Acceleration without Convergence?
Territorial Capabilities and the Uneven Scaling of Biomethane in the European Union

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Abstract

This paper examines whether EU biomethane targets function as spatially neutral acceleration instruments or whether their effects are conditioned by territorially embedded capability structures, potentially reinforcing pre-existing asymmetries across Member States. Under REPowerEU and the revised Renewable Energy Directive, biomethane has been assigned a strategic role in supporting decarbonisation and reducing fossil fuel dependency, with an EU-wide production target of 35 bcm by 2030. While target-based governance is commonly viewed as a mechanism for reducing uncertainty and mobilising investment, transition processes unfold within uneven institutional and economic geographies, raising questions about their territorial distributive effects.

Drawing on regional development and innovation systems literature, we conceptualise territorial capability structures as systemic configurations shaping the capacity of territories to mobilise and scale transition technologies. These include sectoral composition and related variety, institutional quality, innovation and absorptive capacity, and energy-system maturity. We introduce the concept of capability-contingent scaling, defined as the conditional ability of territories to translate uniform acceleration policies into technological deployment depending on their capability endowments.

Empirically, we construct a country-level panel dataset for the EU-27 covering 2015–2023 and estimate dynamic fixed-effects models linking biomethane production to territorial capability indicators, including interactions with a post-REPowerEU dummy capturing policy intensification. Additional dispersion analyses examine whether cross-country inequality in biomethane production evolves in the post-policy period.

By integrating acceleration governance with territorial capability theory, the paper advances a spatially sensitive framework for analysing EU-wide quantitative targets and their implications for uneven technological scaling.

1. Introduction

The European Union increasingly governs the energy transition through quantitative, technology-specific targets designed to accelerate decarbonisation, enhance energy security, and coordinate investment across Member States. Under the REPowerEU initiative and the revised Renewable Energy Directive (RED III), biomethane has acquired strategic relevance, with a target of 35 bcm of annual production by 2030. Renewable gases are framed as scalable and dispatchable complements to intermittent renewables, capable of simultaneously contributing to climate neutrality and reducing dependence on imported fossil fuels.

Within sustainability transitions scholarship, such quantitative targets are understood as central acceleration instruments. Embedded in broader policy mixes, they provide directionality, align expectations, reduce uncertainty and mobilise capital towards selected technological pathways (Rogge & Reichardt, 2016; Geels et al., 2017). In mission-oriented innovation frameworks, targets function as coordination devices that guide public and private actors toward shared transformation objectives (Mazzucato, 2018).

However, transitions do not unfold uniformly across space. A growing body of literature emphasises that socio-technical change is territorially embedded and shaped by heterogeneous institutional capacities, industrial structures, and innovation systems (Coenen et al., 2012; Binz et al., 2020). The geography of transition matters: territorial capabilities, related variety, and institutional quality condition the ability of regions to absorb, adapt, and scale new technologies (Boschma, 2005; Asheim et al., 2011; Camagni & Capello, 2013). Thus, the implicit spatial neutrality of target-based governance becomes analytically problematic.

EU-level targets are formulated centrally but implemented through territorially differentiated governance structures. When acceleration instruments enter uneven institutional landscapes, scaling trajectories may diverge rather than converge. Classic development theory suggests that policy shocks introduced into unequal contexts may activate cumulative causation, reinforcing initial advantages (Myrdal, 1957). Recent regional development research likewise highlights the persistent effects of institutional quality (Rodríguez-Pose, 2013).

Empirically, biomethane deployment across the EU exhibits a strongly uneven geography: a limited group of Member States leads in production capacity, while others remain marginal despite formal commitments. Although recent studies address biogas plant location determinants (Coll-Martínez et al., 2024), limited work examines how EU-level acceleration policies interact with territorial capability structures.

This paper addresses this gap by asking:

Are EU biomethane targets spatially neutral acceleration instruments, or do they interact with territorially embedded capability structures in ways that amplify structural asymmetries?

We argue that EU biomethane targets exhibit structural non-neutrality under territorial heterogeneity. We conceptualise this mechanism as *capability-contingent scaling*: the conditional expansion of transition technologies depending on territorially embedded institutional, sectoral and innovation capabilities. In such settings, uniform policy intensification may reinforce cumulative advantage dynamics unless complemented by targeted capability-building measures.

The paper contributes to transition governance literature by integrating acceleration policy analysis with territorial capabilities and uneven-development theory, improving understanding of how EU-level policy instruments shape spatially differentiated transformation trajectories.

2. Theoretical Framework

2.1 Target-Based Acceleration Governance in Spatially Differentiated Systems

Acceleration instruments such as quantitative targets are widely analysed in sustainability transitions research. Embedded in policy mixes, they orient expectations, stabilise investor confidence, and stimulate value-chain development (Rogge & Reichardt, 2016). Mission-oriented innovation frameworks also conceptualise targets as devices that coordinate heterogeneous stakeholders towards shared missions (Mazzucato, 2018).

However, most contributions focus on sectoral dynamics rather than the spatial differentiation of implementation contexts. Even when multi-level governance is acknowledged, a recurrent assumption persists: increased policy ambition produces proportionate scaling responses across territories.

Yet, transitions unfold within territorially specific socio-technical configurations. Place-based institutional, economic, and infrastructural structures shape how policy signals translate into technological change (Coenen et al., 2012). The growing field of "geographies of transition" highlights how regional innovation systems, governance arrangements, and capability endowments condition scaling (Binz et al., 2020). Spatial heterogeneity therefore becomes a critical dimension of transition analysis (Weber & Truffer, 2017).

2.2 Territorial Capability Structures

To conceptualise territorial heterogeneity, we draw on regional development and innovation systems literature, which describes territorial capability structures as systemic configurations that enable or constrain innovation mobilisation and scaling (Boschma, 2005; Asheim et al., 2011).

Relevant dimensions include:

- Sectoral composition & related variety: agricultural specialisation shapes feedstock availability and farmer-industry linkages;
- Institutional quality & governance capacity: regulatory coordination, permitting efficiency, public-sector effectiveness;
- Innovation & absorptive capacity: R&D intensity, technological expertise, learning processes;
- Infrastructure & energy-system maturity: gas-grid integration potential, availability of injection points, local system readiness.

Capabilities are historically rooted, markedly uneven across territories, and change slowly. Institutional quality in particular exhibits strong path dependency and significantly shapes development trajectories (Rodríguez-Pose, 2013).

2.3 Capability-Contingent Scaling and Cumulative Dynamics

We introduce capability-contingent scaling to describe how technological expansion under acceleration policies depends on territorial capability endowments.

A uniform acceleration shock—such as intensified biomethane targets—interacts with heterogeneous territorial systems. High-capability territories translate policy signals into rapid scaling by mobilising financing, coordinating stakeholders, and integrating technologies. Low-capability territories face structural bottlenecks: fragmented governance, limited absorptive capacity, administrative delays, and infrastructural constraints.

Drawing from cumulative causation theory (Myrdal, 1957), differentiated early responses can activate self-reinforcing dynamics: experience accumulation, supply-chain development, institutional learning, and network formation further strengthen leaders' advantages. Acceleration instruments introduced into unequal contexts may thus promote divergence rather than convergence.

This framework links three bodies of literature:

- transition governance & acceleration policies;
- territorial capability & regional innovation systems;

- cumulative causation & uneven development.

This integration allows us to move beyond a purely determinist account of "where biomethane is located" toward an explanation of how policy intensification interacts with territorial heterogeneity to shape uneven scaling trajectories.

3. Research Hypotheses

Based on this framework, we derive three hypotheses:

H1 (Capability Effect):
Higher territorial capability levels are positively associated with biomethane diffusion.

H2 (Policy Mediation Effect):
The post-REPowerEU period strengthens the positive association between territorial capabilities and biomethane diffusion, indicating capability-contingent scaling.

H3 (Divergence Effect):
Cross-country dispersion in biomethane production increases following EU policy intensification.

Together, these hypotheses test whether EU biomethane targets operate as spatially neutral coordination devices or as structurally contingent accelerators within heterogeneous territorial systems.

4. Empirical Strategy

4.1 Data and Variables

We construct a country-level panel dataset covering the EU-27 over the period 2015–2023.

The dependent variable captures biogas and biomethane diffusion, measured as annual production per capita (GWh per 1,000 inhabitants). To address zero-production observations in early years for several Member States, the variable is transformed using a $\log(1 + x)$ specification.

Territorial capability structures are proxied through four dimensions:

1. Agricultural structure:
   Agricultural value added as a percentage of GDP (Eurostat), reflecting feedstock potential and sectoral integration capacity.
2. Institutional quality:
   Government Effectiveness index (World Governance Indicators), capturing administrative capacity and regulatory coordination.
3. Innovation capacity:
   R&D expenditure as a percentage of GDP (Eurostat), representing absorptive and technological scaling capability.
4. Renewable energy readiness:
   Lagged share of renewables in final energy consumption, reflecting prior transition maturity and path dependency.

Control variables include GDP per capita and energy demand proxies to account for macroeconomic scale and consumption patterns.

A dummy variable identifies the post-REPowerEU period (2022 onwards), capturing policy intensification.

4.2 Econometric Specification

To account for dynamic scaling processes, we estimate a two-way fixed effects panel model with a lagged dependent variable:

$$Y_{it} = \rho Y_{i,t-1} + \beta^{\top} Cap_{it} + \gamma Post_t + \delta^{\top}(Cap_{it} \times Post_t) + \theta^{\top} X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where:

- Y_{it}denotes log-transformed biomethane production per capita;
- Cap_{it}represents territorial capability proxies;
- $Post_t$identifies the post-policy intensification period;
- $Cap_{it} \times Post_t$captures capability-contingent scaling effects;
- X_{it}includes macroeconomic controls;
- $\mu_i$and $\lambda_t$denote country and year fixed effects.

The inclusion of the lagged dependent variable captures path dependency and inertia in renewable gas deployment. Country fixed effects control for time-invariant structural heterogeneity, while year fixed effects absorb common shocks, including energy price fluctuations and macroeconomic disturbances. Standard errors are clustered at the country level.

To assess divergence dynamics (H3), we analyse changes in cross-country dispersion measures (e.g., coefficient of variation and Theil index) over time and estimate a regression of dispersion on the post-policy period indicator.

5. Expected Results and Interpretation

We expect to find:

- A positive association between territorial capability indicators and biomethane diffusion (supporting H1).
- A significant positive interaction between territorial capabilities and the post-policy period (supporting H2), indicating capability-contingent scaling.
- An increase in cross-country dispersion following policy intensification (supporting H3).

These would demonstrate that EU-level targets are structurally non-neutral: instead of producing proportional scaling, acceleration policies may amplify pre-existing structural advantages.

6. Implications for Transition Governance

If confirmed, findings challenge the assumption that ambitious target-setting ensures spatially balanced transition dynamics. Accelerating transitions within heterogeneous territorial systems can reinforce divergence without complementary capability-building interventions (e.g., administrative strengthening,

infrastructural investment, innovation support). Recognising capability-contingent scaling is essential to design equitable and effective transition pathways within multi-level governance systems.

References

Asheim, B., Boschma, R., & Cooke, P. (2011). Constructing regional advantage: Platform policies based on related variety and differentiated knowledge bases. *Regional Studies, 45*(7), 893–904. https://doi.org/10.1080/00343404.2010.543126

Binz, C., Coenen, L., Murphy, J. T., & Truffer, B. (2020). Geographies of transition—From topical concerns to theoretical engagement. *Environmental Innovation and Societal Transitions, 34*, 1–3. https://doi.org/10.1016/j.eist.2019.11.002

Boschma, R. (2005). Proximity and innovation: A critical assessment. *Regional Studies, 39*(1), 61–74. https://doi.org/10.1080/0034340052000320887

Camagni, R., & Capello, R. (2013). Regional innovation patterns and the EU regional policy reform: Toward smart innovation policies. *Growth and Change, 44*(2), 355–389. https://doi.org/10.1111/grow.12012

Coenen, L., Benneworth, P., & Truffer, B. (2012). Toward a spatial perspective on sustainability transitions. *Research Policy, 41*(6), 968–979. https://doi.org/10.1016/j.respol.2012.02.014

Coll-Martínez, E., Labrouche, G., Nadel, S., & Orozco, L. (2024). Regional determinants of biogas production units setup: Evidence from France. *Papers in Regional Science*, *103*(1), 100007. https://doi.org/10.1016/j.pirs.2024.100007

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. *Science, 357*(6357), 1242–1244. https://doi.org/10.1126/science.aao3760

Mazzucato, M. (2018). Mission-Oriented Research & Innovation in the European Union. European Commission, B-1049 Brussels.Myrdal, G. (1957). *Economic theory and underdeveloped regions*. Duckworth.

Myrdal, G. (1957). *Economic Theory and Underdeveloped Regions*. Duckworth.

Rodríguez-Pose, A. (2013). Do institutions matter for regional development? *Regional Studies, 47*(7), 1034–1047. https://doi.org/10.1080/00343404.2012.748978

Rogge, K. S., & Reichardt, K. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy, 45*(8), 1620–1635. https://doi.org/10.1016/j.respol.2016.04.004

Weber, K. M., & Truffer, B. (2017). Moving innovation systems research to the next level: towards an integrative agenda. *Oxford Review of Economic Policy*, *33*(1), 101-121. https://doi.org/10.1093/oxrep/grx002