

Governance and Regional Heterogeneity in Municipal Waste Eco-Transition: County-Level Evidence from Poland*

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*Presented at the 47th IBIMA International Conference, 29-30 June 2026, Madrid, Spain

Abstract

The transition towards a circular economy has increased the importance of understanding the factors that determine the effectiveness of municipal waste management systems. Although previous studies have identified numerous socio-economic determinants of waste management performance, considerably less attention has been devoted to governance-related characteristics and their spatial heterogeneity at the local level.

This study addresses this gap by investigating the determinants of municipal waste eco-transition across Polish counties during 2017–2024, with particular emphasis on governance-related characteristics of local waste-management systems and regional differences in their effects. The analysis combines balanced panel data with two-way fixed-effects models, spatial autoregressive (SAR) models, and spatial heterogeneity models incorporating voivodeship-specific interaction effects.

The results reveal significant spatial dependence in municipal waste eco-transition and substantial regional heterogeneity. Traditional socio-economic and settlement-related variables explain little of the observed variation, whereas governance-related characteristics account for a considerably larger share. Greater fragmentation of local waste-service markets is associated with lower selective collection performance, while more diversified waste-stream structures are positively related to eco-transition outcomes. Furthermore, the effects of governance-related variables and local income differ significantly across voivodeships, indicating that institutional and regional contexts shape municipal waste-management performance.

The findings demonstrate that improving municipal waste eco-transition depends less on socio-economic modernization and more on effective governance arrangements, institutional coordination, and region-specific policy design.

Keywords: municipal waste management; governance; spatial econometrics; spatial heterogeneity; selective waste collection; Poland.

Introduction

Municipal waste management has become an important component of environmental policy and sustainable development. Increasing waste generation, urbanization, and changing consumption patterns have intensified pressure on local waste-management systems, while the transition toward a circular economy has strengthened the role of selective collection and recycling. As a result, improving the effectiveness of municipal waste-management systems has become a major challenge for local governments.

Municipal waste systems exhibit substantial territorial variation. Previous studies indicate that waste-management outcomes are influenced by socio-economic conditions, settlement patterns, institutional arrangements, and

infrastructural factors. However, existing research continues to focus predominantly on modernization-related explanations associated with income, urbanization, and economic development. Comparatively less attention has been devoted to governance-related organizational characteristics of local waste-management systems and their spatially differentiated effects.

This study investigates the determinants of municipal waste eco-transition across Polish counties in the years 2017–2024. Municipal waste eco-transition is measured as the share of selectively collected household waste. Particular attention is devoted to governance-related characteristics of local waste-management systems, including governance fragmentation and organizational complexity, as well as to spatial dependence and regional heterogeneity in eco-transition outcomes. The study contributes to the literature in three ways. First, it applies both panel and spatial econometric approaches to the analysis of municipal waste eco-transition at the county level in Poland. Second, it shifts attention from traditional socio-economic explanations toward governance-related organizational characteristics of local waste-management systems. Third, it investigates regional heterogeneity by incorporating voivodeship-specific interaction effects into spatial panel models.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature on municipal waste management, spatial heterogeneity, and governance-related determinants of eco-transition. Section 3 presents the dataset, variables, and econometric methodology. Section 4 discusses the empirical results, while Section 5 concludes.

Literature Review

The transition toward a circular economy has increased the importance of selective waste collection and recycling as key components of municipal waste-management systems. According to the European Union waste hierarchy, waste prevention, reuse, and recycling should progressively replace landfill-oriented systems in order to support more resource-efficient and environmentally sustainable development (European Commission, 2008). Recent sustainability-transition literature further emphasizes that municipal waste management should be understood not only as a technical or infrastructural issue but also as a governance challenge involving local governments, private operators, households, and environmental institutions. Consequently, the effectiveness of municipal waste eco-transition depends not only on economic modernization but also on institutional capacity, coordination, and organizational effectiveness (UNEP, 2011).

A considerable body of empirical research examines the socio-economic determinants of municipal waste generation and recycling performance. Studies focusing on Poland identify income, urbanization, migration, population density, and tourism intensity as important factors shaping municipal waste systems (Antczak, 2019). However, evidence suggests that these relationships are not spatially uniform. Using geographically weighted regression, Antczak (2019) demonstrates significant regional variation in the effects of socio-economic factors, while Antczak (2020) identifies spatial clustering in waste-management problems and illegal dumping sites. These findings are consistent with the broader spatial econometric literature, which emphasizes that environmental and socio-economic processes are often characterized by spatial dependence and spatial heterogeneity (Anselin, 2010; Brunsdon et al., 1996; Fotheringham et al., 2002).

Research on selective waste collection also reveals substantial regional disparities in recycling performance. Krzywnicka et al. (2020) identify considerable differences between Polish counties in recycling structures and selectively collected waste fractions, suggesting that local waste-management outcomes are influenced not only by socio-economic conditions but also by institutional capacity and organizational characteristics.

The institutional dimension of municipal waste management has attracted increasing attention in recent years. Drawing on the literature on polycentric governance, Ciechelska et al. (2023) argue that waste-management systems consist of multiple decision-making centers operating across territorial scales, making coordination among actors a key determinant of system effectiveness. Similarly, Kolsut (2016) demonstrates that inter-municipal cooperation can improve service efficiency, particularly in areas characterized by dispersed settlement structures and fragmented administrative arrangements.

Although existing studies highlight the importance of socio-economic, institutional, and spatial factors, several research gaps remain. First, much of the literature focuses on waste generation rather than eco-transition outcomes related to selective collection. Second, spatial econometric approaches remain relatively rare in county-level analyses of municipal waste systems in Poland. Third, the relationship between governance-related organizational characteristics and spatially differentiated eco-transition outcomes remains insufficiently explored.

This study addresses these gaps by combining panel and spatial econometric approaches to investigate municipal waste eco-transition across Polish counties in the years 2017–2024. Particular attention is devoted to governance-related characteristics of local waste-management systems and their regionally differentiated effects.

Dataset and Methodology

Data and Variables

The empirical analysis is based on a balanced panel dataset covering Polish counties (powiats; local administrative units below the NUTS-3 level) over the period 2017–2024. The study investigates spatial differences in municipal waste eco-transition, operationalized as the share of selectively collected household waste in total household waste. This indicator was adopted as a proxy for the local advancement of eco-transition in municipal waste-management systems, reflecting the ability of local systems to shift from mixed waste disposal toward more organized and environmentally sustainable forms of waste collection. The data were obtained primarily from the Polish Local Data Bank (Bank Danych Lokalnych – BDL) maintained by Statistics Poland (GUS). The variables used in the analysis are presented in Table 1.

The explanatory variables are grouped into three broad categories: socio-economic characteristics, housing and settlement structure, and governance-related features of local waste-management systems. The first group includes classical socio-economic indicators commonly used in environmental and regional-development studies. These variables are introduced primarily to verify whether traditional modernization mechanisms explain spatial differences in selective waste collection performance. Higher wealth and stronger fiscal capacity may increase environmental awareness and infrastructural capabilities, while industrialization and urban concentration may simultaneously generate greater organizational complexity and more demanding waste streams.

The second group captures differences in housing and settlement structure. These variables reflect the spatial organization of residential systems, which may strongly influence the operation and effectiveness of selective waste collection. In practice, waste segregation functions differently in dispersed single-family housing systems than in dense multi-family urban areas, where monitoring, storage, and household-level accountability are often more difficult.

Table 1. Variables used in the empirical analysis

Variable	Description
Dependent variable	
<i>waste_households</i>	Share of selectively collected household waste in total household waste.
Socio-economic characteristics	
<i>ln_income</i>	Log of own-source municipal revenues per capita.
<i>ln_wages</i>	Log of average gross wages.
<i>unemployment</i>	Unemployment rate.
<i>ln_industry</i>	Log of industrial output sold per capita.
<i>industry_emp</i>	Share of employment in industry and construction.
Housing and settlement structure	
<i>urbanization</i>	Urbanization rate.
<i>ln_density</i>	Log of population density.
<i>ind_housing_share</i>	Share of single-family housing completions in total housing completions.
Governance-related features of local waste-management systems	
<i>firms_10k</i>	Waste collection firms per 10,000 inhabitants.
<i>other_waste_share</i>	Share of mixed waste from non-household sources in total mixed waste.
<i>ln_envexp</i>	Log of current municipal environmental expenditures per capita.

Notes: The dependent variable measures the share of selectively collected household waste in total household waste. Variables with the prefix “ln_” are logarithmically transformed due to skewed distributions.

The third and conceptually most important category concerns governance and organizational characteristics of local waste-management systems. Unlike classical socio-economic variables, these indicators aim to capture institutional manageability, governance fragmentation, and the complexity of local waste streams. The number of waste-service firms operating within local waste-management systems may be interpreted as a proxy for governance fragmentation and institutional complexity. Polycentric governance literature emphasizes that the effectiveness of public-service provision depends not only on the number of actors involved but also on the capacity to coordinate activities across organizational boundaries (Ostrom, 2010; Carlisle & Gruby, 2019). While the presence of multiple service providers may increase competition and flexibility, a larger number of actors may simultaneously raise coordination costs, reduce accountability, and complicate monitoring and enforcement mechanisms. In the context of municipal waste management, fragmented service provision may therefore hinder the implementation of consistent waste-separation standards and weaken system-wide coordination.

The share of mixed waste originating from non-household sources captures the degree to which local waste-management systems operate in a more diversified institutional environment. Counties characterized by larger commercial, service-sector, and institutional activities typically handle a wider range of waste streams and involve a broader set of organizational actors. Consequently, waste-management systems in such areas may require more advanced coordination mechanisms, monitoring procedures, and contractual arrangements. The variable is therefore interpreted as a proxy for organizational complexity and functional diversification of local waste-management systems. In this sense, the indicator captures the governance challenges associated with coordinating heterogeneous waste streams rather than the scale of economic activity itself.

Current municipal environmental expenditures per capita (*ln_envexp*) are included as an indicator of the operational engagement of local governments in environmental-service provision. Although expenditure levels do not directly measure governance quality, they reflect the scale of resources devoted to the management and maintenance of local environmental systems, including waste-related services. From a governance perspective, environmental expenditures may therefore capture the administrative and organizational effort associated with the operation of local waste-management systems. At the same time, higher expenditures may also reflect the presence of greater environmental challenges and operational pressures, making the expected direction of the relationship theoretically ambiguous.

Governance structures are inherently difficult to observe using administrative statistical data. Consequently, the study relies on indirect indicators that capture observable manifestations of governance arrangements, organizational complexity, and coordination challenges within local waste-management systems. Rather than measuring governance directly, the selected variables are intended to approximate dimensions of institutional fragmentation, system complexity, and organizational manageability that may influence municipal waste eco-transition outcomes.

Methodology

The first stage of the analysis focuses on the distribution of the dependent variable, defined as the share of selectively collected household waste in total household waste. Because the dataset is organized at the county level and therefore possesses an explicit spatial structure, particular attention is devoted to the geographical distribution of municipal waste eco-transition across both counties and voivodeships. The analysis includes descriptive statistics and spatial visualization of average values observed in 2017–2024.

Although the county (powiat) constitutes the primary unit of observation throughout the econometric analysis, selected descriptive statistics and heterogeneity analyses are presented at the voivodeship level. This aggregation serves two complementary purposes. First, voivodeships represent the principal regional governance framework within which local waste-management policies are coordinated in Poland, providing a meaningful context for interpreting spatial variation among counties. Second, aggregating county-level outcomes facilitates the identification of broader regional patterns that may not be evident from local-level results alone. Importantly, no econometric model is estimated at the voivodeship level; rather, voivodeships are used exclusively to summarize county-level outcomes and to model regional heterogeneity through interaction effects.

Spatial dependence is additionally examined using Moran's I statistic, which measures the global spatial autocorrelation. Positive and statistically significant values of Moran's I indicate that neighboring counties tend to exhibit similar levels of selective collection performance and suggests the existence of spatial clustering. All spatial analyses conducted in the study, including Moran's I statistics and spatial econometric models, are based on a row-standardized first-order queen contiguity spatial-weights matrix.

The baseline econometric specification is estimated using a two-way fixed effects (FE) panel model controlling for both county-specific and time-specific effects. The general model can be expressed as:

$$y_{it} = X_{it}\beta + \mu_i + \tau_t + \varepsilon_{it}$$

where y_{it} denotes the share of selectively collected waste in county i and year t , X_{it} represents the vector of explanatory variables, μ_i captures county-specific fixed effects, τ_t denotes time effects, and ε_{it} is the error term. Separate FE specifications are estimated for different groups of explanatory variables, including socio-economic, housing, governance specifications.

Additionally to FE panel models, spatial autoregressive panel models (SAR) are estimated. The SAR specification incorporates the spatial lag of the dependent variable, allowing eco-transition outcomes in one county to depend on outcomes observed in neighboring counties. The SAR model takes the following form:

$$y_{it} = \rho W y_{it} + X_{it}\beta + \mu_i + \tau_t + \varepsilon_{it}$$

where W denotes the spatial weights matrix, $W y_{it}$ represents the spatial lag of the dependent variable, and ρ measures the strength of spatial dependence. Positive and significant values of ρ indicate the existence of spatial spillovers and regional clustering effects. The exploratory stage of the analysis compares the explanatory performance of alternative FE and SAR specifications corresponding to different categories of explanatory variables.

In the final stage of the analysis, regional heterogeneity models are estimated in order to examine whether the effects of selected governance- and income-related variables differ across Polish voivodeships. To take into account the possible heterogeneity, voivodeship-specific interaction terms for selected variables are incorporated into SAR specifications. The heterogeneity specification can be written as:

$$y_{it} = \rho W y_{it} + X_{it}\beta + (X_{it} \times R_i)\gamma + \mu_i + \tau_t + \varepsilon_{it}$$

where R_i denotes the regional (voivodeship) indicator and $X_{it} \times R_i$ represents interaction terms between explanatory variables and regional affiliation. Under this specification, coefficients β describe baseline effects for the reference voivodeship, while coefficients γ capture region-specific deviations from these baseline relationships. This approach makes it possible to investigate spatially differentiated institutional and socio-economic mechanisms while maintaining a consistent spatial econometric framework for the entire country.

Empirical Results

This section presents the main empirical findings of the study. The analysis begins with an analysis of the spatial distribution of municipal waste eco-transition across Polish counties and voivodeships, followed by an assessment of global spatial autocorrelation. The subsequent stages compare alternative panel and spatial model specifications and finally investigate regional heterogeneity in the effects of selected governance- and income-related determinants.

Spatial distribution of municipal waste eco-transition

The descriptive statistics presented in Table 2 and the maps shown in Figure 1 reveal substantial regional variation in municipal waste eco-transition across Poland. At the voivodeship level, average shares of selectively collected household waste range from 32.3% in Swietokrzyskie to 48.6% in Lubelskie, indicating considerable differences in local waste-management performance. Intra-regional heterogeneity is also observed. In Lubelskie and Slaskie, county-level averages vary by more than 50 percentage points, suggesting that local waste-management outcomes depend not only on broad regional-development patterns but also on local institutional and organizational conditions.

The estimated global Moran's I statistic equals 0.390 ($p < 0.001$), confirming strong positive spatial autocorrelation. Counties characterized by high levels of selective collection tend to be located near other high-performing counties, while low-performing counties also form distinct spatial clusters. These findings indicate that municipal waste eco-transition is shaped not only by local conditions but also by broader spatial processes, providing justification for the application of spatial econometric models.

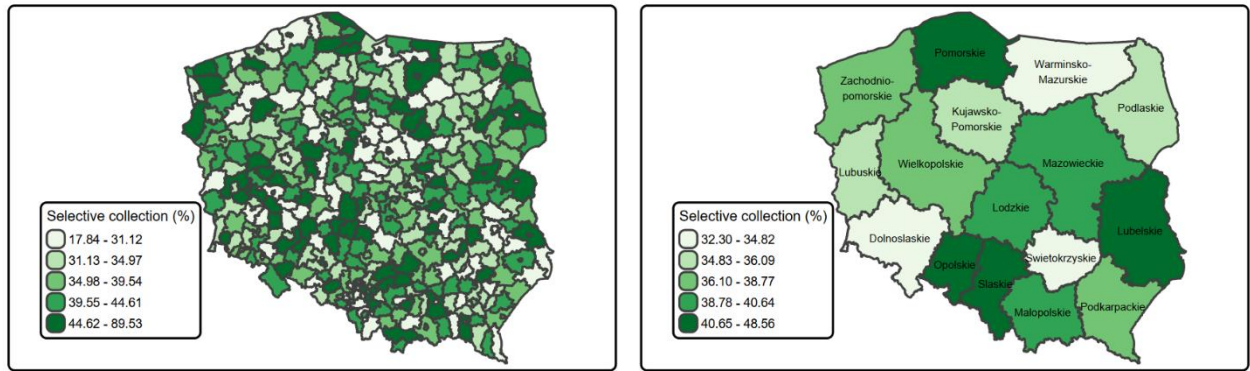


Figure 1. Spatial distribution of municipal waste eco-transition in Poland

Notes: The maps present average shares of selectively collected household waste over the period 2017–2024. Left panel presents county-level average in 2017–2024, while the right panel presents averages aggregated at the voivodeship level.

Exploratory FE and SAR panel models

Table 3 compares alternative fixed-effects (FE) and spatial autoregressive (SAR) specifications based on different groups of explanatory variables. In addition to models based on individual categories of explanatory variables, the analysis includes an integrated specification combining the most important variables from different categories and a wide specification including the full set of explanatory variables. The results indicate that classical socio-economic and housing variables possess almost no explanatory power with respect to municipal waste eco-transition. Both specifications generate negligible goodness-of-fit measures, while the estimated spatial lag parameter remains high, suggesting that these variables fail to account for the observed spatial clustering.

Table 2. Regional differences in selectively collected household waste across Polish voivodeships (2017–2024)

Voivodeship	Counties	Mean	SD	Min	Max
Lubelskie	24	48.6	14.1	30.6	83.9
Śląskie	36	45.3	13.3	30.6	89.5
Opolskie	12	41.4	9.2	23.5	53.4
Pomorskie	20	40.7	5.3	29.4	47.4
Łódzkie	24	39.2	8.1	25.1	52.1
Małopolskie	22	38.9	6.4	30.0	59.9
Mazowieckie	42	38.8	7.5	24.5	55.7
Podkarpackie	25	37.9	7.2	18.5	48.5
Wielkopolskie	35	37.1	6.6	23.9	53.5
Zachodniopomorskie	21	36.1	5.6	28.8	53.1
Kujawsko-Pomorskie	23	36.1	6.6	25.3	48.7
Podlaskie	17	35.1	7.8	23.1	48.4
Lubuskie	14	34.8	6.5	24.3	47.0
Warmińsko-Mazurskie	21	34.6	7.6	26.0	57.9
Dolnośląskie	30	33.0	5.9	17.8	44.6
Świętokrzyskie	14	32.3	7.6	18.8	48.2

Notes: The table presents descriptive statistics for county-level averages of the share of selectively collected household waste over the period 2017–2024. Mean values indicate the average level of municipal waste eco-transition within each voivodeship, while standard deviations reflect intra-regional heterogeneity across counties.

In contrast, governance-related variables substantially improve model performance. The governance specification achieves considerably higher explanatory power than socio-economic and housing models, while the inclusion of additional variables provides only marginal improvements. This pattern suggests that organizational characteristics of local waste-management systems are more important determinants of eco-transition outcomes than traditional modernization-related factors.

Table 3. Comparison of exploratory panel and spatial models

Model specification	FE models		SAR models
	Within R^2	Adjusted R^2	Spatial ρ
Socio-economic	0.002	-0.146	0.383
Housing	0.001	-0.146	0.383
Governance	0.222	0.108	0.355
Governance + housing	0.224	0.109	0.354
Integrated	0.224	0.109	0.354
Wide	0.225	0.109	0.354

Notes: FE models include county and time fixed effects. Spatial coefficients refer to SAR specifications estimated using first-order queen contiguity weights. Residual Moran's I statistics are calculated for SAR-model residuals. All spatial coefficients and Moran's I statistics are significant at the 1% level.

The SAR estimates reported in Table 4 identify three particularly important relationships. First, the number of waste-service firms per 10,000 inhabitants (*firms_10k*) exerts a negative effect on selective collection performance, supporting the interpretation that fragmented service provision may hinder coordination within local waste-management systems. Second, the share of mixed waste originating from non-household sources (*other_waste_share*) is positively associated with eco-transition outcomes, suggesting that more diversified waste-management systems tend to achieve higher selective collection rates. Third, environmental expenditure (*ln_envexp*) exhibits a negative relationship with selective collection performance, potentially reflecting the reactive nature of local environmental spending.

The integrated SAR specification confirms the dominant role of governance-related variables. Once organizational characteristics are included, income and housing variables become statistically insignificant. Despite the inclusion of spatial lags, residual spatial autocorrelation remains present, indicating the existence of additional regional heterogeneity.

Table 4. Spatial panel models of municipal waste eco-transition

Variables	Governance model	Governance + housing	Integrated model
Spatial lag (ρ)	0.355***	0.354***	0.354***
<i>firms_10k</i>	-1.039*	-1.080*	-1.081*
<i>other_waste_share</i>	0.450***	0.450***	0.450***
<i>ln_envexp</i>	-3.904***	-3.920***	-3.924***
<i>ind_housing_share</i>	—	0.01	0.010
<i>urbanization</i>	—	0.091	0.090
<i>ln_density</i>	—	0.353	0.357
<i>ln_income</i>	—	—	0.029
Within (R^2) (FE benchmark)	0.222	0.224	0.224
Observations	3040	3040	3040
Counties	380	380	380

Notes: Reported values are coefficient estimates from SAR panel models with two-way fixed effects. Spatial dependence is modeled using a row-standardized first-order queen contiguity matrix. Residual Moran's I statistics are calculated for SAR-model residuals. ***, **, and * denote statistical significance at the 0.1%, 1%, and 5% levels, respectively. The model specifications correspond to the categories of explanatory variables presented in Table 1. The integrated specification combines the most important variables from several groups.

Regional heterogeneity of municipal waste eco-transition

The final stage of the analysis examines whether the effects of governance-related and income variables differ across voivodeships. To address this issue, SAR models with voivodeship-specific interaction terms are estimated. The results indicate that a large part of the residual spatial dependence observed in baseline SAR specifications reflects regionally differentiated institutional and economic relationships. In both heterogeneity models, residual Moran's I statistics become statistically insignificant, suggesting that regional variation in coefficient structures accounts for much of the previously unexplained spatial autocorrelation.

Table 5. Regional heterogeneity of municipal waste eco-transition determinants

Model specification	Main regional interactions	Spatial lag (ρ)	Residual Moran's (I)	Residual Moran p-value
Governance + housing heterogeneity	$firms_10k \times voivodeship$ $other_waste_share \times voivodeship$	0.352***	-0.043	0.883
Income heterogeneity	$ln_income \times voivodeship$	0.259***	-0.051	0.924

Notes: Reported values summarize SAR panel models with two-way fixed effects and voivodeship-specific interaction terms. Residual Moran's I statistics are calculated for SAR-model residuals. The governance + housing specification includes regional interactions for *firms_10k* and *other_waste_share*, while the income heterogeneity specification includes regional interactions for *ln_income*.

Figure 2 reveals considerable regional heterogeneity in the effects of governance-related variables. The negative impact of market fragmentation (*firms_10k*) is strongest in several eastern and southern voivodeships, including Lubelskie, Slaskie, and Swietokrzyskie, whereas the relationship becomes weaker or positive in parts of western and northern Poland. Similarly, the positive association between *other_waste_share* and eco-transition outcomes varies across regions, indicating differences in the organizational and institutional contexts of local waste-management systems.

The income heterogeneity model further demonstrates that the relationship between local revenues and selective collection performance is not spatially uniform. Positive income effects are observed in some regions, while negative relationships emerge in others. These findings suggest that the effectiveness with which financial resources are transformed into environmental outcomes depends strongly on regional institutional conditions rather than on income levels alone.

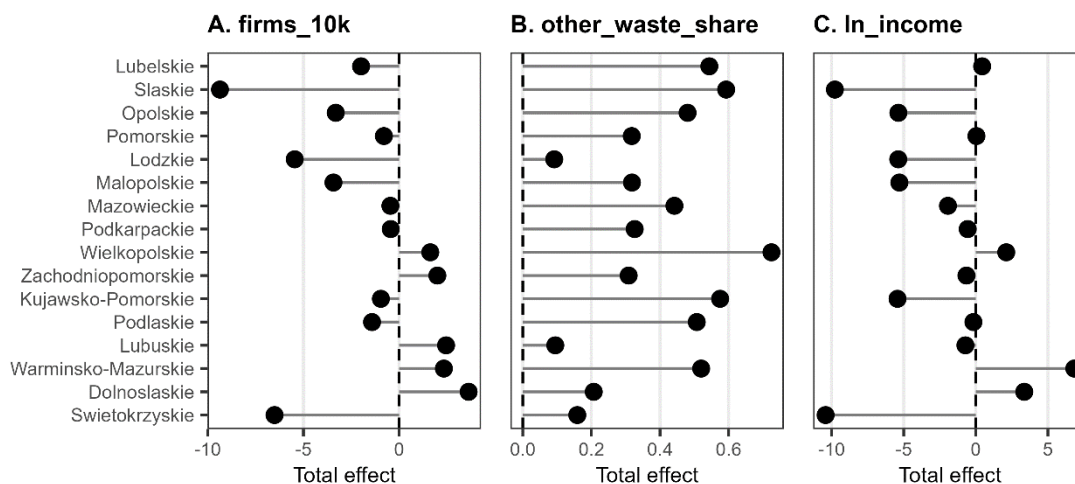


Figure 2. Voivodeship-specific effects in SAR heterogeneity models

Notes: The figure presents voivodeship-specific total effects derived from SAR panel models with regional interaction terms. Horizontal segments connect estimated coefficients with the zero-reference line. Lubelskie serves as the reference voivodeship. Panel A presents total effects for *firms_10k*, Panel B for *other_waste_share*, and Panel C for *ln_income*.

Conclusions

This study examined the determinants of municipal waste eco-transition across Polish counties in the years 2017–2024 using panel and spatial econometric approaches. The results reveal strong regional variation in selective collection performance and significant spatial dependence, indicating that municipal waste eco-transition is shaped by both local and broader regional processes.

The empirical analysis shows that traditional socio-economic and settlement-related variables possess limited explanatory power. In contrast, governance-related organizational characteristics of local waste-management systems explain a considerably larger share of variation in eco-transition outcomes. In particular, greater fragmentation of local waste-service markets is associated with weaker selective collection performance, while more diversified waste-management systems tend to achieve better outcomes.

An important finding concerns the presence of pronounced regional heterogeneity. The effects of governance-related characteristics and local income differ substantially across voivodeships, and the introduction of regional interaction effects removes residual spatial autocorrelation observed in baseline SAR models. The findings suggest that spatial dependence in municipal waste eco-transition partly reflects regionally differentiated governance structures rather than purely geographical proximity. Consequently, relationships identified at the national level do not operate uniformly across Poland. The findings suggest that improving municipal waste eco-transition requires stronger coordination within local waste-management systems and policy approaches adapted to regional conditions rather than relying solely on economic growth or infrastructural expansion.

Several limitations should be acknowledged. Governance-related characteristics are captured through indirect indicators, and the analysis focuses primarily on selective collection rather than broader circular-economy outcomes. Future research could incorporate more direct institutional measures and additional indicators of circular-economy performance.

By integrating governance and spatial perspectives, the study contributes to a better understanding of municipal waste eco-transition and its regional determinants in Poland.

Acknowledgment

Research project supported by AGH University of Krakow through an institutional subsidy for maintaining research capacity (Research Capacity Grant) and by program „Excellence initiative - research university” for the AGH University of Krakow.

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