“Regional budget allocation and renewable energy development in Ukraine: Implications for public expenditure management”

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REGIONAL BUDGET ALLOCATION AND RENEWABLE ENERGY DEVELOPMENT IN UKRAINE: IMPLICATIONS FOR PUBLIC EXPENDITURE MANAGEMENT

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Abstract

Efficient regional public expenditure is critical for aligning decentralized economic development with renewable energy, energy security, and reconstruction priorities. This study aims to examine whether expenditure across selected regional budget programs is systematically associated with renewable energy development in Ukraine and whether these relationships remain robust across alternative temporal, distributional, and nonlinear specifications. The analysis uses a balanced panel of 25 Ukrainian regions for 2018–2021 and applies program-specific two-way fixed-effects models with CR2 standard errors, Benjamini–Hochberg adjustments, lagged and same-sample specifications, wild-cluster-bootstrap inference, presence–intensity decomposition, alternative transformations, winsorization, and formal quadratic tests. In the baseline capacity growth models, expenditure from local target funds ($\beta = 0.9152$, $p = 0.0192$) and electric transport measures ($\beta = 0.1499$, $p = 0.0126$) showed nominally positive associations, but neither survived multiplicity adjustment ($q = 0.1054$). Wild-cluster-bootstrap inference did not confirm these estimates, producing p-values of 0.4871 and 0.3597, respectively, while both programs were observed in only five region–year cases across two regions. No program coefficient was significant at the 5% level in the electricity production models; SME support produced the strongest negative estimate ($\beta = -0.2152$, $p = 0.0580$, $q = 0.5995$), whereas installed renewable capacity remained positively associated with production ($\beta = 0.4108$–0.4803, $p = 0.0041$–0.0220). Lagged, presence–intensity, transformed, winsorized, and nonlinear specifications provided no multiplicity-robust evidence, with formal U-test q-values no lower than 0.5789.

Keywords energy transition, fiscal decentralization, subnational governance, program-level expenditure, installed renewable capacity, renewable electricity production, panel data

JEL Classification H72, Q42, Q48, R58

INTRODUCTION

The transition toward renewable energy has become a major economic and public policy priority, driven by climate commitments, energy security concerns, and sustainable growth objectives. International organizations emphasize that public investment can accelerate this transition by financing infrastructure, supporting innovation, reducing investment barriers, and encouraging private sector participation. However, its effectiveness depends on expenditure composition, targeting, coordination, and implementation quality, as poorly designed spending may generate limited outcomes (Sakrak et al., 2022; World Bank et al., 2023; European Commission, 2024).

Ukraine provides a relevant setting for examining these relationships. Before the full-scale war, renewable energy capacity expanded through national policies, private investment, and decentralized regional initiatives. Still, development remained uneven due to regional differences in fiscal capacity, infrastructure, economic conditions, and institutional capacity. Regional authorities influence this process through programs related to economic development, environmental protection, energy saving, transport, entrepreneurship, and infrastructure. The European Commission and the World Bank, therefore, stress the importance of efficient public expenditure and stronger subnational governance in decentralized energy transition systems (European Commission, 2024; World Bank et al., 2023).

This study focuses on 2018–2021, representing the last period for which the required regional fiscal and renewable-energy indicators are publicly available on a sufficiently consistent and comparable basis across all territorial units. Extending the panel beyond 2021 is constrained by wartime restrictions on data disclosure, disruptions to statistical reporting, and changes in territorial and institutional conditions following the full-scale Russian invasion. Rather than diminishing the relevance of the analysis, this makes the 2018–2021 period an important pre-war benchmark against which the post-war effectiveness of regional expenditure management can later be assessed once comparable data become available. The selected regional budget programs also retain policy relevance because the corresponding expenditure categories remain embedded in Ukraine's budgetary and regulatory framework and continue to be implemented by regional and local authorities. Their pre-war performance therefore provides evidence on how existing public-spending instruments were associated with renewable energy development before the wartime shock and may help inform their subsequent redesign and prioritization during reconstruction. This is particularly important because recovery policy will require public expenditure to support energy security, infrastructure resilience, and decarbonization simultaneously, while improving the targeting, coordination, and efficiency of scarce fiscal resources (IMF, 2023; World Bank et al., 2023). Accordingly, this study examines whether selected regional budget-program expenditures are systematically associated with annual renewable-capacity growth and renewable electricity production, and whether these associations remain robust across alternative temporal, distributional, and nonlinear specifications.

1. LITERATURE REVIEW

Public expenditure is increasingly viewed as an important component of the energy transition because it can support renewable energy deployment, environmental protection, public health, and broader socio-economic development. Investments in cleaner energy systems may reduce air pollution and associated health risks while also contributing to more sustainable patterns of production and consumption (Badreddine & Larbi Cherif, 2024; Trinh, 2025). The effects of public investment are nevertheless multidimensional, as changes in government spending may influence income, energy demand, and carbon emissions simultaneously rather than affecting renewable energy capacity alone (Binh & Nguyen, 2023). This complexity has encouraged the development of sustainable finance instruments and policy frameworks intended to align public and private capital with long-term decarbonization objectives (Krause et al., 2024; Streimikiene et al., 2024). Renewable energy expansion is also increasingly linked to energy security and resilience, particularly in Europe, where geopolitical risks have heightened the strategic importance of diversified, domestically available energy sources (Kuzior et al., 2025; Vasylieva et al., 2025a; Zábojník & Branch, 2025).

A central issue in this literature is not simply the volume of public spending but its composition, targeting, and institutional implementation. Government expenditure can support renewable energy investment and economic development, though its effects vary by program structure, administrative efficiency, and the broader fiscal environment (Fernandes et al., 2025; Okunevičiūtė Neverauskienė et al., 2025). Specific instruments, including feed-in tariffs, power purchase agreements, and fiscal incentives, may influence both investment decisions and renewable electricity generation by altering expected returns and reducing financing risks (Lyeonov et al., 2025). The effectiveness of such measures also depends on how responsibilities and financial resources are

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distributed across levels of government, since decentralized fiscal systems can either improve policy responsiveness or create coordination and implementation gaps (Lyeonov et al., 2025b; Filipova et al., 2025). Governance quality, public financial management, and institutional reform, therefore, shape the extent to which budget allocations are converted into completed projects and measurable energy outcomes (Ntuli et al., 2025; Hedau & Malla, 2024).

The regional dimension is particularly important because renewable energy projects are implemented across territories that differ in infrastructure, economic capacity, resource endowments, and administrative capacity. Decentralization and the localization of energy systems can create more flexible policy responses and allow investment priorities to be adapted to local needs (Belgibayeva et al., 2025). Evidence on biomass and other territorially embedded energy initiatives also shows that renewable investment can produce region-specific economic effects through local supply chains, employment, and demand (Nakamura et al., 2012). However, regional outcomes depend not only on available resources but also on the commitment and policy behavior of local authorities, which often act as intermediaries between national strategies and project-level implementation (Rakowska & Ozimek, 2021). Public-private partnerships and collaborative governance can strengthen this process by combining public objectives with private financing, technical expertise, and implementation capacity (Kuzior et al., 2023; Oe et al., 2025; Topazly et al., 2025).

Complementary investments and institutional capabilities also condition regional renewable energy development. Smart grids, microgrids, digital monitoring, and data-driven energy management systems can improve system efficiency and facilitate the integration of distributed renewable generation (Gualandri & Kuzior, 2023; Wojciechowski et al., 2025; Zhu et al., 2026). Technological modernization alone, however, is insufficient when infrastructure projects are weakly coordinated or when public institutions lack the capacity to plan, procure, and monitor investments effectively (Tomczyk et al., 2025). Social spending, behavioral interventions, and communication strategies may additionally influence public acceptance and participation in sustainability policies (Yurchyk et al., 2024; Rouillé, 2024; Bappayo & Adamu, 2025). At the same time, innovation capacity and entrepreneurial orientation determine how effectively firms and regions respond to public incentives and convert them into new renewable energy projects (Fitriningrum et al., 2025).

These relationships are particularly relevant in Ukraine, where pronounced regional heterogeneity, institutional constraints, and uneven economic development have shaped both subnational fiscal capacity and renewable energy deployment. The shadow economy and weaknesses in formal institutions may reduce available fiscal resources and complicate the implementation of development programs (Dobrovolska et al., 2024). Broader structural and economic pressures have also affected investment conditions and the ability of public authorities to sustain long-term policy priorities (Pecheniuk et al., 2024). The full-scale war has further intensified these challenges by disrupting infrastructure, investment flows, and macroeconomic stability, while simultaneously increasing the strategic importance of energy resilience and decentralized generation (Vasylieva et al., 2025b). The choice of the 2018–2021 period is therefore both data-driven and analytically justified, as it represents the last interval for which regional fiscal and renewable-energy indicators are publicly available on a sufficiently complete and comparable basis before wartime restrictions, territorial disruptions, and changes in statistical reporting substantially reduced cross-regional comparability. At the same time, the analyzed budget-program categories remain embedded in Ukraine's public-finance framework and continue to be implemented, making evidence on their prewar performance relevant for the future evaluation, prioritization, and redesign of these instruments during reconstruction, once comparable post-war data become available.

Previous research indicates that public spending can support renewable energy development, but its contribution depends on expenditure composition, governance quality, territorial conditions, and implementation capacity. Existing studies mainly focus on national policies, individual fiscal instruments, or cross-country comparisons, while paying less attention to differences among regional budget program categories and to whether program-level associations remain stable across alternative specifications. This study addresses that gap by examining how selected regional expenditures relate to renewable-capacity growth and renewable electricity production in Ukraine, including whether the observed relationships are robust to temporal, distributional, and nonlinear tests. The examined expenditure categories differ in their expected proximity to renewable energy outcomes. Co-financing, energy saving, environmental protection, and selected capital investment programs may operate through relatively direct infrastructure or project-support channels. SME support, electric transport, and broader economic development programs are more likely to have indirect or complementary relationships that depend on program composition, recipient activities, grid conditions, and implementation quality. Because the official categories combine heterogeneous activities, the analysis does not impose category-specific directional hypotheses. Instead, it treats the program-level tests as exploratory, with false-discovery-rate control applied to each outcome family.

This study aims to examine, from a regional public management perspective, whether the allocation of public expenditure across selected budget program categories is systematically associated with renewable energy development in Ukraine, as reflected in annual installed capacity growth and renewable electricity production, and whether these associations remain robust across alternative temporal, distributional, and nonlinear specifications.

2. METHOD

This study applies a quantitative panel-data approach to examine the relationship between regional public expenditure and renewable energy development in Ukraine. The balanced panel covers 25 Ukrainian territorial units (24 oblasts and Kyiv City) over 2018–2021, resulting in 100 region–year observations. The complete list of territorial units and the treatment of territories with incomplete official reporting coverage are presented in Appendix A, Table A6. Gross regional product and capital investment in environmental protection were obtained from the State Statistics Service of Ukraine (State Statistics Service of Ukraine, n.d.). Regional budget expenditure by functional program category was collected from the Ministry of Finance of Ukraine's "Budget for Citizens" portal (Ministry of Finance of Ukraine, n.d.). Data on renewable electricity production and installed renewable energy capacity were obtained from the Energy Map database maintained by DiXi Group (DiXi Group, n.d.).

The cleaned analytical dataset and supporting documentation for data construction are publicly available on Zenodo (Lyeonov et al., 2026). The repository records the source indicators, original measurement units, regional budget-program classifications, territorial coverage, and treatment of zero and missing observations. It also documents the conversion of monetary variables into constant 2021 UAH, the filters and aggregation rules applied to the Energy Map data, the correction of repeated monthly cumulative records in the installed-capacity series, and the within-region construction of one-year-lagged variables. The deposited materials provide the data required to reproduce the descriptive statistics and principal econometric estimates reported in the study.

Two indicators were used to represent renewable energy development. The first is annual growth in installed renewable energy capacity, calculated as the first difference in the natural logarithm of installed capacity. Because this transformation requires the previous year's value, the capacity growth sample covers 2019–2021 and includes 75 observations. The second dependent variable is renewable electricity production, transformed as $\ln(1+x)$ to accommodate zero values and reduce distributional skewness; these models use the full sample of 100 observations. The production specifications additionally control for contemporaneous installed renewable capacity, meaning that program coefficients represent associations with electricity generation conditional on the existing scale of renewable assets rather than total effects operating through capacity expansion.

The principal explanatory variables comprise 11 regional budget program categories related to economic development, environmental protection, energy saving, entrepreneurship, transport, and regional investment. Monetary variables were

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converted into constant 2021 UAH and expressed in millions before transformation. Because expenditure distributions contained both zero values and substantial right-skewness, program expenditure and environmental investment were transformed using ln(1+x). Gross regional product was also expressed in real terms and logarithmically transformed. Each program category was entered into a separate model to avoid over-parameterization and unstable estimates in the relatively small regional panel.

The baseline specification is expressed as:

$$Y_{it} = \beta_1 Programme_{kit} + \beta_2 \ln\left(GRP_{it}\right) + \beta_3 \ln\left(1 + EnvInv_{it}\right) + \mu_i + \lambda_t + \varepsilon_{it}, \quad (1)$$

where Y_{it} denotes renewable-capacity growth or logged renewable electricity production in region i and year t; Programmekit is logged real expenditure under program k; μ_i represents region fixed effects; and λ_t represents year fixed effects. For electricity production, logged installed renewable capacity was included as an additional covariate. Region fixed effects control for time-invariant territorial characteristics, while year fixed effects absorb common macroeconomic, regulatory, and energy market shocks. The coefficients, therefore, identify conditional within-region associations rather than causal program effects.

Statistical inference was based on CR2 cluster-robust covariance matrices, clustered by region, and on Satterthwaite-adjusted degrees of freedom. This approach was selected because the panel contains only 25 regional clusters and some expenditure categories exhibit limited within-region variation. Since eleven program coefficients were assessed separately for each outcome, Benjamini–Hochberg adjustments were applied within each outcome-specific family to control the false discovery rate. The analysis also included one-year-lagged expenditure models, contemporaneous models estimated on the same restricted sample, and wild-cluster bootstrap inference to assess the sensitivity of the findings to small-cluster asymptotics. Additional robustness checks used the inverse hyperbolic sine transformation, winsorized expenditure measures, and alternative program-presence and spending-intensity specifications. All lagged variables were generated after sorting the panel by territorial unit and year and were calculated strictly within each territorial unit, preventing values from being carried across regional boundaries.

To separate program activation from expenditure intensity without estimating unstable decompositions for extremely sparse categories, eligibility for the presence–intensity analysis was determined through a common coverage screen applied to the full 2018–2021 panel. A program was retained only when zero expenditure accounted for at least 20% of observations, the category contained at least 20 positive observations, positive expenditure occurred in at least 10 regions, and at least five regions switched between zero and positive expenditure over time. The screen was applied before estimating outcome-specific models, and the same eligible program set was used for both dependent variables. Five categories met these requirements: contributions to authorized capital, energy saving measures, SME support, natural resource protection, and other environmental activities. All five also retained sufficient positive observations and regional variation in the 2019–2021 capacity growth sample. For each eligible program, a presence indicator was combined with logged positive expenditure, centered on the mean of positive observations. The presence coefficient, therefore, represents the estimated difference between zero expenditure and program operation at the reference positive spending level, while the intensity coefficient captures variation across positive expenditure observations.

Nonlinear specifications were estimated only for programs with sufficiently broad expenditure coverage and variation. Eligibility required at least 60 positive region–year observations, positive expenditure in at least 18 regions, at least 20 distinct positive expenditure values, and at least eight regions with three or more distinct expenditure levels during 2018–2021. Seven categories satisfied these criteria: co-financing of investment projects, environmental measures under territorial development programs, contributions to authorized capital, other economic activity measures, energy saving measures, SME support, and natural resource protection. The same set was used for both outcomes to avoid outcome-dependent selection.

For each eligible program, the nonlinear model included centered logged expenditure and its squared term. Formal U-shape and inverted-U-shape tests were conducted over the 5th–95th percentile interval of the transformed expenditure variable. Evidence of a nonlinear relationship required appropriately signed endpoint slopes, a statistically significant formal U-test, a turning point within the tested interval, and adequate empirical support around that point. Support was considered sufficient only when at least 10 observations and five regions were located on each side of the estimated turning point. Where no numerical U-test p-value was returned because the endpoint slopes did not exhibit the required reversal, $p = 1$ was assigned solely for the Benjamini–Hochberg adjustment so that all seven screened hypotheses remained in the same outcome-specific testing family. Extrapolated turning points outside the tested interval were not substantively interpreted.

3. RESULTS

3.1. Descriptive statistics

The descriptive statistics in Table A1 cover a balanced panel of 25 Ukrainian regions over 2018–2021, yielding 100 region–year observations. Public expenditures vary substantially across both categories and regions. The highest average allocations were recorded for contributions to authorized capital, other economic activities, electric transport, and project co-financing. However, medians were far lower than means, and standard deviations often exceeded average values, indicating that a small number of exceptionally large allocations strongly influenced the distributions.

Most expenditure variables are highly right-skewed and heavy-tailed. Skewness ranged from 3.06 to 6.65, whilst excess kurtosis exceeded 40 for several categories. Local target funds, electric transport, and other environmental activities had median values of zero, showing that these programs were absent in at least half of the region–year observations. Accordingly, these variables reflect both program participation and expenditure intensity, which should be considered when interpreting the regression results.

Renewable energy indicators also differed markedly across regions. Average renewable electricity generation was 300.52 million kWh, compared with a median of 89.68 million kWh and a maximum of 2,079.96 million kWh. Following the revised data aggregation, average installed renewable capacity was 246.83 MW, with a median of 105.16 MW and a maximum of 1,167.40 MW. Strong regional disparities were also observed in gross regional product and environmental investment.

The data are characterized by substantial heterogeneity, numerous zero observations, and influential upper-tail values. These features justify zero-compatible transformations, including the natural logarithm of 1 + x and the inverse hyperbolic sine transformation, together with winsorized-spending sensitivity checks. Sparse expenditure categories are also examined using specifications that distinguish between program presence and positive spending intensity. The descriptive statistics alone, however, do not confirm U-shaped or inverted-U-shaped relationships, which require formal testing of quadratic terms, endpoint slopes, and turning points.

Table A2 reports substantial differences in the territorial diffusion of regional expenditure categories. Co-financing of investment projects, other economic activity measures, and environmental measures under territorial development programs were the most widely used, with positive spending in 89–93 observations and 24 regions. By contrast, electric transport measures and expenditures from local target funds were recorded in only 5 observations and 2 regions, despite their presence in all 4 years. Their very high zero shares of 95% indicate that these variables are driven by a small number of territorially concentrated allocations and should therefore be interpreted cautiously. Other environmental activities and environmental measures financed from target funds also exhibit substantial zero inflation, with 51% and 49% shares, respectively. Before calculating the program coverage indicators, all monetary expenditure values were adjusted for annual inflation and converted into constant 2021 UAH. These patterns suggest that the subsequent analysis should distinguish between program presence and expenditure intensity, whilst quadratic specifications should be avoided for expenditure categories with extremely limited regional coverage.

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The correlation results in Tables A3 and A4 reveal important differences between pooled cross-regional relationships and within-region variation over time. In the pooled Spearman matrix, most expenditure categories are weakly or moderately correlated. However, a strong association is observed between local target-fund expenditure and electric transport spending ($\rho = 0.806$), reflecting their highly concentrated and overlapping territorial coverage. Real GRP is also strongly correlated with environmental investment ($\rho = 0.771$), whilst renewable electricity production and installed capacity are closely related ($\rho = 0.921$). After removing time-invariant regional differences, most expenditure correlations decline considerably and remain below 0.45 in absolute value. In particular, the correlation between real GRP and environmental investment falls to 0.022, indicating that their strong pooled relationship is mainly attributable to persistent differences in regional economic scale. However, the within-region correlation between renewable electricity production and installed capacity remains high at 0.822, supporting the inclusion of installed capacity in the production equation but also requiring subsequent multicollinearity diagnostics. Overall, the results favor parsimonious fixed-effects specifications over models that include all expenditure categories simultaneously; the correlations remain descriptive and do not imply causal relationships.

The multicollinearity diagnostics reported in Table A5 indicate that the pooled specifications are affected by severe collinearity between electric transport expenditure and local target-fund expenditure, with VIF values exceeding 43 and tolerances approaching 0.02 in both outcome models. Real GRP also exhibits moderately high pooled VIF values of 6.38–6.64, while environmental investment and several environmental expenditure categories show moderate collinearity. However, these problems largely disappear after the regressors are residualized with respect to region- and year-fixed effects. In the two-way fixed-effects specifications, all VIF values fall below 2.6, and all tolerance values exceed 0.39. This indicates that the high pooled collinearity is mainly driven by persistent cross-regional differences and the highly concentrated territorial coverage of selected programs rather than by within-region variation over time. Multicollinearity is therefore unlikely to distort the preferred fixed-effects estimates materially. However, electric transport and local target-fund expenditure should still be interpreted cautiously because each is observed in only two regions.

3.2. Linear two-way fixed-effects estimates

The linear two-way fixed-effects estimates are reported in Tables 1 and 2. To reduce overparameterization, each specification introduces one expenditure category at a time, together with real gross regional product, real environmental-protection investment, region fixed effects, and year fixed effects. The production specifications additionally control for installed renewable energy capacity. Statistical inference is based on CR2 standard errors clustered by region and Satterthwaite-adjusted degrees of freedom. As the expenditure variables were transformed using the natural logarithm of 1 + x, the coefficients should not be interpreted as exact elasticities, particularly for categories containing numerous zero or small values.

3.3. Installed renewable energy capacity growth

Table 1 presents the results for the annual change in logged installed renewable energy capacity. At the conventional 5% significance level, positive associations are obtained for expenditures from local target funds ($\beta = 0.9152$, $p = 0.0192$) and electric transport measures ($\beta = 0.1499$, $p = 0.0126$). However, both categories were recorded in only five region–year observations and two regions. Their estimates, therefore, rely on extremely limited within-panel variation and should be regarded as exploratory rather than as evidence of general relationships across Ukrainian regions. Moreover, neither coefficient remains statistically significant after correcting for the 11 simultaneous program tests, with both Benjamini–Hochberg adjusted q-values equal to 0.1054.

None of the remaining expenditure categories is significantly associated with annual capacity growth. Their confidence intervals generally encompass both negative and positive values, indicating considerable uncertainty about the direction of the associations. Real GRP and environ-

Table 1. Linear two-way fixed-effects estimates for annual growth in installed renewable energy capacity

Program	B	CR2 SE	p-value	95% CI	BH q-value	Within R^2
Co-financing of investment projects	−0.0453	0.0868	0.6273	[−0.2800, 0.1900]	0.7667	0.005
Environmental measures under territorial development programs	0.0318	0.0588	0.5992	[−0.0978, 0.1610]	0.7667	0.006
Contributions to authorized capital	−0.0430	0.0600	0.5444	[−0.2890, 0.2030]	0.7667	0.007
Expenditures from local target funds	0.9152	0.3573	0.0192	[0.1670, 1.6600]	0.1054	0.007
Other economic activity measures	0.1041	0.1732	0.5635	[−0.2920, 0.5000]	0.7667	0.014
Energy-saving measures	0.1487	0.1580	0.3734	[−0.2140, 0.5110]	0.7667	0.016
SME support	−0.0511	0.1304	0.7269	[−0.5240, 0.4220]	0.7996	0.004
Electric transport measures	0.1499	0.0546	0.0126	[0.0359, 0.2640]	0.1054	0.004
Natural resource protection	0.1077	0.1017	0.3574	[−0.1920, 0.4080]	0.7667	0.029
Environmental measures financed from target funds	0.0358	0.2857	0.9074	[−0.8230, 0.8950]	0.9074	0.003
Other environmental activities	−0.2094	0.1198	0.1322	[−0.5040, 0.0854]	0.4847	0.033

Note: Each row represents a separate model. The dependent variable is the annual change in the natural logarithm of installed renewable energy capacity. The estimation sample comprises 75 observations across 25 regions for 2019–2021. All models include logged real GRP, the natural logarithm of 1 + real environmental investment, region fixed effects, and year fixed effects. Expenditures are measured in millions of constant 2021 UAH and transformed using the natural logarithm of 1 + x. Standard errors are CR2 region-clustered standard errors with Satterthwaite degrees-of-freedom corrections. BH q-values apply the Benjamini–Hochberg adjustment to the 11 program coefficients.

mental investment are also statistically insignificant throughout the specifications. By contrast, the year coefficients indicate that capacity growth was substantially lower in 2020 and 2021 than in 2019. Although the models have overall R^2 values of approximately 0.59–0.60, their within-R^2 values range from 0.003 to 0.033. Most of the explanatory power, therefore, derives from persistent regional differences and common-year effects rather than from changes in the individual expenditure categories.

3.4. Renewable electricity production

Table 2 reports the production specifications after controlling for installed renewable capacity. None of the 11 expenditure categories is statistically significant at the 5% level. SME support has a negative coefficient and is weakly significant at the 10% level ($\beta = -0.2152$, $p = 0.0580$), but its confidence interval includes zero, and its adjusted q-value is 0.5995. Consequently, the estimate should be treated as suggestive rather than as evidence of a systematic negative association. The other expenditure coefficients are imprecisely estimated, including those for categories that showed nominally significant associations with capacity growth.

Installed renewable capacity is the only consistently significant substantive predictor of electricity production. Its coefficient ranges from 0.4108 to 0.4803 across the 11 specifications, with CR2 p-values ranging from 0.0041 to 0.0220. For sufficiently large positive values of production, the estimates suggest that a 1% increase in installed capacity is associated with an approximately 0.41–0.48% increase in renewable electricity generation, holding the remaining variables and fixed effects constant. This result confirms the importance of accounting for the existing generation asset base when analyzing regional electricity production.

Real GRP and environmental investment remain statistically insignificant in all production specifications. The 2019 year effect is insignificant, whereas the 2020 and 2021 coefficients are consistently positive and significant relative to 2018, indicating common increases in renewable production after accounting for installed capacity and regional characteristics. Overall R^2 values range from 0.978 to 0.980, largely reflecting the explanatory contribution of installed capacity and the fixed effects. The more informative within R^2 values range from 0.257 to 0.333.

Further details of the baseline estimates are reported in Appendix B, Tables B1 and B2. Table B1 presents the complete program coefficients, CR2 standard errors, Satterthwaite-adjusted degrees of freedom, confidence intervals, and model-fit

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Table 2. Linear two-way fixed-effects estimates for renewable electricity production

Program	Program β	CR2 SE	p-value	BH q-value	Installed-capacity β	CR2 SE	p-value	Within R^2
Co-financing of investment projects	−0.0608	0.0517	0.2725	0.5995	0.4115	0.1339	0.0185	0.272
Environmental measures under territorial development programs	−0.0114	0.0554	0.8398	0.9655	0.4235	0.1417	0.0220	0.258
Contributions to authorized capital	0.0136	0.0362	0.7305	0.9655	0.4203	0.1344	0.0176	0.259
Expenditures from local target funds	0.0395	0.7463	0.9655	0.9655	0.4223	0.1342	0.0175	0.257
Other economic activity measures	0.0497	0.0851	0.5715	0.9655	0.4108	0.1361	0.0183	0.262
Energy-saving measures	−0.1495	0.0932	0.1396	0.5995	0.4219	0.1344	0.0177	0.289
SME support	−0.2152	0.0747	0.0580	0.5995	0.4803	0.1084	0.0041	0.333
Electric transport measures	−0.2695	0.1455	0.2533	0.5995	0.4692	0.1162	0.0059	0.290
Natural resource protection	0.0039	0.0335	0.9124	0.9655	0.4219	0.1342	0.0178	0.257
Environmental measures financed from target funds	−0.1721	0.1205	0.2096	0.5995	0.4295	0.1298	0.0142	0.273
Other environmental activities	0.0235	0.0652	0.7297	0.9655	0.4189	0.1328	0.0174	0.258

Note: Each row represents a separate model. The dependent variable is the natural logarithm of 1 + renewable electricity production. The sample comprises 100 observations across 25 regions for 2018–2021. All models include installed renewable capacity, logged real GRP, the natural logarithm of 1 + real environmental investment, region fixed effects, and year fixed effects. Other definitions correspond to Table 1.

statistics for annual growth in installed renewable energy capacity. The results confirm that the nominally positive estimates for local target-fund expenditure and electric transport are exceptions within an otherwise predominantly insignificant set of program coefficients. The within-R^2 values are low across all capacity-growth specifications, indicating that annual changes in the individual expenditure categories explain only a limited proportion of the variation remaining after regional and year fixed effects are removed. Table B2 reports the corresponding detailed estimates for renewable electricity production. These specifications provide no statistically robust evidence of direct program-level associations with production, whereas installed renewable energy capacity remains positive and significant in every model. The stability of this coefficient reinforces the conclusion that the existing regional renewable asset base is the principal observable correlate of electricity generation during the analyzed period.

Table B3 summarizes the stability of the common control variables and year effects across the separate program specifications. Real GRP and environmental investment remain statistically insignificant for both dependent variables, suggesting that short-term within-region changes in these controls are not systematically associated with renewable capacity growth or electricity production after controlling for fixed effects. The year effects, however, display clear temporal patterns. Capacity growth is consistently lower in 2020 and 2021 than in 2019, whereas renewable electricity production is higher in 2020 and 2021 than in 2018. These contrasting patterns are compatible with a period in which the rate of new capacity expansion slowed while electricity generation from the accumulated renewable asset base continued to increase. Nevertheless, the year coefficients capture all common national developments and should not be assigned to any single policy, market, or institutional mechanism.

Finally, Table B4 evaluates the evidential strength of the only program coefficients reaching conventional or marginal significance. Although local target-fund expenditure and electric transport are positively associated with capacity growth at the unadjusted 5% level, both variables are observed in only 5 region–year cases across 2 regions. Their estimates consequently depend on a very narrow evidence base and do not remain significant after the Benjamini–Hochberg correction for multiple testing. The negative SME-support coefficient in the production model is significant only at the 10%

level and is likewise not robust to the multiple-testing adjustment. Accordingly, these estimates are treated as exploratory signals requiring sensitivity analysis rather than as confirmatory findings. Across Tables B1–B4, the overall evidence therefore supports a cautious conclusion: selected budget programs may coincide with renewable-energy changes in particular regions and years, but the baseline models do not establish broad, stable, or causal effects of regional public expenditure on renewable energy development.

The baseline results provide little evidence of broad and stable associations between annual regional expenditure categories and renewable energy development. The two nominally significant capacity-growth estimates are based on exceptionally sparse program coverage and do not survive adjustment for multiple testing. In contrast, the relationship between installed capacity and actual renewable electricity production is positive and consistent across all specifications. These findings represent conditional associations and should not be interpreted causally.

3.5. Lagged program-expenditure specifications

Table 3 reports the one-year lagged expenditure specifications. Across both renewable-energy outcomes, none of the 11 lagged program coefficients is statistically significant, even before multiple-testing adjustments. For annual installed-capacity growth, the smallest p-value is obtained for other environmental activities ($\beta = -0.1722$, $p = 0.1139$), followed by SME support ($\beta = -0.1828$, $p = 0.2718$) and other economic activity measures ($\beta = -0.2861$, $p = 0.2790$). All confidence intervals include zero, and the Benjamini–Hochberg adjusted q-values range from 0.8073 to 0.9510. The results therefore provide no evidence that higher expenditure in the preceding year is systematically associated with subsequent growth in regional renewable energy capacity.

Importantly, the previously observed contemporaneous positive associations between local target-fund expenditure and electric transport do not persist in the lagged specifications. Their lagged coefficients become negative, at –0.9756 and –0.3110, respectively, and are statistically insignificant. As shown in Tables B5 and B7, both estimates are also highly imprecise, reflecting the extremely limited territorial and temporal coverage of these programs. The confidence interval for lagged target-fund expenditure ranges from –17.3129 to 15.3617, while the electric transport interval ranges from –1.9069 to 1.2849. Consequently, the contemporaneous positive coefficients cannot be interpreted as temporally robust relationships.

The lagged production results likewise provide no statistically significant program-level associations. The strongest negative estimate is observed for SME support ($\beta = -0.1068$, $p = 0.1030$), but the corresponding confidence interval includes zero, and the adjusted q-value is 0.7489. Co-financing, energy saving expenditure, electric transport, natural resource protection, and environmental measures financed from target funds also have negative lagged coefficients. In contrast, territorial environmental programs, capital contributions, local target funds, other economic measures, and other environmental activities have positive coefficients. However, none of these estimates is sufficiently precise to distinguish the reported association from zero. Detailed inference is presented in Table B6.

The common controls display different patterns across the two outcomes, as summarized in Table B8. In the capacity-growth models, real GRP and environmental investment remain statistically insignificant. At the same time, the 2020 coefficient is consistently negative and significant, and the 2021 coefficient is negative but varies between conventional and marginal significance. In the lagged production specifications, real GRP is consistently negative and statistically significant, with coefficients ranging from –3.0234 to –2.7191, whereas environmental investment remains insignificant. Unlike in the full-period contemporaneous production models, installed renewable capacity is not statistically significant in the restricted 2019–2021 lagged sample. The positive, highly significant year effects for 2020 and 2021 nevertheless remain stable.

To distinguish temporal specification from sample composition, the contemporaneous production models were re-estimated over 2019–2021, matching the sample used in the one-year-lagged models. As reported in Table B11, most program coefficients remain statistically insignificant under both

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Table 3. One-year lagged TWFE estimates for renewable energy development

Program	Capacity growth: β (CR2 SE)	p-value	BH q-value	Electricity production: β (CR2 SE)	p-value	BH q-value
Co-financing of investment projects	−0.0103 (0.1390)	0.9427	0.9510	−0.0560 (0.0542)	0.3306	0.7489
Environmental measures under territorial development programs	−0.0185 (0.0886)	0.8406	0.9510	0.0218 (0.0343)	0.5446	0.7489
Contributions to authorized capital	−0.0224 (0.0687)	0.7675	0.9510	0.0425 (0.0301)	0.2620	0.7489
Expenditures from local target funds	−0.9756 (2.1070)	0.7100	0.9510	1.1851 (1.2184)	0.4791	0.7489
Other economic activity measures	−0.2861 (0.2490)	0.2790	0.8073	0.1038 (0.1060)	0.3515	0.7489
Energy-saving measures	0.0381 (0.2620)	0.8897	0.9510	−0.0641 (0.0748)	0.4276	0.7489
SME support	−0.1828 (0.1225)	0.2718	0.8073	−0.1068 (0.0390)	0.1030	0.7489
Electric transport measures	−0.3110 (0.1700)	0.2936	0.8073	−0.1040 (0.0920)	0.4330	0.7489
Natural resource protection	−0.0057 (0.0885)	0.9510	0.9510	−0.0139 (0.0458)	0.7741	0.8652
Environmental measures financed from target funds	−0.0848 (0.2120)	0.7000	0.9510	−0.0374 (0.1332)	0.7866	0.8652
Other environmental activities	−0.1722 (0.0904)	0.1139	0.8073	0.0169 (0.1251)	0.8974	0.8974

Note: Each cell represents a separate two-way fixed-effects model. The capacity-growth dependent variable is the annual change in logged installed renewable capacity. The production dependent variable is the natural logarithm of 1 + renewable electricity generation. Expenditure is lagged by one year. All models include real GRP, real environmental investment, region fixed effects, and year fixed effects. Production models additionally include contemporaneous installed renewable capacity. N = 75, regions = 25, and years = 3. CR2 standard errors are clustered by region and use Satterthwaite-adjusted degrees of freedom. BH q-values apply the Benjamini–Hochberg correction separately across the 11 program coefficients for each outcome.

specifications. The principal exception under CR2 inference is contemporaneous expenditure from local target funds (β = 1.1700, p = 0.0002, BH q = 0.0021), whereas the corresponding lagged estimate is imprecise and insignificant (β = 1.1851, p = 0.4791). However, the contemporaneous result is not corroborated by a wild-cluster-bootstrap test based on 9,999 Rademacher replications (p = 0.4687). Given that target-fund expenditure is positive in only five region–year observations across two regions, its CR2 significance appears highly sensitive to sparse territorial variation and should not be interpreted as a robust or general association. SME support remains negative but statistically insignificant in both the contemporaneous (β = −0.1390, p = 0.1300) and lagged (β = −0.1068, p = 0.1030) same-sample specifications. The lagged and same-sample results provide no robust basis for causal claims concerning delayed program effects.

3.6. Wild-cluster-bootstrap robustness tests

Wild-cluster-bootstrap inference was used to assess whether the program coefficients remained statistically credible when inference was based on the empirical distribution generated by regional clusters rather than conventional asymptotic critical values. The tests used 9,999 Rademacher bootstrap replications, imposed the null hypothesis, and clustered observations by the 25 regions. Table B9 summarizes the results across the four families of models, while the complete coefficient-level results are reported in Table B10.

The bootstrap results provide little support for robust program-level associations with renewable energy development. Among the contemporaneous capacity-growth specifications, only expenditure on other environmental activities produced a bootstrap p-value below 0.05 (β = −0.2094, p = 0.0457). However, its Benjamini–Hochberg-adjusted q-value was 0.5028, and the same coefficient was not statistically significant under CR2 inference. The result should therefore be treated as an isolated, inference-sensitive finding rather than evidence of a stable negative association. None of the remaining contemporaneous capacity coefficients approached significance under the bootstrap.

The bootstrap results also overturn the two positive contemporaneous capacity growth associations initially identified using CR2 standard errors. Local target-fund expenditure had a CR2 p-value of 0.0192, but its wild-bootstrap p-value increased to 0.4871. Similarly, the coefficient for electric transport had a CR2 p-value of 0.0126 but a bootstrap p-value of 0.3597. Despite relatively large bootstrap test statistics, the corresponding p-values are high because inference is based on the bootstrap reference distribution rather than on conventional t-distribution critical values. These discrepancies are consistent with the very limited regional support for both expenditure categories and indicate that their original statistical significance was not robust.

No one-year lagged capacity-growth coefficient was significant at the 5% level. Expenditure on other environmental activities provided the strongest lagged signal ($\beta = -0.1722$, $p = 0.0659$), but its adjusted q-value was 0.7250. Thus, neither the contemporaneous nor the lagged capacity models contain a program coefficient that survives adjustment for multiple comparisons.

The contemporaneous production specifications similarly produce no significant coefficient at the conventional 5% level. SME-support expenditure has the lowest bootstrap p-value ($\beta = -0.2152$, $p = 0.0980$), followed by environmental measures financed from target funds ($\beta = -0.1721$, $p = 0.1092$) and energy-saving expenditure ($\beta = -0.1495$, $p = 0.1604$). These estimates indicate possible negative associations, but their high adjusted q-values and sensitivity to the inference procedure preclude confirmatory interpretation.

In the lagged production models, SME support is the only coefficient significant at the unadjusted 5% level ($\beta = -0.1068$, $p = 0.0163$). Nevertheless, the corresponding adjusted q-value is 0.1793, exceeding both the 5% and 10% false-discovery thresholds. Moreover, the coefficient was not significant under the CR2 inference, with a p-value of 0.1030. The apparent lagged association is therefore method-sensitive and should be interpreted as an exploratory signal rather than a robust delayed effect of SME-support expenditure on renewable electricity production.

As shown in Table B9, each family contains at most one coefficient with an unadjusted bootstrap p-value below 0.10, and no coefficient in any family has an adjusted q-value below 0.10. Table 4 further demonstrates that the findings identified as nominally significant depend strongly on the selected inference method. The wild-cluster-bootstrap results reinforce the central conclusion of the baseline analysis: the data do not provide stable evidence that the examined regional expenditure programs were systematically associated with renewable capacity growth or electricity production during the analyzed period.

Table 4. Comparison of CR2 and wild-cluster-bootstrap inference for the principal findings

Outcome and timing	Program	β	CR2 p-value	Bootstrap p-value	BH q-value	Assessment
Capacity growth, contemporaneous	Local target funds	0.9152	0.0192	0.4871	0.7596	CR2 significance not supported by bootstrap
Capacity growth, contemporaneous	Electric transport	0.1499	0.0126	0.3597	0.7596	CR2 significance not supported by bootstrap
Capacity growth, contemporaneous	Other environmental activities	−0.2094	0.1322	0.0457	0.5028	Bootstrap-only nominal significance; not multiplicity-robust
Capacity growth, one-year lagged	Other environmental activities	−0.1722	0.1139	0.0659	0.7250	Weak bootstrap signal only
Production, contemporaneous	SME support	−0.2152	0.0580	0.0980	0.5824	Marginal under both procedures
Production, one-year lagged	SME support	−0.1068	0.1030	0.0163	0.1793	Bootstrap-only significance; not multiplicity-robust

Note: The table includes coefficients attaining $p < 0.10$ under either CR2 or wild-cluster-bootstrap inference, together with the two initially significant contemporaneous capacity coefficients. No listed result survives the Benjamini–Hochberg adjustment at $q < 0.10$.

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3.7. Program presence and positive spending intensity

Program eligibility for the presence–intensity decomposition was determined using a common rule-based screen applied to the full 2018–2021 panel before the outcome-specific models were estimated. A program was retained when it satisfied all four conditions: a zero-observation share of at least 20%, at least 20 positive region–year observations, positive expenditure in at least 10 regions, and at least five regions switching between zero and positive expenditure during the study period. Five programs met these conditions: contributions to authorized capital, energy-saving measures, SME support, natural-resource protection, and other environmental activities. The same set of programs was used for both outcomes to avoid outcome-dependent selection. All five retained programs also exhibited sufficient positive observations and regional variation in the 2019–2021 capacity-growth sample.

Among these five eligible programs, the presence–intensity models reported in Table B12 provide no evidence that moving from zero expenditure to program operation at the reference positive-spending level, or that variation in positive-spending intensity, was systematically associated with annual renewable-capacity growth. All coefficients are statistically insignificant, all confidence intervals include zero, and none survive the Benjamini–Hochberg correction. Thus, the null findings from the linear capacity models are not explained by combining program participation and expenditure intensity within a single log1p variable.

For renewable electricity production, all estimated differences between zero expenditure and program operation at the reference positive-spending level are statistically insignificant (Table B13). Only SME-support intensity is nominally negative ($\beta = -0.278$, $p = 0.036$; 95% CI [−0.526, −0.030]), while program presence itself is insignificant. However, this result does not survive multiple-testing adjustment ($q = 0.360$) and is based on low effective degrees of freedom. It should therefore be treated as exploratory. Overall, separating program presence from positive-spending intensity does not alter the main conclusion: no multiplicity-robust program-level associations are identified for either renewable capacity growth or electricity production.

3.8. IHS-transformation robustness

The inverse hyperbolic sine specifications (Table B14) closely reproduce the baseline log1p results. For annual capacity growth, expenditure from local target funds remains nominally positive and significant ($\beta = 0.912$, $p = 0.019$), but it does not survive the Benjamini–Hochberg adjustment ($q = 0.211$) and continues to rely on only five positive observations across two regions. The positive electric transport coefficient is not significant under IHS inference ($\beta = 0.150$, $p = 0.395$), with an exceptionally low effective degree of freedom of 0.48, confirming that inference for this sparse category is highly unstable. No other capacity coefficient is significant. For renewable electricity production, SME support remains the strongest negative association ($\beta = -0.175$, $p = 0.054$), but it is only marginally significant and has a high adjusted q-value of 0.596. All other production coefficients are insignificant. Overall, changing the expenditure transformation does not alter the principal conclusion: no program-level association is robust to multiple-testing adjustment.

3.9. Winsorized positive spending robustness

Winsorizing positive program expenditure while retaining structural zeros yields estimates very similar to the baseline results (Table B15). None of the nine eligible expenditure categories is significantly associated with annual renewable-capacity growth, and all adjusted q-values exceed 0.79. For renewable electricity production, SME support remains the strongest negative association ($\beta = -0.220$, $p = 0.066$), but it is only marginally significant and does not survive the Benjamini–Hochberg correction ($q = 0.595$). Energy saving expenditure and environmental measures financed from target funds also retain negative coefficients, although neither is statistically significant. Overall, limiting the influence of extreme positive expenditure values does not materially change coefficient signs or the substantive conclusion that no program-level association is robust to multiple-testing adjustment.

3.10. Formal quadratic and U-shape tests

Formal nonlinear testing was restricted to the seven programs satisfying the coverage and variation criteria. Local target-fund expenditure, electric transport measures, environmental measures financed from target funds, and other environmental activities were excluded because they did not provide sufficient positive observations, territorial coverage, or within-program expenditure variation for credible quadratic estimation.

Among the seven eligible programs, the formal nonlinear tests reported in Table B16 provide no evidence of either a U- or an inverted-U-shaped association with annual renewable-capacity growth. None of the quadratic coefficients is statistically significant, with p-values ranging from 0.2777 to 0.9784. Numerical formal U-test p-values were returned for five specifications and range from 0.2740 to 0.4135. For the remaining two specifications, the endpoint slopes did not display the reversal required for a formal U-shaped or inverted-U-shaped relationship; these cases were assigned $p = 1$ solely for the multiple-testing adjustment. After applying the Benjamini–Hochberg correction across all seven screened programs, the five numerical tests have $q = 0.5789$, while the two non-returned tests have $q = 1.0000$. Co-financing, contributions to authorized capital, and energy saving expenditure also fail the minimum support criterion around their turning points. The capacity growth results provide no support for nonlinear program-level associations.

The production specifications lead to the same conclusion. None of the seven quadratic coefficients is statistically significant. Four specifications return numerical formal U-test p-values, ranging from 0.1086 to 0.4688, while three do not exhibit the endpoint-slope reversal required for a formal test. After assigning $p = 1$ to the latter cases solely for the Benjamini–Hochberg adjustment, no adjusted q-value is below 0.6988. The closest result is the direction implied for environmental measures under territorial development programs, but its formal U-test remains insignificant ($p = 0.1086$; $q = 0.6988$). The capital contribution specification also fails the support criterion because only four regions lie above its turning point. The nonlinear tests, therefore, indicate that the linear null findings do not conceal systematic U- or inverted-U-shaped relationships.

The regional dimension of the results is reflected primarily in the territorial coverage and within-region variation of the budget programs rather than in separate oblast-specific coefficients. The analyzed panel comprises 24 oblasts and Kyiv City, but program coverage differs substantially across these territorial units. Co-financing of investment projects, other economic activity measures, and environmental measures under territorial development programs was implemented in 24 regions, whereas SME support covered 21 regions, natural-resource protection covered 18 regions, and energy-saving measures covered 18 regions. By contrast, expenditures from local target funds and electric-transport measures were recorded in only two regions, which explains why their nominally significant coefficients cannot be interpreted as representative of Ukraine as a whole. The nonlinear results likewise show heterogeneous territorial support: for example, the estimated turning point for contributions to authorized capital is supported by only four regions above the threshold, whereas the co-financing specification has observations on both sides of the turning point across a much broader set of regions. Thus, the empirical evidence should be interpreted as reflecting heterogeneous regional implementation patterns rather than uniform responses across Ukrainian oblasts.

The nonlinear tests, therefore, indicate that the linear null findings do not conceal systematic U- or inverted-U-shaped relationships and that the available evidence varies considerably in territorial support across Ukrainian regions. Importantly, the absence of broad program-level relationships does not imply identical outcomes across regions; rather, the results point to substantial territorial heterogeneity in program availability, spending intensity, and empirical support.

4. DISCUSSION

The results provide a more cautious interpretation of the role of regional public expenditure in renewable energy development than studies reporting that government spending and fiscal support can

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stimulate green investment and renewable energy expansion (Fernandes et al., 2025; Okunevičiūtė Neverauskienė et al., 2025). Although local target fund expenditure and electric transport measures were positively associated with annual capacity growth in the baseline models ($\beta = 0.9152$, $p = 0.0192$ and $\beta = 0.1499$, $p = 0.0126$, respectively), neither estimate survived the Benjamini–Hochberg adjustment, with $q = 0.1054$ for both. Moreover, wild-cluster-bootstrap p-values increased to 0.4871 and 0.3597, while each category was observed in only five region–year cases across two regions. These findings do not demonstrate that such expenditure is ineffective; rather, they show that nominal budget allocations alone do not provide stable evidence of renewable-capacity expansion when territorial coverage, multiple testing, and inferential sensitivity are considered. This interpretation is consistent with research emphasizing that the contribution of public spending depends on program design, the quality of financial management, and the institutional capacity to transform allocated resources into completed investments (Ntuli et al., 2025; Hedau & Malla, 2024). It also supports the view that fiscal decentralization may produce heterogeneous outcomes because regional authorities differ in implementation capacity, infrastructure, and coordination with national policy (Filipova et al., 2025).

The production results further indicate that the existing renewable asset base was more closely associated with electricity generation than annual changes in broad regional expenditure categories. None of the eleven program coefficients was significant at the 5% level, whereas the installed capacity coefficient remained positive across all specifications, ranging from 0.4108 to 0.4803, with p-values between 0.0041 and 0.0220. This finding is compatible with literature showing that renewable energy outcomes depend on infrastructure deployment, technological integration, and the operational capacity of regional energy systems (Gualandri & Kuzior, 2023; Wojciechowski et al., 2025; Zhu et al., 2026). By contrast, many of the examined budget categories (such as SME support, electric transport, and general economic development measures) may influence renewable generation only indirectly, depending on whether funded activities are linked to renewable projects, grid infrastructure, innovation, or energy-intensive enterprises. The weak negative estimate for SME support in the baseline production model ($\beta = -0.2152$, $p = 0.0580$, $q = 0.5995$) and the nominally negative intensity effect ($\beta = -0.278$, $p = 0.036$, $q = 0.360$) should therefore not be interpreted as evidence that entrepreneurship support reduces renewable production. They may instead reflect program composition, delayed effects, allocation toward regions facing weaker economic conditions, or the limited alignment of general SME measures with renewable energy objectives. This qualification is consistent with evidence that entrepreneurial and innovation capacity can support green investment only when policy incentives, institutional conditions, and firm-level capabilities are sufficiently aligned (Fitriningrum et al., 2025).

The robustness and nonlinear analyses reinforce the conclusion that expenditure scale alone was not systematically related to renewable-energy outcomes during 2018–2021. Neither the lagged, presence–intensity, IHS-transformed, nor winsorized specifications produced a program association that remained significant after multiplicity adjustment, and the formal nonlinear tests yielded no adjusted q-value below 0.5789. Consequently, the data do not support the existence of general expenditure thresholds, U-shaped relationships, or diminishing-return patterns, despite the broader literature stressing that sustainable finance effectiveness may depend on the scale, structure, and coordination of funding (Krause et al., 2024; Streimikiene et al., 2024). The absence of robust program-level relationships is nevertheless compatible with research highlighting the importance of local context, collaborative governance, and territorially adapted implementation rather than uniform expenditure responses (Belgibayeva et al., 2025; Rakowska & Ozimek, 2021). Public-private partnerships may also be necessary to complement regional budgets with financing, technical expertise, and project-management capacity (Kuzior et al., 2023; Oe et al., 2025; Topazly et al., 2025). For Ukraine, the findings imply that regional public-expenditure management should prioritize the connection between budget programs and measurable implementation outputs, such as commissioned renewable capacity, grid connections, completed infrastructure, and generated electricity, rather than treating expenditure growth itself as evidence of energy transition progress.

CONCLUSION

This study examined whether the allocation of regional public expenditure across selected budget program categories was systematically associated with renewable energy development in Ukraine and whether any observed relationships remained stable across alternative temporal, distributional, and nonlinear specifications.

The empirical results provide no robust evidence that higher expenditure under the analyzed regional budget programs was systematically associated with either annual renewable-capacity growth or renewable electricity production. Although several program categories produced nominally significant or marginal associations in individual specifications, these findings were sensitive to sparse territorial coverage, the choice of statistical inference method, and adjustment for multiple testing. By contrast, installed renewable capacity remained the most consistent correlate of renewable electricity generation, highlighting the importance of the existing regional renewable-energy asset base. The lagged, same-sample, presence–intensity, alternative-transformation, and winsorized specifications did not materially alter the overall findings. Likewise, the nonlinear analysis provided no support for systematic U-shaped, inverted-U-shaped, or threshold-type relationships between program expenditure and renewable-energy outcomes.

From a public management perspective, these findings suggest that regional authorities should not assume that larger allocations within broad budget categories will automatically translate into expanded renewable energy. Budget programs should instead be linked to clearly defined implementation outputs, including commissioned capacity, grid connection, project completion, electricity generation, and verified environmental benefits. Particularly sparse or territorially concentrated programs should initially be implemented as monitored pilots with transparent eligibility rules, comparable reporting standards, and ex-post evaluation requirements. The consistent relationship between installed capacity and electricity production further indicates that expenditure management should focus on overcoming practical barriers to asset deployment, such as project preparation, permitting, grid access, co-financing, procurement, and implementation capacity, rather than relying solely on nominal expenditure increases.

The results are limited by the short four-year observation period, small number of regions, the extremely sparse territorial coverage of several programs, and very low effective degrees of freedom in some specifications. The observational fixed-effects design identifies conditional within-region associations rather than causal program effects, whereas separately estimating expenditure categories may leave residual confounding from correlated budget programs. Moreover, controlling for contemporaneous installed capacity in the production models may absorb part of the pathway through which expenditure could influence generation. Future research should extend the time horizon, use project- or municipality-level data, distinguish committed from actually disbursed expenditure, and apply quasi-experimental or event-study designs where credible policy discontinuities are available. Further work should also examine spatial spillovers, distributed lag structures, mediation through installed capacity, institutional implementation quality, and differences between program availability, absorption capacity, and completed renewable energy investments.

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APPENDIX A. Descriptive statistics and correlation analysis

Table A1. Descriptive statistics

Variable	Unit	N	Mean	SD	Median	Min.	Max.	Skewness	Excess kurtosis
Co-financing of investment projects	UAH million	100	41.14	91.69	17.30	0.00	631.03	4.67	23.17
Environmental measures under territorial development programs	UAH million	100	31.68	53.09	13.12	0.00	287.57	3.06	9.97
Contributions to authorized capital	UAH million	100	56.06	292.17	1.13	0.00	2,125.00	6.51	41.79
Expenditures from local target funds	UAH million	100	11.68	57.88	0.00	0.00	319.21	4.72	20.76
Other economic activity measures	UAH million	100	55.82	248.61	3.36	0.00	2,014.61	6.09	40.16
Energy-saving measures	UAH million	100	5.86	16.94	0.35	0.00	138.96	5.50	36.84
SME support	UAH million	100	1.68	5.38	0.65	0.00	44.29	6.65	45.65
Electric transport measures	UAH million	100	44.50	243.44	0.00	0.00	1,771.29	5.86	34.86
Natural resource protection	UAH million	100	10.24	23.37	0.89	0.00	116.20	3.26	10.49
Environmental measures financed from target funds	UAH million	100	15.75	44.92	0.17	0.00	250.02	4.13	17.12
Other environmental and natural-resource activities	UAH million	100	8.56	32.25	0.00	0.00	211.74	4.88	24.58
Renewable electricity generation	million kWh	100	300.52	459.57	89.68	0.00	2,079.96	2.21	4.53
Installed renewable energy capacity	MW	100	246.83	307.67	105.16	0.26	1,167.40	1.57	1.54
Gross regional product	UAH million	100	172,103.75	200,392.15	98,106.00	33,905.00	1,276,376.00	3.42	13.06
Capital investment in environmental protection	UAH thousand	100	536,833.36	1,170,819.76	78,304.60	6,864.90	6,945,708.40	3.60	14.18

Note: The sample comprises 25 Ukrainian regional units observed annually from 2018 to 2021. Budget expenditure variables and gross regional product are expressed in millions of constant 2021 UAH, while capital investment in environmental protection is expressed in thousands of constant 2021 UAH. SD denotes standard deviation, and kurtosis is reported as excess kurtosis. Installed renewable energy capacity reflects the corrected annual regional aggregation of the underlying Energy Map data.

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Table A2. Zero observations and territorial coverage of regional expenditure programs

Program	Observations	Zero observations	Zero share, %	Positive observations	Regions with positive spending	Years with positive spending	Mean positive spending, million constant 2021 UAH	Median positive spending, million constant 2021 UAH
Electric transport measures	100	95	95	5	2	4	1,012.00	848.00
Expenditures from local target funds	100	95	95	5	2	4	260.00	322.00
Other environmental activities	100	51	51	49	16	4	19.50	1.54
Environmental measures financed from target funds	100	49	49	51	13	4	34.30	10.50
Natural resource protection	100	39	39	61	18	4	18.80	5.18
Energy-saving measures	100	37	37	63	18	4	10.40	2.19
Contributions to authorized capital	100	34	34	66	22	4	93.50	5.63
SME support	100	26	26	74	21	4	2.55	1.23
Environmental measures under territorial development programs	100	11	11	89	24	4	39.60	18.40
Other economic activity measures	100	9	9	91	24	4	68.20	4.70
Co-financing of investment projects	100	7	7	93	24	4	49.10	20.00

Note: Monetary values are expressed in millions of constant 2021 UAH. Positive spending refers to region–year observations with expenditure greater than zero. The number of regions with positive spending indicates territorial program coverage over the full 2018–2021 period.

Table A3. Pooled Spearman correlation matrix

Panel A. Variables 1–8

No.	Variable	1	2	3	4	5	6	7	8
1	Co-financing	1.000							
2	Territorial environmental measures	0.243	1.000						
3	Capital contributions	–0.135	0.073	1.000					
4	Local target funds	0.365	0.368	0.188	1.000				
5	Other economic activity	0.381	0.236	–0.095	0.301	1.000			
6	Energy-saving measures	0.034	0.148	–0.116	0.218	0.354	1.000		
7	SME support	–0.032	–0.057	0.241	0.106	0.059	0.193	1.000	
8	Electric transport	0.356	0.235	0.132	0.806	0.321	0.218	0.242	1.000
9	Natural resource protection	–0.049	–0.060	0.315	0.008	–0.159	–0.137	0.134	0.113
10	Environmental target-fund measures	0.238	0.249	0.100	0.320	0.315	0.295	–0.102	0.244
11	Other environmental activities	0.184	0.068	0.090	0.307	0.176	0.074	0.444	0.377
12	Real GRP	0.346	0.188	0.278	0.249	0.324	0.240	0.243	0.348
13	Environmental investment	0.203	0.144	0.260	0.173	0.125	0.192	0.171	0.298
14	RES electricity production	–0.065	0.011	0.003	–0.209	0.142	–0.070	–0.004	–0.305
15	Installed RES capacity	0.036	–0.005	–0.125	–0.257	0.181	–0.137	–0.059	–0.298

Panel B. Variables 9–15

No.	Variable	9	10	11	12	13	14	15
9	Natural resource protection	1.000						
10	Environmental target-fund measures	–0.534	1.000					
11	Other environmental activities	0.413	–0.423	1.000				
12	Real GRP	0.178	0.128	0.428	1.000			
13	Environmental investment	0.228	0.233	0.172	0.771	1.000		
14	RES electricity production	–0.271	0.134	–0.204	0.246	0.200	1.000	
15	Installed RES capacity	–0.240	0.096	–0.206	0.201	0.197	0.921	1.000

Note: The table reports Spearman rank correlations for the pooled sample of 100 region–year observations. All monetary variables were adjusted for inflation and expressed in constant 2021 UAH. Expenditure variables and environmental investment were transformed using the natural logarithm of 1 + x. GRP and installed renewable energy capacity were expressed in natural logarithms, whilst renewable electricity production was transformed using the natural logarithm of 1 + x.

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Table A4. Within-region Pearson correlation matrix

Panel A. Variables 1–8									
No.	**Variable**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	Co-financing	1.000							
2	Territorial environmental measures	0.210	1.000						
3	Capital contributions	–0.024	0.063	1.000					
4	Local target funds	0.127	0.062	–0.008	1.000				
5	Other economic activity	–0.082	–0.092	–0.086	0.076	1.000			
6	Energy-saving measures	0.118	0.137	–0.216	0.126	0.150	1.000		
7	SME support	–0.055	–0.229	0.093	–0.344	–0.009	–0.011	1.000	
8	Electric transport	–0.043	–0.186	–0.115	0.338	0.129	0.040	0.449	1.000
9	Natural resource protection	0.046	–0.046	0.125	0.357	0.056	0.151	–0.159	0.233
10	Environmental target-fund measures	0.114	0.170	0.186	0.285	–0.039	0.185	–0.044	0.068
11	Other environmental activities	0.001	–0.064	–0.143	–0.213	0.191	0.081	0.243	0.056
12	Real GRP	0.053	0.077	0.110	–0.225	–0.154	–0.459	–0.035	–0.116
13	Environmental investment	–0.003	–0.126	0.046	0.001	0.012	–0.223	–0.074	–0.022
14	RES electricity production	–0.007	–0.039	0.006	–0.193	–0.082	–0.464	–0.233	–0.211
15	Installed RES capacity	0.018	–0.083	–0.001	–0.175	0.005	–0.341	–0.039	–0.079

Panel B. Variables 9–15								
No.	**Variable**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
9	Natural resource protection	1.000						
10	Environmental target-fund measures	0.086	1.000					
11	Other environmental activities	–0.143	–0.073	1.000				
12	Real GRP	–0.294	–0.125	–0.116	1.000			
13	Environmental investment	0.069	0.028	–0.208	0.022	1.000		
14	RES electricity production	–0.236	–0.223	–0.029	0.680	0.058	1.000	
15	Installed RES capacity	–0.176	–0.156	0.033	0.560	0.057	0.822	1.000

Note: The table reports Pearson correlations calculated after subtracting each region's four-year mean from every transformed variable. The coefficients, therefore, represent within-region co-movement over time rather than persistent differences between regions. Variable transformations and monetary units correspond to those reported in Table A3. The correlations are descriptive and do not account for common year effects.

Table A5. Multicollinearity diagnostics for pooled and two-way fixed-effects specifications

Variable	Pooled capacity model: VIF	Pooled capacity model: tolerance	Pooled production model: VIF	Pooled production model: tolerance	TWFE capacity model: VIF	TWFE capacity model: tolerance	TWFE production model: VIF	TWFE production model: tolerance
Co-financing of investment projects	1.50	0.665	1.51	0.663	1.14	0.878	1.17	0.858
Environmental measures under territorial development programs	1.38	0.724	1.38	0.724	1.30	0.767	1.35	0.740
Contributions to authorized capital	3.10	0.322	3.27	0.305	1.22	0.817	1.23	0.810
Expenditures from local target funds	43.20	0.023	43.20	0.023	2.04	0.491	2.04	0.490
Other economic activity measures	2.62	0.381	2.74	0.365	1.11	0.899	1.15	0.867
Energy-saving measures	1.93	0.517	2.07	0.482	1.27	0.787	1.27	0.787
SME support	2.27	0.441	2.30	0.435	2.49	0.402	2.56	0.391
Electric transport measures	43.30	0.023	43.80	0.023	2.27	0.440	2.31	0.433
Natural resource protection	1.97	0.509	1.97	0.509	1.31	0.763	1.32	0.756
Environmental measures financed from target funds	3.29	0.304	3.30	0.303	1.20	0.832	1.21	0.828
Other environmental activities	3.29	0.304	3.42	0.292	1.22	0.818	1.24	0.807
Real gross regional product	6.38	0.157	6.64	0.151	1.13	0.883	1.18	0.851
Environmental investment	4.07	0.246	4.13	0.242	1.15	0.868	1.16	0.866
Installed renewable energy capacity	–	–	1.67	0.598	–	–	1.27	0.785

Note: VIF denotes the variance inflation factor. Tolerance is calculated as the reciprocal of the VIF. The pooled diagnostics are based on the transformed regressors before controlling for fixed effects. The TWFE diagnostics are calculated after residualizing each regressor with respect to region- and year-fixed effects. Values of VIF above 5 indicate potentially problematic multicollinearity, while values above 10 indicate severe multicollinearity. The capacity specification excludes installed renewable energy capacity, whereas the production specification includes it as a control.

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Table A6. Territorial units included in the balanced panel

No.	Territorial unit	Administrative status	Treatment in the analysis
1	Vinnytsia	Oblast	Included
2	Volyn	Oblast	Included
3	Dnipropetrovsk	Oblast	Included
4	Donetsk	Oblast	Included according to the territorial coverage available in the official source data
5	Zhytomyr	Oblast	Included
6	Zakarpattia	Oblast	Included
7	Zaporizhzhia	Oblast	Included
8	Ivano-Frankivsk	Oblast	Included
9	Kyiv	Oblast	Included separately from Kyiv City
10	Kirovohrad	Oblast	Included
11	Luhansk	Oblast	Included according to the territorial coverage available in the official source data
12	Lviv	Oblast	Included
13	Mykolaiv	Oblast	Included
14	Odesa	Oblast	Included
15	Poltava	Oblast	Included
16	Rivne	Oblast	Included
17	Sumy	Oblast	Included
18	Ternopil	Oblast	Included
19	Kharkiv	Oblast	Included
20	Kherson	Oblast	Included
21	Khmelnytskyi	Oblast	Included
22	Cherkasy	Oblast	Included
23	Chernivtsi	Oblast	Included
24	Chernihiv	Oblast	Included
25	Kyiv City	City with special status	Included as a separate territorial unit

Note: The balanced panel comprises 24 oblasts and Kyiv City observed annually from 2018 to 2021. The Autonomous Republic of Crimea and Sevastopol are excluded because comparable observations were unavailable across the data sources and study period. Kyiv Oblast and Kyiv City are treated as separate territorial units. For Donetsk and Luhansk oblasts, the observations correspond to the territorial reporting coverage available in the official statistical and administrative sources for each year; the study does not reconstruct economic, budgetary, or energy activity outside the applicable reporting perimeter. The same territorial structure was used when merging data from the State Statistics Service of Ukraine, the Ministry of Finance of Ukraine's Open Budget portal, and the Energy Map database.

APPENDIX B

Table B1. Detailed CR2 inference and model-fit statistics: Annual growth in installed renewable energy capacity

Program	B	SE	df	p-value	95% CI	BH q-value	R^2	Adjusted R^2	Within R^2	RSE
Co-financing of investment projects	–0.0453	0.0868	4.28	0.6273	[–0.2800, 0.1900]	0.7667	0.592	0.328	0.005	0.611
Environmental measures under territorial development programs	0.0318	0.0588	10.90	0.5992	[–0.0978, 0.1610]	0.7667	0.592	0.329	0.006	0.611
Contributions to authorized capital	–0.0430	0.0600	2.11	0.5444	[–0.2890, 0.2030]	0.7667	0.592	0.329	0.007	0.611
Expenditures from local target funds	0.9152	0.3573	18.80	0.0192	[0.1670, 1.6600]	0.1054	0.592	0.329	0.007	0.611
Other economic activity measures	0.1041	0.1732	8.40	0.5635	[–0.2920, 0.5000]	0.7667	0.595	0.334	0.014	0.608
Energy-saving measures	0.1487	0.1580	8.23	0.3734	[–0.2140, 0.5110]	0.7667	0.596	0.335	0.016	0.608
SME support	–0.0511	0.1304	2.45	0.7269	[–0.5240, 0.4220]	0.7996	0.591	0.328	0.004	0.611
Electric transport measures	0.1499	0.0546	19.80	0.0126	[0.0359, 0.2640]	0.1054	0.591	0.327	0.004	0.612
Natural resource protection	0.1077	0.1017	3.47	0.3574	[–0.1920, 0.4080]	0.7667	0.601	0.344	0.029	0.604
Environmental measures financed from target funds	0.0358	0.2857	3.34	0.9074	[–0.8230, 0.8950]	0.9074	0.591	0.327	0.003	0.612
Other environmental activities	–0.2094	0.1198	5.87	0.1322	[–0.5040, 0.0854]	0.4847	0.603	0.347	0.033	0.602

Note: N = 75, regions = 25, and years = 3 in every model. RSE denotes residual standard error. Region and year coefficients are not displayed.

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Table B2. Detailed CR2 inference and model-fit statistics: Renewable electricity production

Program	Program β	SE	df	p-value	95% CI	BH q-value	Capacity β	SE	p-value	95% CI	R^2	Adjusted R^2	Within R^2	RSE
Co-financing of investment projects	−0.0608	0.0517	8.37	0.2725	[−0.1790, 0.0576]	0.5995	0.4115	0.1339	0.0185	[0.0935, 0.7295]	0.978	0.969	0.272	0.359
Environmental measures under territorial development programs	−0.0114	0.0554	12.20	0.8398	[−0.1320, 0.1090]	0.9655	0.4235	0.1417	0.0220	[0.0836, 0.7634]	0.978	0.968	0.258	0.362
Contributions to authorized capital	0.0136	0.0362	3.28	0.7305	[−0.0963, 0.1240]	0.9655	0.4203	0.1344	0.0176	[0.0996, 0.7410]	0.978	0.968	0.259	0.362
Expenditures from local target funds	0.0395	0.7463	1.13	0.9655	[−7.1900, 7.2600]	0.9655	0.4223	0.1342	0.0175	[0.1012, 0.7434]	0.978	0.968	0.257	0.362
Other economic activity measures	0.0497	0.0851	10.80	0.5715	[−0.1380, 0.2380]	0.9655	0.4108	0.1361	0.0183	[0.0921, 0.7295]	0.978	0.968	0.262	0.361
Energy-saving measures	−0.1495	0.0932	10.10	0.1396	[−0.3570, 0.0579]	0.5995	0.4219	0.1344	0.0177	[0.1001, 0.7437]	0.979	0.969	0.289	0.354
SME support	−0.2152	0.0747	3.23	0.0580	[−0.4430, 0.0131]	0.5995	0.4803	0.1084	0.0041	[0.2172, 0.7434]	0.980	0.971	0.333	0.343
Electric transport measures	−0.2695	0.1455	1.43	0.2533	[−1.2100, 0.6710]	0.5995	0.4692	0.1162	0.0059	[0.1892, 0.7492]	0.979	0.969	0.290	0.354
Natural resource protection	0.0039	0.0335	5.45	0.9124	[−0.0802, 0.0879]	0.9655	0.4219	0.1342	0.0178	[0.1001, 0.7438]	0.978	0.968	0.257	0.362
Environmental measures financed from target funds	−0.1721	0.1205	5.28	0.2096	[−0.4770, 0.1330]	0.5995	0.4295	0.1298	0.0142	[0.1187, 0.7403]	0.978	0.969	0.273	0.359
Other environmental activities	0.0235	0.0652	6.72	0.7297	[−0.1320, 0.1790]	0.9655	0.4189	0.1328	0.0174	[0.1009, 0.7369]	0.978	0.968	0.258	0.362

Note: N = 100, regions = 25, and years = 4 in every model. Region and year coefficients are not displayed.

Table B3. Stability of common control and year effects across the parsimonious models

Outcome	Variable	Coefficient range	CR2 p-value range	Summary
Annual capacity growth	Real GRP	–0.740 to –0.512	0.689–0.799	Not statistically significant
Annual capacity growth	Environmental investment	–0.058 to –0.002	0.631–0.984	Not statistically significant
Annual capacity growth	Year 2020	–0.899 to –0.847	0.003–0.010	Consistently negative
Annual capacity growth	Year 2021	–1.080 to –0.934	0.039–0.069	Negative; significance varies between 5% and 10%
Electricity production	Real GRP	–1.204 to –0.334	0.315–0.723	Not statistically significant
Electricity production	Environmental investment	–0.054 to –0.022	0.472–0.776	Not statistically significant
Electricity production	Installed RES capacity	0.411 to 0.480	0.004–0.022	Consistently positive
Electricity production	Year 2019	0.008 to 0.151	0.513–0.965	Not statistically significant
Electricity production	Year 2020	0.539 to 0.770	0.008–0.038	Consistently positive
Electricity production	Year 2021	0.808 to 1.157	0.009–0.048	Consistently positive

Note: The ranges show the lowest and highest coefficients and p-values across the 11 separate program specifications. Reference years are 2019 for the capacity-growth models and 2018 for the production models.

Table B4. Evidential status of the nominally significant or weakly significant program coefficients

Outcome	Program	β	CR2 p-value	BH q-value	Positive observations	Regions with positive spending	Evidential status
Annual capacity growth	Expenditures from local target funds	0.9152	0.0192	0.1054	5	2	Nominally significant but highly sparse; exploratory
Annual capacity growth	Electric transport measures	0.1499	0.0126	0.1054	5	2	Nominally significant but highly sparse; exploratory
Electricity production	SME support	–0.2152	0.0580	0.5995	74	21	Weak nominal evidence; not robust to multiple-testing adjustment

Note: Benjamini–Hochberg adjustments were calculated separately across the 11 program coefficients for each dependent variable. No expenditure coefficient has $q < 0.10$.

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Table B5. Detailed one-year lagged estimates for annual growth in installed renewable energy capacity

Program	β	CR2 SE	Satterthwaite df	p-value	95% CI	BH q-value
Co-financing of investment projects	−0.0103	0.1390	7.62	0.9427	[−0.3336, 0.3130]	0.9510
Environmental measures under territorial development programs	−0.0185	0.0886	7.37	0.8406	[−0.2259, 0.1889]	0.9510
Contributions to authorized capital	−0.0224	0.0687	2.74	0.7675	[−0.2533, 0.2085]	0.9510
Expenditures from local target funds	−0.9756	2.1070	1.27	0.7100	[−17.3129, 15.3617]	0.9510
Other economic activity measures	−0.2861	0.2490	9.68	0.2790	[−0.8434, 0.2712]	0.8073
Energy-saving measures	0.0381	0.2620	5.34	0.8897	[−0.6227, 0.6989]	0.9510
SME support	−0.1828	0.1225	2.04	0.2718	[−0.7001, 0.3345]	0.8073
Electric transport measures	−0.3110	0.1700	1.15	0.2936	[−1.9069, 1.2849]	0.8073
Natural resource protection	−0.0057	0.0885	4.77	0.9510	[−0.2366, 0.2251]	0.9510
Environmental measures financed from target funds	−0.0848	0.2120	7.62	0.7000	[−0.5779, 0.4083]	0.9510
Other environmental activities	−0.1722	0.0904	5.10	0.1139	[−0.4032, 0.0588]	0.8073

Note: N = 75, covering 25 regions and the capacity-growth years 2019–2021. Each row represents a separate model. The dependent variable is the annual change in logged installed renewable energy capacity. All specifications include real GRP, real environmental investment, region fixed effects, and year fixed effects.

Table B6. Detailed one-year lagged estimates for renewable electricity production

Program	β	CR2 SE	Satterthwaite df	p-value	95% CI	BH q-value
Co-financing of investment projects	−0.0560	0.0542	8.18	0.3306	[−0.1805, 0.0685]	0.7489
Environmental measures under territorial development programs	0.0218	0.0343	7.25	0.5446	[−0.0587, 0.1023]	0.7489
Contributions to authorized capital	0.0425	0.0301	2.72	0.2620	[−0.0591, 0.1441]	0.7489
Expenditures from local target funds	1.1851	1.2184	1.27	0.4791	[−8.3268, 10.6970]	0.7489
Other economic activity measures	0.1038	0.1060	9.59	0.3515	[−0.1338, 0.3414]	0.7489
Energy-saving measures	−0.0641	0.0748	5.41	0.4276	[−0.2521, 0.1239]	0.7489
SME support	−0.1068	0.0390	2.15	0.1030	[−0.2639, 0.0503]	0.7489
Electric transport measures	−0.1040	0.0920	1.22	0.4330	[−0.8757, 0.6677]	0.7489
Natural resource protection	−0.0139	0.0458	4.77	0.7741	[−0.1334, 0.1056]	0.8652
Environmental measures financed from target funds	−0.0374	0.1332	7.58	0.7866	[−0.3475, 0.2727]	0.8652
Other environmental activities	0.0169	0.1251	5.16	0.8974	[−0.3017, 0.3355]	0.8974

Note: N = 75, covering 25 regions and the production years 2019–2021. Each model includes contemporaneous installed renewable capacity, real GRP, real environmental investment, region fixed effects, and year fixed effects.

Table B7. Comparison of contemporaneous and one-year lagged program estimates

Program	Capacity: contemporaneous β (p)	Capacity: lagged β (p)	Production: contemporaneous β (p)	Production: lagged β (p)
Co-financing of investment projects	−0.0453 (0.6273)	−0.0103 (0.9427)	−0.0608 (0.2725)	−0.0560 (0.3306)
Environmental measures under territorial development programs	0.0318 (0.5992)	−0.0185 (0.8406)	−0.0114 (0.8398)	0.0218 (0.5446)
Contributions to authorized capital	−0.0430 (0.5444)	−0.0224 (0.7675)	0.0136 (0.7305)	0.0425 (0.2620)
Expenditures from local target funds	0.9152 (0.0192)	−0.9756 (0.7100)	0.0395 (0.9655)	1.1851 (0.4791)
Other economic activity measures	0.1041 (0.5635)	−0.2861 (0.2790)	0.0497 (0.5715)	0.1038 (0.3515)
Energy-saving measures	0.1487 (0.3734)	0.0381 (0.8897)	−0.1495 (0.1396)	−0.0641 (0.4276)
SME support	−0.0511 (0.7269)	−0.1828 (0.2718)	−0.2152 (0.0580)	−0.1068 (0.1030)
Electric transport measures	0.1499 (0.0126)	−0.3110 (0.2936)	−0.2695 (0.2533)	−0.1040 (0.4330)
Natural resource protection	0.1077 (0.3574)	−0.0057 (0.9510)	0.0039 (0.9124)	−0.0139 (0.7741)
Environmental measures financed from target funds	0.0358 (0.9074)	−0.0848 (0.7000)	−0.1721 (0.2096)	−0.0374 (0.7866)
Other environmental activities	−0.2094 (0.1322)	−0.1722 (0.1139)	0.0235 (0.7297)	0.0169 (0.8974)

Note: Contemporaneous production estimates are based on 100 observations from 2018–2021, whereas the lagged production estimates are based on 75 observations from 2019–2021. The columns are therefore not strictly the same sample comparisons. Because the contemporaneous and lagged production columns in this table use different estimation periods, Appendix Table B11 provides the preferred same-sample comparison for 2019–2021.

Table B8. Stability of controls and year effects in the lagged specifications

Outcome	Variable	Coefficient range	CR2 p-value range	Interpretation
Annual capacity growth	Real GRP	−0.8278 to −0.5139	0.6750–0.8005	Not statistically significant
Annual capacity growth	Environmental investment	−0.0441 to −0.0159	0.7281–0.8958	Not statistically significant
Annual capacity growth	Year 2020	−0.9278 to −0.8410	0.0038–0.0088	Consistently negative
Annual capacity growth	Year 2021	−1.0844 to −0.9994	0.0456–0.0622	Negative; significance varies
Electricity production	Real GRP	−3.0234 to −2.7191	0.0038–0.0210	Consistently negative
Electricity production	Environmental investment	−0.0350 to −0.0148	0.4940–0.7957	Not statistically significant
Electricity production	Installed RES capacity	0.0740 to 0.1424	0.4834–0.6514	Positive but not statistically significant
Electricity production	Year 2020	0.7495 to 0.7943	<0.001 in all models	Consistently positive
Electricity production	Year 2021	1.3970 to 1.4896	<0.001 in all models	Consistently positive

Note: Coefficient and p-value ranges are calculated across the 11 separate program specifications. The reference year is 2019 for the capacity-growth models and 2019 for the restricted lagged production sample, with the reported year coefficients comparing 2020 and 2021 against that reference.

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Table B9. Summary of wild-cluster-bootstrap inference by model family

Outcome	Timing	Minimum bootstrap p-value	Coefficients with p < 0.05	Coefficients with p < 0.10	Coefficients with BH q < 0.10
Annual capacity growth	Contemporaneous	0.0457	1	1	0
Annual capacity growth	One-year lagged	0.0659	0	1	0
Renewable electricity production	Contemporaneous	0.0980	0	1	0
Renewable electricity production	One-year lagged	0.0163	1	1	0

Note: Wild-cluster-bootstrap tests use 9,999 Rademacher replications, impose the null hypothesis, and cluster observations by region. Benjamini–Hochberg adjustments are calculated separately across the 11 program coefficients within each outcome–timing family.

Table B10. Wild-cluster-bootstrap inference for program–expenditure coefficients

Panel A. Annual capacity growth: contemporaneous expenditure					
Program	**β**	**Bootstrap statistic**	**Bootstrap p-value**	**BH q-value**	**N**
Co-financing of investment projects	–0.0453	–0.5478	0.6601	0.7596	75
Environmental measures under territorial development programs	0.0318	0.5481	0.5862	0.7596	75
Contributions to authorized capital	–0.0430	–0.8378	0.3271	0.7596	75
Expenditures from local target funds	0.9152	2.6186	0.4871	0.7596	75
Other economic activity measures	0.1041	0.6282	0.6713	0.7596	75
Energy-saving measures	0.1487	1.0459	0.3905	0.7596	75
SME support	–0.0511	–0.4284	0.6906	0.7596	75
Electric transport measures	0.1499	2.6541	0.3597	0.7596	75
Natural resource protection	0.1077	1.2094	0.3994	0.7596	75
Environmental measures financed from target funds	0.0358	0.1297	0.9186	0.9186	75
Other environmental activities	–0.2094	–1.9716	0.0457	0.5028	75
Panel B. Annual capacity growth: one-year lagged expenditure					
Program	**β**	**Bootstrap statistic**	**Bootstrap p-value**	**BH q-value**	**N**
Co-financing of investment projects	–0.0103	–0.0815	0.9489	0.9575	75
Environmental measures under territorial development programs	–0.0185	–0.2212	0.8286	0.9575	75
Contributions to authorized capital	–0.0224	–0.4085	0.6265	0.9575	75
Expenditures from local target funds	–0.9756	–0.6413	0.6859	0.9575	75
Other economic activity measures	–0.2861	–1.1881	0.3050	0.9575	75
Energy-saving measures	0.0381	0.1689	0.9575	0.9575	75
SME support	–0.1828	–1.9808	0.4230	0.9575	75
Electric transport measures	–0.3110	–2.7523	0.5557	0.9575	75
Natural resource protection	–0.0057	–0.0703	0.9466	0.9575	75
Environmental measures financed from target funds	–0.0848	–0.4353	0.7083	0.9575	75
Other environmental activities	–0.1722	–2.0403	0.0659	0.7250	75

Table B9 (cont.). Summary of wild-cluster-bootstrap inference by model family

Panel C. Renewable electricity production: contemporaneous expenditure					
Program	**β**	**Bootstrap statistic**	**Bootstrap p-value**	**BH q-value**	**N**
Co-financing of investment projects	–0.0608	–1.2229	0.2647	0.5824	100
Environmental measures under territorial development programs	–0.0114	–0.2248	0.8445	0.9406	100
Contributions to authorized capital	0.0136	0.4379	0.6880	0.9406	100
Expenditures from local target funds	0.0395	0.0782	0.9406	0.9406	100
Other economic activity measures	0.0497	0.6068	0.5837	0.9406	100
Energy-saving measures	–0.1495	–1.7069	0.1604	0.5824	100
SME support	–0.2152	–3.2750	0.0980	0.5824	100
Electric transport measures	–0.2695	–2.8329	0.2630	0.5824	100
Natural resource protection	0.0039	0.1225	0.9083	0.9406	100
Environmental measures financed from target funds	–0.1721	–1.4969	0.1092	0.5824	100
Other environmental activities	0.0235	0.3861	0.7063	0.9406	100
Panel D. Renewable electricity production: one-year lagged expenditure					
Program	β	Bootstrap statistic	Bootstrap p-value	BH q-value	N
Co-financing of investment projects	–0.0560	–1.1031	0.3529	0.7241	75
Environmental measures under territorial development programs	0.0218	0.6626	0.5267	0.7241	75
Contributions to authorized capital	0.0425	1.6047	0.4309	0.7241	75
Expenditures from local target funds	1.1851	1.3039	0.2556	0.7241	75
Other economic activity measures	0.1038	1.0097	0.3448	0.7241	75
Energy-saving measures	–0.0641	–0.9250	0.4089	0.7241	75
SME support	–0.1068	–3.0402	0.0163	0.1793	75
Electric transport measures	–0.1040	–1.6041	0.5261	0.7241	75
Natural resource protection	–0.0139	–0.3410	0.7768	0.8545	75
Environmental measures financed from target funds	–0.0374	–0.2921	0.7690	0.8545	75
Other environmental activities	0.0169	0.1511	0.8878	0.8878	75

Note: Wild-cluster-bootstrap inference is based on 9,999 Rademacher replications, with the null hypothesis imposed and clustering by region. All specifications contain 25 regional clusters. Capacity-growth models contain 75 observations. Contemporaneous production models contain 100 observations, while one-year lagged production models contain 75 observations. BH q-values are calculated separately within each panel across the 11 program coefficients. The bootstrap statistic should be interpreted together with its bootstrap p-value, rather than compared directly with conventional t-distribution critical values. A separate focal wild-cluster-bootstrap test for the restricted-sample local target-fund coefficient produced p = 0.4687. Contemporaneous production bootstrap results are based on the original 2018–2021 sample and therefore do not assess the restricted-sample estimates reported in Table B11.

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Table B11. Same-sample comparison of contemporaneous and one-year-lagged program estimates for renewable electricity production, 2019–2021

Program	Contemporaneous β (CR2 SE)	CR2 p-value	BH q-value	One-year-lagged β (CR2 SE)	CR2 p-value	BH q-value	Sign change
Co-financing of investment projects	−0.0013 (0.0428)	0.9780	0.9970	−0.0560 (0.0542)	0.3306	0.7489	No
Environmental measures under territorial development programs	0.0170 (0.0390)	0.6720	0.9510	0.0218 (0.0343)	0.5446	0.7489	No
Contributions to authorized capital	−0.0001 (0.0338)	0.9970	0.9970	0.0425 (0.0301)	0.2620	0.7489	Yes
Expenditures from local target funds	1.1700 (0.2560)	0.0002	0.0021	1.1851 (1.2184)	0.4791	0.7489	No
Other economic activity measures	0.0032 (0.0752)	0.9670	0.9970	0.1038 (0.1060)	0.3515	0.7489	No
Energy-saving measures	−0.0384 (0.0934)	0.6920	0.9510	−0.0641 (0.0748)	0.4276	0.7489	No
SME support	−0.1390 (0.0615)	0.1300	0.7130	−0.1068 (0.0390)	0.1030	0.7489	No
Electric transport measures	0.2290 (0.0407)	0.2320	0.7780	−0.1040 (0.0920)	0.4330	0.7489	Yes
Natural-resource protection	0.0490 (0.0483)	0.3760	0.7780	−0.0139 (0.0458)	0.7741	0.8652	Yes
Environmental measures financed from target funds	0.1290 (0.1420)	0.4240	0.7780	−0.0374 (0.1332)	0.7866	0.8652	Yes
Other environmental activities	0.0547 (0.0631)	0.4200	0.7780	0.0169 (0.1251)	0.8974	0.8974	No

Note: Each coefficient is obtained from a separate two-way fixed-effects model. Both contemporaneous and lagged specifications use the same 75 observations covering 25 regions over 2019–2021. All models include contemporaneous installed renewable capacity, logged real GRP, the natural logarithm of 1 + real environmental investment, region fixed effects, and year fixed effects. CR2 standard errors are clustered by region and use Satterthwaite-adjusted degrees of freedom. Benjamini–Hochberg corrections are applied separately across the 11 program coefficients within each timing specification. Sign changes are descriptive and do not constitute formal tests of differences between coefficients. The contemporaneous local target-fund coefficient was additionally assessed using 9,999 Rademacher wild-cluster-bootstrap replications, with the null hypothesis imposed and clustering by region. The resulting bootstrap p-value was 0.4687, indicating that its CR2 significance is not robust.

Table B12. Program-presence and positive-spending-intensity models for annual growth in installed renewable energy capacity

Program	Component	β	CR2 SE	Satterthwaite df	CR2 p-value	95% CI	BH q-value	Reference positive spending, million constant 2021 UAH
Contributions to authorized capital	Program presence	–0.4700	0.4750	6.54	0.3580	[–1.6100, 0.6700]	0.6650	8.01
	Positive-spending intensity	0.0592	0.0724	2.64	0.4810	[–0.1900, 0.3090]	0.6680	8.01
Energy-saving measures	Program presence	0.1870	0.3030	5.13	0.5630	[–0.5860, 0.9600]	0.6680	3.48
	Positive-spending intensity	0.1650	0.1630	10.90	0.3330	[–0.1940, 0.5240]	0.6650	3.48
Natural resource protection	Program presence	0.1900	0.3740	6.25	0.6290	[–0.7160, 1.1000]	0.6680	6.68
	Positive-spending intensity	0.1160	0.1260	5.21	0.3980	[–0.2040, 0.4360]	0.6650	6.68
Other environmental activities	Program presence	–0.3600	0.3780	3.73	0.3990	[–1.4400, 0.7210]	0.6650	3.45
	Positive-spending intensity	–0.1890	0.1310	5.87	0.1990	[–0.5110, 0.1330]	0.6650	3.45
SME support	Program presence	–0.4080	0.2480	3.37	0.1880	[–1.1500, 0.3330]	0.6650	1.38
	Positive-spending intensity	0.0879	0.1900	3.97	0.6680	[–0.4420, 0.6180]	0.6680	1.38

Note: Each pair of rows represents a separate two-way fixed-effects model in which program expenditure is decomposed into a program-presence indicator and centered positive-spending intensity. Reference positive spending is the back-transformed mean of logged expenditure among positive observations and is expressed in millions of constant 2021 UAH. Accordingly, the program-presence coefficient represents the estimated difference between zero expenditure and program operation at this reference positive-spending level, holding the other covariates and fixed effects constant; it should not be interpreted as an unconditional program-activation effect. The dependent variable is the annual change in the natural logarithm of installed renewable energy capacity. All models include logged real GRP, the natural logarithm of 1 + real environmental investment, region fixed effects, and year fixed effects. The sample contains 75 observations across 25 regions for 2019–2021. Benjamini–Hochberg adjustments are calculated separately within each outcome across the ten presence and positive-intensity coefficients. Program eligibility was assessed using the full 2018–2021 panel. Eligible categories were required to have a zero share of at least 20%, at least 20 positive observations, positive spending in at least 10 regions, and at least five regions switching between zero and positive expenditure. The same five-program set was used for both outcomes to avoid outcome-dependent selection. The capacity-growth models themselves use the 2019–2021 sample.

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Table B13. Program-presence and positive-spending-intensity models for renewable electricity production

Program	Component	β	CR2 SE	Satterthwaite df	CR2 p-value	95% CI	BH q-value	Reference positive spending, million constant 2021 UAH
Contributions to authorized capital	Program presence	0.0308	0.1510	8.99	0.8430	[–0.3120, 0.3730]	0.8470	8.01
	Positive-spending intensity	0.0133	0.0432	3.69	0.7750	[–0.1110, 0.1370]	0.8470	8.01
Energy-saving measures	Program presence	–0.2670	0.1890	6.65	0.2030	[–0.7190, 0.1850]	0.6780	3.48
	Positive-spending intensity	–0.1300	0.0940	13.20	0.1910	[–0.3320, 0.0733]	0.6780	3.48
Natural-resource protection	Program presence	–0.0427	0.1570	6.50	0.7940	[–0.4200, 0.3350]	0.8470	6.68
	Positive-spending intensity	0.0160	0.0555	8.11	0.7800	[–0.1120, 0.1440]	0.8470	6.68
Other environmental activities	Program presence	–0.0251	0.1260	7.08	0.8470	[–0.3210, 0.2710]	0.8470	3.45
	Positive-spending intensity	0.0498	0.0799	6.88	0.5530	[–0.1400, 0.2390]	0.8470	3.45
SME support	Program presence	0.0211	0.0745	5.76	0.7870	[–0.1630, 0.2050]	0.8470	1.38
	Positive-spending intensity	–0.2780	0.0890	3.96	0.0360	[–0.5260, –0.0296]	0.3600	1.38

Note: Each pair of rows represents a separate two-way fixed-effects model in which program expenditure is decomposed into a program-presence indicator and centered positive-spending intensity. The dependent variable is the natural logarithm of 1 + renewable electricity production. All specifications include contemporaneous installed renewable capacity, logged real GRP, the natural logarithm of 1 + real environmental investment, region fixed effects, and year fixed effects. The sample comprises 100 observations across 25 regions for 2018–2021. Benjamini–Hochberg adjustments are calculated separately within each outcome across the ten presence and positive-intensity coefficients. Program eligibility was determined using the same full-panel coverage criteria reported in Table B12, and the same five-program set was retained for both outcomes.

Table B14. IHS-transformation robustness estimates for regional program expenditure

Panel A. Annual growth in installed renewable energy capacity						
Program	**IHS β**	**CR2 SE**	**Satterthwaite df**	**CR2 p-value**	**BH q-value**	**N**
Co-financing of investment projects	–0.0380	0.0719	3.69	0.6270	0.7670	75
Environmental measures under territorial development programs	0.0263	0.0509	11.00	0.6160	0.7670	75
Contributions to authorized capital	–0.0437	0.0603	2.39	0.5330	0.7670	75
Expenditures from local target funds	0.9120	0.3560	18.70	0.0192	0.2110	75
Other economic activity measures	0.0886	0.1470	8.78	0.5620	0.7670	75
Energy-saving measures	0.1280	0.1270	7.87	0.3430	0.7670	75
SME support	–0.0347	0.1100	2.79	0.7740	0.8430	75

Table B14 (cont.). IHS-transformation robustness estimates for regional program expenditure

Electric transport measures	0.1500	0.0545	0.48	0.3950	0.7670	75
Natural-resource protection	0.0880	0.0899	3.58	0.3890	0.7670	75
Environmental measures financed from target funds	0.0555	0.2560	2.93	0.8430	0.8430	75
Other environmental activities	−0.1680	0.0988	5.72	0.1420	0.7670	75
Panel B. Renewable electricity production						
Program	**IHS β**	**CR2 SE**	**Satterthwaite df**	**CR2 p-value**	**BH q-value**	**N**
Co-financing of investment projects	−0.0583	0.0460	7.71	0.2420	0.6650	100
Environmental measures under territorial development programs	−0.0052	0.0481	11.90	0.9160	0.9970	100
Contributions to authorized capital	0.0132	0.0312	3.95	0.6940	0.9540	100
Expenditures from local target funds	0.0036	0.7220	1.14	0.9970	0.9970	100
Other economic activity measures	0.0423	0.0710	11.10	0.5630	0.9370	100
Energy-saving measures	−0.1240	0.0750	9.84	0.1310	0.6650	100
SME support	−0.1750	0.0630	3.71	0.0542	0.5960	100
Electric transport measures	−0.2380	0.1050	1.46	0.1960	0.6650	100
Natural-resource protection	0.0031	0.0288	5.56	0.9180	0.9970	100
Environmental measures financed from target funds	−0.1320	0.1140	4.30	0.3090	0.6800	100
Other environmental activities	0.0287	0.0516	6.56	0.5960	0.9370	100

Note: Each row represents a separate two-way fixed-effects model. Program expenditure is measured in millions of constant 2021 UAH and transformed using the inverse hyperbolic sine function. Capacity-growth models include real GRP, real environmental investment, region fixed effects, and year fixed effects. Production models additionally control for contemporaneous installed renewable capacity. CR2 standard errors are clustered by region and use Satterthwaite-adjusted degrees of freedom. Benjamini–Hochberg adjustments are calculated separately across the 11 program coefficients within each outcome. IHS coefficients are not directly comparable in magnitude with the baseline log1p coefficients; robustness should be assessed primarily through coefficient signs, statistical significance, and the resulting substantive conclusions.

Table B15. Winsorized positive-spending robustness estimates

Panel A. Annual growth in installed renewable energy capacity						
Program	**Winsorized β**	**CR2 SE**	**Satterthwaite df**	**CR2 p-value**	**BH q-value**	**N**
Co-financing of investment projects	−0.0469	0.0875	4.23	0.6190	0.7960	75
Environmental measures under territorial development programs	0.0308	0.0588	10.80	0.6120	0.7960	75
Contributions to authorized capital	−0.0430	0.0600	2.11	0.5440	0.7960	75
Other economic activity measures	0.1080	0.1810	8.02	0.5670	0.7960	75
Energy-saving measures	0.1600	0.1610	7.91	0.3500	0.7960	75
SME support	−0.0512	0.1300	2.45	0.7260	0.8160	75
Natural-resource protection	0.1080	0.1020	3.47	0.3580	0.7960	75
Environmental measures financed from target funds	0.0384	0.2850	3.32	0.9010	0.9010	75
Other environmental activities	−0.2100	0.1200	5.86	0.1320	0.7960	75

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Table B15 (cont.). Winsorized positive-spending robustness estimates

Panel B. Renewable electricity production						
Program	**Winsorized β**	**CR2 SE**	**Satterthwaite df**	**CR2 p-value**	**BH q-value**	**N**
Co-financing of investment projects	−0.0619	0.0526	8.39	0.2710	0.6100	100
Environmental measures under territorial development programs	−0.0126	0.0559	12.10	0.8260	0.9100	100
Contributions to authorized capital	0.0138	0.0362	3.31	0.7270	0.9100	100
Other economic activity measures	0.0501	0.0874	10.40	0.5790	0.9100	100
Energy-saving measures	−0.1540	0.0960	9.77	0.1410	0.6100	100
SME support	−0.2200	0.0817	3.36	0.0661	0.5950	100
Natural-resource protection	0.0039	0.0335	5.44	0.9100	0.9100	100
Environmental measures financed from target funds	−0.1700	0.1200	5.24	0.2130	0.6100	100
Other environmental activities	0.0265	0.0640	6.66	0.6920	0.9100	100

Note: Each row represents a separate two-way fixed-effects model. Positive program-expenditure values were winsorized at the 1st and 99th percentiles, while zero observations were retained unchanged. Local target-fund expenditure and electric-transport measures were excluded because each contains only five positive observations, making percentile-based winsorization inappropriate. Expenditure is expressed in millions of constant 2021 UAH and transformed using the natural logarithm of 1 + winsorized expenditure. Capacity-growth models include real GRP, real environmental investment, region fixed effects, and year fixed effects. Production models additionally control for contemporaneous installed renewable capacity. CR2 standard errors are clustered by region and use Satterthwaite-adjusted degrees of freedom. Benjamini–Hochberg adjustments are calculated separately across the nine eligible program coefficients within each outcome.

Table B16. Formal quadratic and U-shape tests for regional program expenditure

Panel A. Annual growth in installed renewable energy capacity													
Program	**Direction implied by quadratic sign**	**Linear β**	**Quadratic β**	**Quadratic CR2 p-value**	**Lower-bound slope**	**Upper-bound slope**	**U-test p-value**	**BH q-value**	**Turningpoint, million UAH**	**Inside tested interval**	**Observations below/above**	**Regions below/above**	**Assessment**
Co-financing of investment projects	Inverted U-shaped	−0.0608	−0.0287	0.7101	0.0989	−0.1728	0.3576	0.5789	5.57	Yes	9/66	5/24	Insufficient support around turning point
Environmental measures under territorial development programs	Inverted U-shaped	0.0311	−0.0012	0.9784	0.0372	0.0258	–	1.0000	–	–	–	–	Required endpoint-slope reversal absent
Contributions to authorized capital	U-shaped	−0.1041	0.0191	0.7083	−0.1586	0.0386	0.4135	0.5789	63.01	Yes	70/5	24/2	Insufficient support around turning point
Other economic activity measures	Inverted U-shaped	0.1021	−0.0060	0.8875	0.1245	0.0679	–	1.0000	–	–	–	–	Required endpoint-slope reversal absent
Energy-saving measures	Inverted U-shaped	0.2333	−0.0581	0.2777	0.3322	−0.0824	0.3428	0.5789	16.45	Yes	68/7	24/3	Insufficient support around turning point
SME support	Inverted U-shaped	0.0788	−0.0912	0.6391	0.1886	−0.0969	0.3444	0.5789	1.81	Yes	60/15	24/9	Nonlinear relationship not supported

Table B16 (cont.). Formal quadratic and U-shape tests for regional program expenditure

Program	Direction implied by quadratic sign	Linear β	Quadratic β	Quadratic CR2 p-value	Lower-bound slope	Upper-bound slope	U-test p-value	BH q-value	Turningpoint, million UAH	Inside tested interval	Observations below/above	Regions below/above	Assessment
Panel A. Annual growth in installed renewable energy capacity													
Natural-resource protection	U-shaped	−0.0669	0.0771	0.3999	−0.2444	0.3738	0.2740	0.5789	3.88	Yes	52/23	20/11	Nonlinear relationship not supported
Panel B. Renewable electricity production													
Program	Direction implied by quadratic sign	Linear β	Quadratic β	Quadratic CR2 p-value	Lower-bound slope	Upper-bound slope	U-test p-value	BH q-value	Turning point, million UAH	Inside tested interval	Observations below/above	Regions below/above	Assessment
Co-financing of investment projects	U-shaped	−0.0277	0.0374	0.2646	−0.2459	0.1269	0.1997	0.6988	25.77	Yes	62/38	20/14	Nonlinear relationship not supported
Environmental measures under territorial development programs	Inverted U-shaped	−0.0376	−0.0369	0.1395	0.1532	−0.2263	0.1086	0.6988	6.96	Yes	30/70	14/23	Nonlinear relationship not supported
Contributions to authorized capital	Inverted U-shaped	0.0465	−0.0131	0.5290	0.0846	−0.0506	0.3073	0.7170	24.20	Yes	90/10	24/4	Insufficient support around turning point
Other economic activity measures	U-shaped	0.0504	0.0015	0.9579	0.0449	0.0586	–	1.0000	–	–	–	–	Required endpoint-slope reversal absent
Energy-saving measures	U-shaped	−0.1806	0.0289	0.3636	−0.2352	−0.0269	–	1.0000	–	–	–	–	Required endpoint-slope reversal absent
SME support	U-shaped	−0.2237	0.0046	0.9317	−0.2297	−0.2135	–	1.0000	–	–	–	–	Required endpoint-slope reversal absent
Natural-resource protection	U-shaped	−0.0020	0.0028	0.9162	−0.0090	0.0124	0.4688	0.8203	3.94	Yes	66/34	20/12	Nonlinear relationship not supported

Note: Each row represents a separate two-way fixed-effects model containing centered log1p program expenditure and its squared term. Nonlinear specifications were estimated only for programs with at least 60 positive region–year observations, positive expenditure in at least 18 regions, at least 20 distinct positive expenditure values, and at least eight regions exhibiting three or more distinct expenditure levels in the full 2018–2021 panel. The same seven-program set was used for both outcomes. Formal U-shape tests were conducted over the 5th–95th percentile interval of the transformed expenditure variable. Capacity-growth models include logged real GRP, the natural logarithm of 1 + real environmental investment, region fixed effects, and year fixed effects. Production models additionally control for contemporaneous installed renewable capacity. CR2 covariance matrices are clustered by region. The direction implied by the quadratic sign is descriptive only: a positive squared coefficient indicates a potential U-shaped direction, whereas a negative squared coefficient indicates a potential inverted-U-shaped direction. This classification does not independently establish a nonlinear relationship. Support requires endpoint slopes with the appropriate signs, a significant formal U-test, a turning point within the tested interval, and at least 10 observations and five regions on each side of the estimated turning point. Rows failing either coverage threshold are classified as having insufficient support around the turning point. Benjamini–Hochberg q-values are calculated separately within each outcome across all seven screened program hypotheses. Where the formal U-test returned no numerical p-value because the endpoint slopes did not exhibit the required reversal, p = 1 was assigned solely for the multiple-testing adjustment; the corresponding U-test p-value is displayed as a dash. Turning points and support counts are reported only when the turning point lies within the tested interval and a numerical formal U-test result is available.