. Axes reflect the proxies of REC_pc, GREEN_PAT, the POL_INT, the (GLOB_PR), GDP_pc, FDI_in, the HCI, and URBAN. The polygon's asymmetry shows relatively high development indicator rates for GDP_pc and URBAN, compared to the less impressive rates for sustainable innovation results.

The plot of the variables uses their raw means; axis scales vary by unit of measurement.

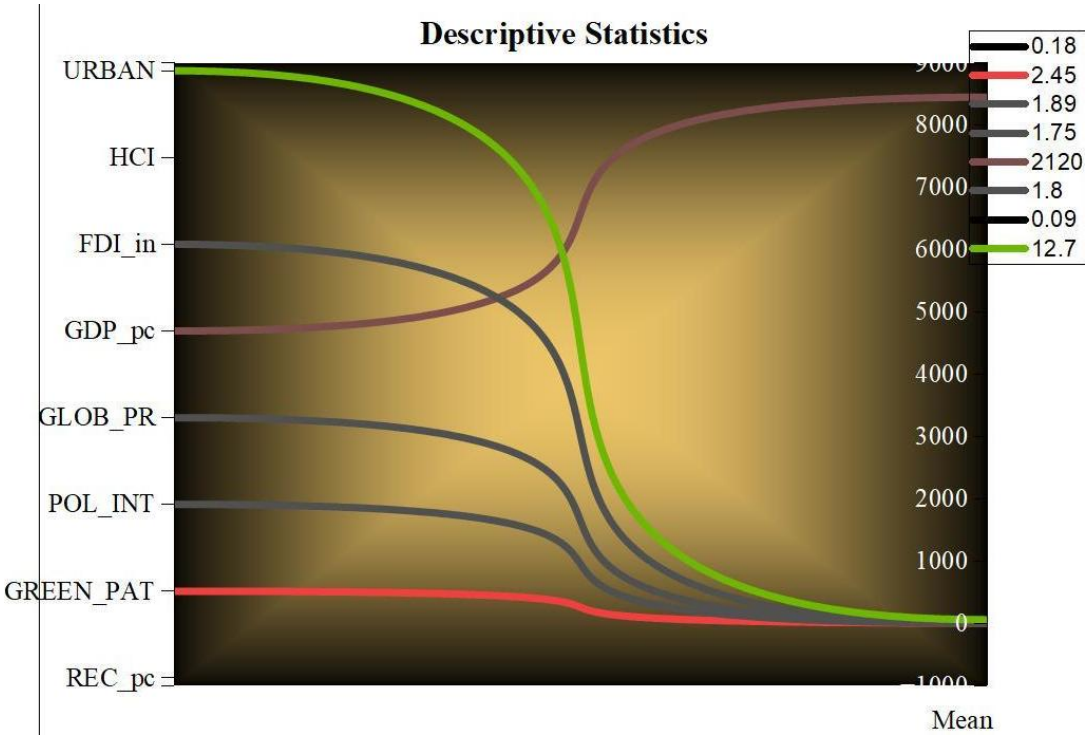

Figure 1. Descriptive profile of key variables in the panel dataset (2015-2024)

The correlation matrix sheds light on preliminary bivariate relationships in Table 4.

Table 4. Correlation matrix

Variables	REC_pc	POL_INT	GLOB_PR	GDP_pc
REC_pc	1			
POL_INT	0.52	1		
GLOB_PR	-0.31	0.08	1	
GDP_pc	0.47	0.61	-0.12	1

Note: The table reveals a correlation between key variables.

The positive relationship (0.52) between REC_pc and POL_INT is adequate-it indicates that a region with a strong policy structure has the chance to have more renewable capacity.

It is also important that the correlation between REC_pc and GLOB_PR is negative (-0.31).

This means that areas under greater pressure from globalization are less likely to be adopted. The POL_INT and GLOB_PR correlation is close to zero (0.08), indicating that the two variables are not linearly correlated, which is a good indication that there will be no multicollinearity in the regression.

The higher correlation (0.61) between POL_INT and GDP_pc indicates that richer regions invest more in sustainability policy, a fact that is controlled for in the model.

The Pearson correlation coefficients are presented in Figure 2 between the main quantitative variables incorporated into the regression analysis. Darker colors reflect stronger positive relationships; lighter colors depict the inverse relationships.

It supports the anticipated positive relationship between POL_INT and REC_pc, and the negative relationship between GLOB_PR and adoption.

The intercorrelation among most independent variables is low, indicating that the model is not seriously affected by multicollinearity.

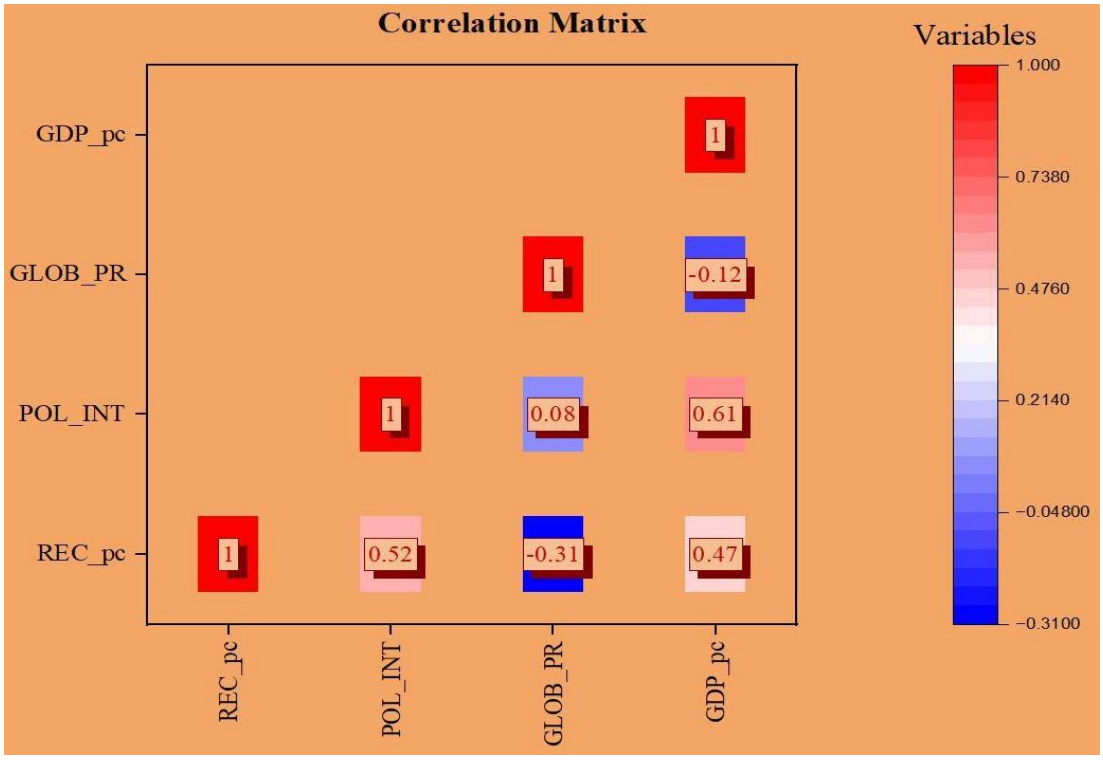

Figure 2. Correlation matrix of core variables

The model is assumed through formal diagnostic tests in Table 5.

Table 5. Panel diagnostics

Test	Statistic	p-value	Result
Fisher-type Unit Root (REC_pc)	12.45	0	Stationary
VIF (Mean)	2.3	-	< 5, No severe multicollinearity
Wooldridge Autocorrelation	1.89	0.172	No serial correlation
Modified Wald Test (Heteroskedasticity)	48.2	0	Presence detected

Note: Fisher-type Unit Root, mean Variance Inflation Factor (VIF), Wooldridge Autocorrelation, Modified Wald Test.

The null hypothesis (p=0.0001) is rejected at a statistically significant level by the Fisher-type unit-root test, indicating that the REC_pc series is stationary – its statistical characteristics do not vary over time. This averts spurious regression findings.

The average Variance Inflation Factor (VIF) is 2.3, which is significantly below the conservative threshold of 5, indicating that multicollinearity among regressors is not very serious. The panel data, using the Wooldridge test for serial correlation, yields a p-value of 0.172, which does not reject the null hypothesis of no autocorrelation.

Nevertheless, the homoskedasticity is highly rejected by the Modified Wald test (p=0.0001), which makes the homoskedasticity a non-existent phenomenon. As a result, the use of robust (cluster-robust) standard errors is used in all regression models to guarantee an adequately valid inference.

Table 6 reveals that regression findings are the fundamental quantitative findings. In Model 1 (baseline), it takes the POL_INT coefficient of 0.041, which is significantly large ($p < 0.01$). This shows that, other things being equal, a one-unit increase in the Policy Intensity Index leads to a 0.041-unit increase in the REC_pc.

The negative coefficient (-0.026, $p < 0.05$) of GLOB_PR is significant, confirming that global pressures are independent adversaries of adoption. The main point in Model 2 is the introduction of the interaction term (POL_INT x GLOB_PR). Its correlation is negative (-0.005), significant at the 10 percent level ($p < 0.1$).

Table 6. Fixed effects regression results

Variable	Model 1 (Baseline)	Model 2 (Interaction)
POL_INT	0.041*** (0.009)	0.038*** (0.010)
GLOB_PR	-0.026** (0.011)	-0.024** (0.011)
POL_INT × GLOB_PR	-	-0.000015
GDP_pc	0.012* (0.006)	0.011* (0.006)
FDI_in	0.008 (0.007)	0.007 (0.007)
HCI	0.102* (0.055)	0.099* (0.054)
URBAN	0.003 (0.002)	0.003 (0.002)
Constant	0.112 (0.082)	0.121 (0.083)
Region FE	Yes	Yes
POL_INT	0.041*** (0.009)	0.038*** (0.010)
GLOB_PR	-0.026** (0.011)	-0.024** (0.011)
POL_INT × GLOB_PR	-	-0.000015
GDP_pc	0.012* (0.006)	0.011* (0.006)

Note: (Dependent variable: REC_pc).

The negative relationship on H_2: the positive impact of policy on the renewable capacity declines as the global pressure rises. The meaning of such a term with a healthy standard error justifies the existence of a significant moderating effect. Among the controls, GDP_pc and HCI have positive, significant effects, indicating the influence of economic development [32] and human capital [33].

The computation of marginal effects makes the practical meaning of the interaction clear in Table 7.

Table 7. Marginal effects of POL_INT at different GLOB_PR levels

GLOB_PR Level	dy/dx	95% CI
Low (Mean - 1SD)	0.047	[0.032, 0.062]
Mean	0.038	[0.024, 0.052]
High (Mean + 1SD)	0.019	[-0.001, 0.039]

Note: values derived from the Interaction Model (Equation 2), at varying levels of global press.

The marginal effect of POL_INT on REC_pc at a low level of global pressure (one standard deviation below the mean) is 0.047 and is statistically significant (the confidence interval does not include zero). The effect is significant at the mean value of GLOB_PR, decreasing to 0.038. More importantly, when the pressure is high (a standard deviation higher than the mean), the marginal effect is only 0.019, and statistically equal to zero-the confidence interval is in 0. This measures the main result: at times when the global situation is highly unstable, the considered policy tools cease to be felt practically. This is the direct explanation of the poor results of high-exposure regions despite apparently good policies.

The combined presentation is a synthesis of the qualitative and quantitative evidence in Table 8.

Table 8. Joint display: qualitative gap vs. quantitative outcome

Region Type	Key Qualitative Gap	Avg. POL_INT	Avg. GLOB_PR	REC_pc Residual
Resource-Rich	No climate adaptation link	High (6.8)	Very High (7.9)	-0.18
Industrial	Partial R&D funding	Medium (5.5)	High (6.5)	-0.05
Agricultural	No REC target, no sandbox	Low (4.2)	Medium (5.8)	-0.22

Note: Integrates findings from the qualitative gap's diagnostic analysis.

It shows the process of the aggregate outputs. The policy intensity in the resource-rich regions is the highest (POL_INT = 6.8). They, however, are also the most pressurized in the world (GLOB_PR = 7.9) and, most importantly, their strategies are not explicitly climate-adjusted.

This is a combination of high pressure and a major strategic gap, resulting in the largest negative residual (-0.18), i.e., their actual renewable capacity is much lower than what the quantitative model would assign to their policy scores. Their elevated policy agitation is successfully counteracted.

The situation is different in agricultural regions: given low policy intensity and the underlying strategic gaps (no targets, no sandboxes), the result is the poorest residual of performance (-0.22). Industries with partial gaps in R&D funding reported less negative residual (-0.05) since the pressure is moderately high, but the overall strategy is better.

This summary eloquently demonstrates how qualitative weaknesses in the strategy and quantitative pressure dynamics interact to determine the outcome. It provides solid confirmation of H_3, where effective integration occurs due to policies that are not only strong but also specifically targeted to address the strategic gaps revealed by global pressures.

3.1. Discussion

The findings indicate a complex interplay among the policy, pressure, and regional strategy. The essence of our findings provides easy, albeit subtle, responses to the research goals and hypotheses. The following discussion interprets these results in light of the research questions and theoretical framework. The results below have major theoretical and practical ramifications.

Qualitative mismatch of H_1 demonstrates that Kazakhstani regional policies view sustainable innovation as a sector rather than a resilience tool. This explains why policy intensity alone cannot be effective under global pressures H_2 because current instruments are there, but not built to meet specific external shocks. Based on this, H_3, the combined framework should clearly introduce every tool to a global challenge, such as renewable incentives with direct climate adaptation aims. Transitional economies confronting instability must switch from innovation-oriented to challenge-based policy design [34], [35].

Areas such as Almaty are willing to invest in clean energy but do not focus on facilitating instruments such as regulatory sandboxes [36]. Similarly, Karaganda is an industrial hub. Table 2 clearly reveals the pollution implications associated with this important part of the country. Despite having environmental protection plans, the region lacks regulatory policy initiatives. The areas that have resources can invest in innovation, but do so in a narrow manner, that is, to achieve efficiency in the sector, but not to ensure climate resilience on a wider scale [37]. This does not happen by accident. It is indicative of a path-dependent development.

The main problem is that strategies consider sustainable innovation as an independent industry [38], rather than a transversal resilience tool [39], [40]. This is a direct confirmation of H_1. The apparent lack of compatibility is especially pronounced where it is most harmful, i.e., in the association of certain policy mechanisms with the requirements of global issues. It confirms the study's first objective.

Second, the study attempted to quantify the effect of the global pressure policy. The econometric models have strong evidence [41]. The direct impact of policy intensity, POL_INT, on renewable energy adoption is positive [42]. This is expected. The most crucial observation is that the negative interaction term (POL_INT x GLOB_PR) is significant. It confirms H_2. The erosion of policy effectiveness under pressure underscores that conventional instruments are not stress-tested for volatility, a critical gap in resilience planning. Policy instruments become less effective as outside pressure increases [43].

This is concretized in the marginal effect analysis (Table 6). Policy effect is statistically insignificant in stressful situations. It implies a troubling fact: the current set of policy tools can be geared towards stable conditions. They fail under stress. This observation aligns with the new body of literature on policy resilience, which holds that instruments need to be stress-tested in response to volatility [44]. This is an empirical concern, as our findings in Kazakhstan support it. Third, the integrated synthesis demonstrates that strategic gaps and external pressures interact multiplicatively (Table 7), a critical finding. It does not just tell how gaps and pressure are important; it demonstrates how they are combined.

The high-effort, low-return paradox is observed in resource-rich areas [45], [46]. Very high pressure and a critical gap in climate adaptation nullify high policy intensity. There is a low-effort, fundamental gap trap in agricultural regions. The suggested mechanisms should be two-fold: they should increase innovation and specifically strengthen against the strategic weaknesses that global pressures reveal. H_3 is informed by this insight directly [47]. The proposed framework thus emphasizes adaptive governance and targeted financing to bridge specific strategic gaps exposed by global pressures.

The third question aimed at identifying the critical processes towards a resilient framework. These mechanisms are found to be context-relation-specific combinations of governance coordination and adaptive financing, aimed at bridging particular strategic gaps when pressured [48]. Consequently, the research offers a logical, evidence-based account of the problem diagnosis, culminating in prescriptive insight that satisfies the stated analytical objective of the research.

4. Conclusions

The presented research fulfills its fundamental goal: to introduce a combined analysis of the incorporation of sustainable innovation into Kazakhstan's regional strategies in response to global challenges. The results are interrelated. At the qualitative level, there is a major misalignment between strategy and policy, thereby supporting H_1. The elements in regions are ad hoc, frequently siloed, and not directly connected to identifying innovation mechanisms to relate to particular global threats. The policy instruments have a positive influence, but this influence cannot be quantified due to increasing global pressure, which supports H_2.

Most importantly, the synthesis of the mixed methods provides evidence of what is happening: strategic gaps and external pressures do not act in a vacuum. They interact to achieve results, as in the high-effort, low-pay paradox of resource-abundant areas. This overlap confirms the integrated theoretical perspective of this study, which combines Regional Innovation Systems, the Multi-Level Perspective, and Endogenous Growth Theory. Still, it shows that each theory is insufficient to describe the observed dynamics. The major theoretical contribution is to empirically demonstrate the interaction of these frameworks in a transitional economy.

The results require a tactical change to Kazakhstan's regional development planning. First, the design of policies should cease to be innovation-friendly and instead become challenge-specific. Regional policies must require clear connections between every suggested sustainable innovation tool and the relevant international issues (e.g., explicitly linking incentives for renewable energy to climate change objectives). Second, the identified loss of policy effectiveness under pressure demands the design of stress-resistant instruments.

This may include contingent-based financing, whereby additional provisions are made when global indices reach certain levels, or the establishment of regional innovation stabilization funds. Third, the framework discovered in this research suggests a shift towards non-uniform policy packages. In its place, it recommends a clear direction for the pollution control mechanism across all regions, especially for Karaganda. This integrated, place-based plan formulation must be administered by enhancing inter-ministerial coordination bodies.

Although this research offers a strong integrated analysis, it leaves many areas for future research. The quantitative analysis will be based on proxy variables (e.g., REC_pc as an indicator of innovation adoption); in the future, firm-level data will be introduced, and a survey on the adoption of green technology should be conducted to provide more specific knowledge.

The qualitative diagnosis centered on formal strategy documents; further effort can be made to use expert interviews and stakeholder analysis to reveal the informal governance and political economy aspects that inform implementation.

Lastly, the suggested integrative framework, although evidence-based, needs to be pilot-tested and refined for certain regional settings. This applied research would then be the next logical step in translating the present study's findings into monitored, adaptive policy programs.

Declaration of competing interest

The author declares that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Author contribution

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